Clarence Colliery Discharge Investigation

Cover image: Upper Wollangambe River catchment (Photo M Krogh OEH).

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Abstract

The NSW Environment Protection Authority (EPA) is currently conducting a five-year statutory licence review of Environment Protection Licence (EPL) no. 726 held by Clarence Colliery Pty Ltd. To support this review the EPA requested that the Office of Environment and Heritage (OEH) make an assessment of the impact of the Clarence Colliery discharge on the Wollangambe River, particularly considering the river runs through the World Heritage Area of the Greater Blue Mountains National Park, a part of the OEH estate. Fieldwork, laboratory and statistical analyses to support this assessment were conducted between October 2014 and February 2015.

The major conclusions from this assessment are:

- The surface headwaters of the Newnes Plateau generally have excellent water quality with very low concentrations of dissolved and total salts and very low concentrations of most metals, metalloids and non-metallic inorganics (excepting iron and aluminium).
- Clarence Colliery LDP002 introduces a high volume, point source of pollution to the Upper Wollangambe River.
- Very little dilution of the discharge (and contained contaminants) is achieved once it joins the Wollangambe River. This is largely due to the volume of the discharge, together with its location high in the headwaters of the Wollangambe River.
- Relative to ‘natural levels’ in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002), the LDP002 discharge has elevated levels of: dissolved and total barium; bicarbonate alkalinity; dissolved and total calcium; dissolved and total cobalt; conductivity; hardness; dissolved and total lithium; dissolved and total magnesium; dissolved and total nickel; dissolved and total potassium; dissolved and total strontium; dissolved and total sulfur; sulfate; alkalinity; total dissolved solids; and dissolved and total zinc.
- Relative to ‘natural levels’ in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002) the LDP002 discharge had lower levels of chloride.
- For a number of analytes measured the difference in concentration was an order of magnitude (10 times) greater than ‘natural levels’ in the streams of the Newnes Plateau, and for some analytes (e.g. nickel, sulfur, sulfate, calcium) concentrations were 50 to 100 times greater.
- Nickel concentrations measured in LDP002 discharge waters were greater than the ANZECC/ARMCANZ (2000) default water quality guideline trigger value for nickel, designed to protect 95% of species; and greater than the NHMRC (2013) Australian drinking water guideline level. The current licence (EPL726) for Clarence Colliery does not specify a limit for nickel.
- Concentrations of zinc measured in LDP002 water (and downstream) exceeded the ANZECC/ARMCANZ (2000) water quality guideline trigger value for zinc designed to protect 95% of species, although they were below the EPL limit set by the EPA for this discharge.
- The LDP002 discharge alters the water chemistry (pH, conductivity, alkalinity, ionic composition, suite of metals, metalloids, non-metallic inorganics) of the receiving waters close to where the discharge joins the Wollangambe River and for a

- considerable distance downstream (including at sites sampled within the Greater Blue Mountains World Heritage Area).
- The LDP002 discharge waters exhibited acute and chronic toxicity to the freshwater cladoceran *Ceriodaphnia dubia* at a variety of dilutions. It also caused significant inhibitory effects on growth of the freshwater green alga *Pseudokirchneriella subcapitata.*
- The LDP002 discharge has the potential to be inducing toxic effects and reproductive impairment in sensitive invertebrate and algal species in the receiving environment of the Wollangambe River, including at sites within the Greater Blue Mountains World Heritage Area.
- OEH's latest sampling suggests that the macroinvertebrate community downstream of the discharge is demonstrably different from that of the pristine headwater streams of the Newnes Plateau. Further, the difference in macroinvertebrate communities extends to sample sites located within the Greater Blue Mountains World Heritage Area.
- Further investigations are needed to determine exactly which components of the LDP002 discharge waters are causing the observed acute and chronic toxicity.
- The full longitudinal extent of the discharge impacts on macroinvertebrate communities in the Wollangambe River also needs to be established.
- There is a clear need to review EPL licence conditions for nickel and conductivity (not currently on EPL726). The EPL limit for zinc, currently set at nearly 200 times the ANZECC/ARMCANZ (2000) water quality guideline trigger value for the protection of 95% of species, should also be reviewed.
- Based on the results of the current study, consideration should also be given to setting EPL licence conditions for other contaminants in the discharge whose levels were found to be significantly higher than background levels in the Upper Wollangambe River and Newnes Plateau headwater streams.
- Given that the LDP002 discharge flows into a near pristine Newnes Plateau headwater stream which subsequently flows into the Greater Blue Mountains World Heritage Area it is recommended that any review of EPL limits is based on ANZECC/ARMCANZ (2000) water quality guideline trigger values which are designed to protect freshwater species.

1. Introduction

The NSW Environment Protection Authority (EPA) is currently conducting a five year statutory licence review of Environment Protection Licence (EPL) no. 726 held by Clarence Colliery Pty Ltd. Clarence Colliery is an underground coal mine at the headwaters of the Wollangambe River, which runs into the World Heritage Area of the Greater Blue Mountains National Park. The EPL authorises a discharge of mine water into the Wollangambe River. The EPA received five submissions from the public, which were based on the results of water sampling done by the University of Western Sydney of the Wollangambe River, upstream and downstream of Clarence Colliery. These results were published by Belmer et al. (2014) and Sullivan et al. (2014) in the conference proceedings of the 7th Australian Stream Management Conference held in Townsville (QLD) in 2014. The conference papers indicated an impact on the water quality and aquatic ecosystem of the Wollangambe River downstream of the Clarence Colliery discharge.

On 25 September 2014 the EPA requested that the Office of Environment and Heritage (OEH) make an assessment of the impact of the discharge on the Wollangambe River, particularly considering the river runs through the World Heritage Area of the Greater Blue Mountains National Park, a part of the OEH estate. In addition to sampling the water and biota of the river, the EPA requested that the discharge from the mine be sampled and analysed for any characteristics of toxicity. The purpose of this report is to describe the methodology, results and conclusions of an OEH investigation into the Clarence Colliery discharge, which was designed to provide an assessment of the impact of this discharge on the Wollangambe River and its ecology.

2. Methods

2.1 Location, context and current monitoring

The Wollangambe River rises on the Newnes Plateau about one kilometre south-east of Happy Valley Springs and flows generally east then north north-east until it eventually joins the Colo River. Whilst the majority of the river is contained within the Greater Blue Mountains World Heritage Area, its upper-most headwaters and tributaries lie primarily within the Newnes State Forest, together with some areas of vacant Crown land and private land holdings clustered along the Bells Line of Road near Clarence and the small township of Mt Wilson. Clarence Colliery itself is located on the Newnes Plateau at Newnes Junction, near the township of Clarence (Latitude 33.4597°S and Longitude 150.2479°E; see Figure 1). The catchment area upstream of the Clarence Colliery dam on the Wollangambe River (33.4558°S and 150.2517°E) is approximately 360 hectares.

According to Centennial Coal's *Clarence Colliery Water Management Plan* (2012a), Clarence Colliery currently undertakes monitoring on the Wollangambe River (upstream of LDP2 and Clarence surface area) and at the main dam (downstream of Clarence surface area). This involves monthly monitoring of pH, conductivity, total suspended solids, filterable manganese and filterable iron. Their licensed discharge point LDP002 is monitored monthly for chloride, oil and grease, pH, total suspended solids, filterable iron, filterable manganese and total manganese; and quarterly for arsenic, boron, cadmium, copper, lead, mercury, selenium, silver, sulfate, zinc, chromium (hexavalent) and fluoride.

The Clarence Colliery LDP002 discharge is covered by an EPA licence (EPL726) which specifies 100th percentile (maximum) concentration limits for a range of constituents (Appendix 1). The licence specifies a volume/mass limit for LDP002 of 25,000 kilolitres per day (25 ML/day). This limit may be exceeded when there is greater than 10 mm of rainfall within a 24 hour period. According to the latest monitoring summary for December

2014 (Centennial Coal 2014) a total of 430.435 ML of water (minimum 1.485 ML/day, average 13.885 ML/day, maximum 20.891 ML/day) was discharged from LDP002 during the reporting period 1 December 2014 to 31 December 2014. Monitoring data (flow and water quality) for LDP002 were supplied by Clarence Colliery with further data being available online (see monitoring reports at www.centennialcoal.com.au/Environment/Clarence.aspx). Monitoring data for Wollangambe River (upstream of LDP2 and Clarence surface area) and at the main dam (downstream of Clarence surface area) do not appear to be publically reported.

In addition to surface waters, Clarence Colliery also monitors groundwater at various locations on the Newnes Plateau, including water levels in piezometers located in Newnes Plateau Shrub Swamps, an endangered ecological community (EEC) protected under the NSW *Threatened Species Conservation Act 1995* (TSC Act) and Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) – see Centennial Coal (2012a).

2.2 Previous studies

A review of previous studies in the area was undertaken by OEH. Two of the earliest studies of water quality in the Newnes Plateau area were those of Johnson (1982), and Toyer and Main (1981), who undertook hydro-chemical studies to characterise the waters and to identify the relationships between chemical characteristics and the natural environment. This included sampling in and around Clarence Colliery and the Wollangambe River. A list of sites sampled by Johnson (1982) and Toyer and Main (1981) is provided in Table A1, Appendix 1 and those closest to Clarence Colliery are identified in Figure 1.

Cohen's (2002) thesis looked at quantifying the impacts of the Clarence Colliery discharge on the Wollangambe River; investigated possible sources and causes of acid mine drainage within the mine; reviewed the treatment processes employed at that time; and recommended a strategy for improving the process of mine water management at the colliery.

Marine Pollution Research Pty Ltd (MPR 2012, 2103a, 2013b, 2014a, 2014b) investigated the possible effects of the Clarence Colliery licensed discharge point (LDP002) on the aquatic ecology of the Wollangambe River upper catchment. A 'snapshot' survey of the aquatic ecology of the study area was undertaken in June 2012, December 2012, May 2013, November 2013 and June 2014, comparing the aquatic ecology habitats, aquatic macroinvertebrate faunal assemblages and fish species present at between five and eight sites. A list of sites sampled by MPR is provided in Table A1, Appendix 1 and those closest to Clarence Colliery are identified in Figure 1.

As described earlier, more recent water sampling was undertaken by the University of Western Sydney (UWS) in the Wollangambe River, upstream and downstream of Clarence Colliery (Belmer et al. 2014 and Sullivan et al. 2014). A list of sites sampled by Belmer et al. (2014) and Sullivan et al. (2014) is provided in Table A1, Appendix 1 and those closest to Clarence Colliery are identified in Figure 1.

A number of smaller studies have been conducted in the general area, including studies associated with the Birds Rock Colliery proposal (SKM 1981), Austen and Butta proposed coal mine (AGC 1978), Hanson (formerly Kables) Quarry (e.g. Kmetoni 1984) and the approved Newnes Kaolin Pty Ltd sand and kaolin mining operation at Newnes Junction (Newnes Kaolin Pty Ltd 2009, SCM 2003); however, water quality monitoring and the variety of analytes measured in these studies have generally been limited. In 2012 OEH (unpublished data) collected a number of samples from streams and swamps on the Newnes Plateau and some individual sites have been sampled for macroinvertebrates as part of OEH's River Health Monitoring Program (which extends back to the early 1990s). A list of sites sampled by OEH is provided in Table A1, Appendix 1 and those closest to Clarence Colliery are identified in Figure 1.

2.3 Greater Blue Mountains World Heritage Area

The Greater Blue Mountains was inscribed on the World Heritage List in 2000 (Commonwealth of Australia undated). The World Heritage criteria against which the Greater Blue Mountains was listed remain the formal criteria for this property. The World Heritage criteria are periodically revised and the criteria against which the property was listed in 2000 may not necessarily be identical to future criteria. The two main criteria for the 2000 listing were:

- *Outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.*
- *Contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.*

The Greater Blue Mountains World Heritage Area (GBMA) is protected and managed under legislation of both the Commonwealth of Australia and the State of New South Wales. All World Heritage properties in Australia are 'matters of national environmental significance' protected and managed under national legislation, the *Environment Protection and Biodiversity Conservation Act 1999*. This Act is the statutory instrument for implementing Australia's obligations under a number of multilateral environmental agreements including the World Heritage Convention. By law, any action that has, will have or is likely to have a significant impact on the World Heritage values of a World Heritage property must be referred to the responsible Minister for consideration. Substantial penalties apply for taking such an action without approval. Once a heritage place is listed, the Act provides for the preparation of management plans which set out the significant heritage aspects of the place and how the values of the site will be managed (Commonwealth of Australia undated).

Importantly, the EPBC Act also aims to protect matters of national environmental significance, such as World Heritage properties, from impacts even if they originate outside the property or if the values of the property are mobile (as in fauna). It thus forms an additional layer of protection designed to protect values of World Heritage properties from external impacts. In 2007, the GBMA was added to the National Heritage List, in recognition of its national heritage significance under the Act (Commonwealth of Australia undated).

Whilst the headwaters of the Wollangambe River where the discharge occurs are not contained within the GMBA, the river itself flows into the GMBA approximately two kilometres downstream of the Clarence Colliery main dam.

2.4 Sites sampled – current investigation

After assessing sites that had previously been sampled in the area, 11 sites were chosen for more detailed sampling as part of the current investigation (see Table 1 and Figure 1).

Table 1: List of sites sampled for the Clarence Colliery discharge investigation

[#]Sampled 21/10/14; *Sampled 22/10/14; [@]Sampled 23/10/14; [&]Sampled 13/11/14

Site	Latitude	Longitude	Sampled for	Organics	Reason for selection
WGRup*	-33.45374°	150.24455°	Water quality, macro-invertebrates.	No	Upstream of LDP002 influence. Access via Clarence Colliery. This site is upstream of the MPR site of the same name.
W1*[&]	-33.45456°	150.24504°	Water quality, macro-invertebrates, toxicity testing	No	Site 500 m upstream of discharge. Upstream of Belmer et al. site W1. Access via Clarence Colliery.
W3[#&]	-33.45555°	150.25736°	Water quality, macro-invertebrates, temperature probe, toxicity testing	No	Site 1.2 km downstream of discharge. Belmer et al. site W3. Access via state forest track.
HAWK585*[&]	-33.45537°	150.25308°	Water quality, macro-invertebrates, toxicity testing	No	Downstream of LDP002 discharge. Sampled by EPA 1999. Approx. 100 m downstream of Belmer et al. site W2. Access via Clarence Colliery.
LDP002* [&]	-33.46013°	150.24716°	Water quality, toxicity testing	Yes	LDP002 discharge. Access via Clarence Colliery.
W10[&]	-33.46123°	150.25867°	Water quality, macro-invertebrates	No	Approx. 2 km downstream of LDP002 discharge and within the Greater Blue Mountains World Heritage Area. Access via state forest track.
Bungle1*	-33.39717°	150.22676°	Water quality, macro-invertebrates	No	Bungleboori Ck reference site. Access via state forest track.
Bungle4[#]	-33.42336°	150.25275°	Water quality, macro-invertebrates	No	Bungleboori Ck reference site. Access via state forest track.
Bungle3[@]	-33.41225°	150.22800°	Water quality, macro-invertebrates, temperature probe	No	Bungleboori Ck reference site. Access via state forest track.
Dingo1[@]	-33.35949°	150.26683°	Water quality, macro-invertebrates, temperature probe	No	Dingo Ck reference site. Access via state forest track.
Dingo2[@]	-33.37580°	150.27342°	Water quality, macro-invertebrates, temperature probe	No	Dingo Ck reference site. Access via state forest track.

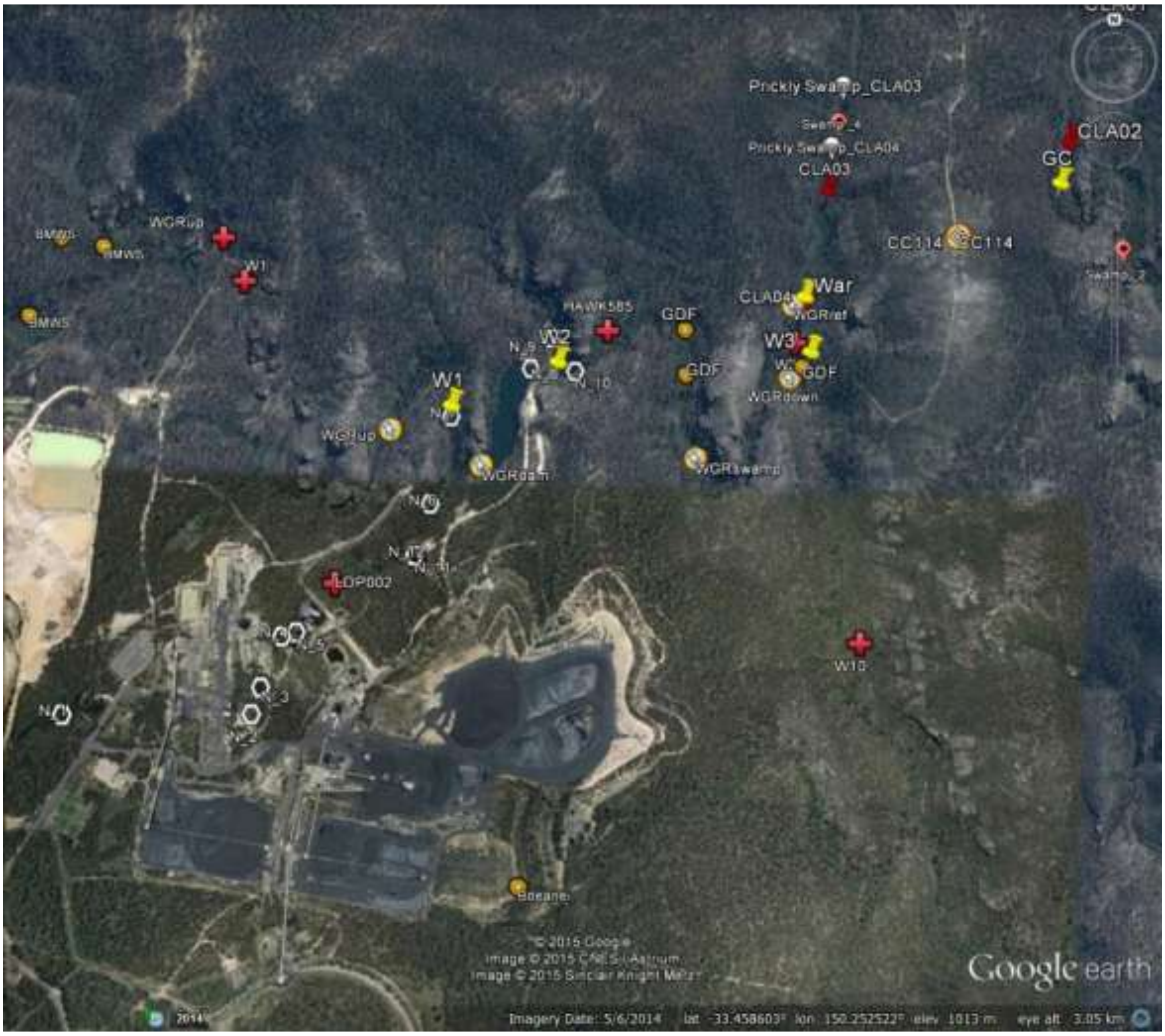

Figure 1: Monitoring sites in and around Clarence Colliery and the Upper Wollangambe River

– current investigation; – MPR 2012; – Belmer et al. 2014 and Sullivan et al. 2014; – Johnson 1982 and Toyer & Main 1981; – records of threatened/ endangered species: GDF=giant dragonfly, BMWS=Blue Mountains water skink

2.5 Water quality assessment

Water quality samples were collected at each site and sent to the OEH Environmental Forensics Laboratories[1] at Lidcombe for analysis. Turbidity (NTU), dissolved oxygen (DO; mg/L), pH, electrical conductivity (µS/cm), and temperature (°C) were measured in situ at each site using a calibrated Horiba multi-parameter water quality meter. Alkalinity was also measured in the field using CHEMetrics total alkalinity test kits.

In the laboratory, water samples were analysed based on standard methods (APHA 2012). These samples were analysed for:

- trace metals – dissolved (in situ 0.45 µm filtered) and total acid extractable (Al, As, Sb, Ba, Be, Bo, Ca, Cd, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, Si, Se, Ag, Na, Sr, S, Tl, Ti, Sn, V, Zn)

[1] NATA accredited

- total organic carbon
- ammonia
- phosphorus (free reactive and total)
- NO_x – N
- TKN
- total dissolved solids
- total suspended solids
- chloride, fluoride, sulfate
- alkalinity
- a range of organic compounds (LDP002 only; see Appendix 2 for full list of analytes).

Details on the methods used for each analysis are provided in Appendix 2.

Concurrent with taking water quality samples for laboratory analyses, water samples were also collected for ecotoxicity assessment (from sites LDP002, W1, W3, Hawk585, W10 and Bungle4). In addition, HOBO Water Temperature Pro v2 data loggers were installed at the W3, Bungle3, Dingo1 and Dingo2 sites at the time of visit and set to log temperature at half hourly intervals. The temperature probes were collected again on 16 and 17 December 2014.

2.6 Ecotoxicity assessments

The Clarence Colliery LDP002 discharge, Wollangambe River (from sites W1, W3 and Hawk585) and Bungleboori Creek (site Bungle4) samples were tested for either acute and chronic toxicity to the cladoceran, *Ceriodaphnia dubia* Richard 1894; acute toxicity to larvae of the rainbowfish, *Melanotaenia duboulayi* (Castelnau,1878); and/or acute toxicity to the unicellular green alga *Pseudokirchneriella subcapitata* Hindak by OEH's ecotoxicology laboratory[2].

The toxicity of the Clarence Colliery LDP002 discharge, Wollangambe River (from sites W1, W3 and Hawk585) and Bungleboori Creek (from site Bungle4) samples were tested using three test species[3]:

- *Ceriodaphnia dubia* Richard 1894 (waterflea)

  48-hour acute immobilisation test

  7-day chronic reproductive impairment test
- *Melanotaenia duboulayi* Castelnau,1878 (crimson spotted rainbowfish)

  72-hour larval imbalance test
- *Pseudokirchneriella subcapitata* Hindak (unicellular green alga)

  72-hour algal growth test.

The waterflea acute toxicity test was conducted to assess the potentially harmful effects of the samples to juveniles of the freshwater crustacean zooplankton species *Ceriodaphnia dubia*. Following exposure for 48 hours to various concentrations of the samples, the

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[2] NATA accredited

[3] Not all samples had the full range of species tested (see results).

number of *C. dubia* immobilised was counted. In this test immobilisation was considered similar to lethality. Immobilisation data were statistically analysed to determine sample concentrations causing a significant adverse effect to *C. dubia* relative to a control group of animals. If more than 50% of exposed animals were immobilised in any of the tested sample concentrations, a 48-hour EC50 (immobilisation) value was calculated, which is the effective concentration of the sample which causes immobilisation in 50% of exposed *C. dubia*. The lower the concentration causing a significant adverse effect, or the lower the EC50 value, the greater the observed toxicity.

The waterflea chronic toxicity test was conducted to assess the sub-lethal toxicity of the samples to *C. dubia*. The chronic reproductive impairment test subjected waterfleas, less than 24 hours old, to a range of sample concentrations over the period of production of three broods. The end points of this test were parental mortality and young production. Following exposure for seven days to various concentrations of the sample, the number of young produced by each parental *C. dubia* was assessed. Parental mortality and young production were statistically analysed to determine sample concentrations causing a significant effect relative to a control group of animals. The lower the concentration causing a significant effect the greater the observed toxicity. Test solutions were renewed every 48-hours.

The acute toxicity to the rainbowfish test was conducted to assess the potentially harmful effects of the samples to larvae of the native freshwater fish species *Melanotaenia duboulayi*. In this test loss of balance (imbalance) was used as the endpoint as opposed to mortality, i.e. where possible, fish were removed from the test solution once they lost the ability to remain normally positioned. Following exposure for 72 hours to various concentrations of the samples, the number of *M. duboulayi* affected was counted. These data were statistically analysed to determine sample concentrations causing a significant adverse effect to *M. duboulayi* relative to a control group. If more than 50% of exposed animals were imbalanced in any of the tested sample concentrations, a 72-hour EC50 (imbalance) value was calculated, which is the effective concentration of the sample which causes imbalance in 50% of exposed *M. duboulayi.* The lower the concentration causing a significant adverse effect, or the lower the EC50 value, the greater the observed toxicity. Test solutions were renewed every 48-hours.

The acute toxicity to the unicellular green alga test was conducted to determine the potential inhibitory effects of water samples on the growth of the freshwater unicellular green alga *Pseudokirchneriella subcapitata* Hindak (formerly known as *Selenastrum capricornutum*). A specific number of algal cells in exponential growth phase were exposed to various dilutions of the test sample for 72 hours under defined conditions. The growth of the algae exposed to the sample was compared with the growth of the algae in a diluent control or in a reference water sample. Typically nutrient medium was added to the sample so that all sample treatments and the controls have the same (added) nutrient concentrations. The growth of the algae was determined by cell yield, which is the change in the algal density over the exposure period. The cell yield data are statistically analysed to determine sample concentrations causing significant ($p<0.05$) inhibition of algal growth relative to the control/reference. The per cent effects (reduction in cell yield) on growth rate for each treatment, and the 72-hour IC50 or the sample concentration causing 50% inhibition of algal growth, were estimated. The lower the sample concentration causing significant growth inhibition and/or the lower the estimated IC50 value, the higher the apparent toxicity.

2.7 Macroinvertebrates

Macroinvertebrate samples were collected in accordance with the NSW AusRivAS protocols (Turak, Waddell & Johnstone 2004). At each macroinvertebrate monitoring site one edge sample was collected using a net over a discontinuous 10 m transect. A live-pick sorting procedure was used with the aim of picking as many macroinvertebrate taxa from the sample as possible. The samples were preserved with ethanol in the field, and brought back to the laboratory for processing.

The macroinvertebrates collected were placed under a dissecting stereo microscope, counted and identified to family level for the major groups Plecoptera, Ephemeroptera, Coleoptera, Hemiptera, Odonata and Trichoptera. Other groups were identified to sub-family (Chironomidae) or class/order (Acarina, Cladocera and Oligochaeta). The most recent available taxonomic keys were used for all identifications.

The macroinvertebrate communities recorded were compared with previous OEH data on macroinvertebrate communities in the general area. A list of sites sampled by OEH and used in this comparison is provided in Appendix 1. Taxa lists were also taken from MPR (MPR 2012, 2103a, 2013b, 2014a, 2014b) and these data were analysed separately and in concert with the OEH data[4].

2.8 Statistical analyses

A principal components analysis (PCA) with a correlation biplot was used to project observations of sites and water quality (as descriptors) to a dimensionally reduced space, using the PrimerE Version 6 software package. PCA results were presented for dissolved metals, total metals and major salt ions (calcium, sulfate, chloride, magnesium, potassium and sodium)[5] to show site similarities and correlations with each chemical group. The data collected in the current study were also compared to water quality data from streams on the Newnes Plateau (data from Johnson 1982, Toyer and Main 1981 and OEH). Statistical tests of differences among groups of sites [upstream (US), downstream (DS) and reference (Ref)] were conducted using the ANOSIM permutation test on normalised data using the Gower metric (Clarke & Gorley 2006; Legendre & Legendre 1998). All statistical tests were conducted using a Type 1 error rate (α) of 0.05.

Multi-dimensional scaling ordinations of the macroinvertebrate assemblages were undertaken using the PrimerE Version 6 software package to assess relationships between site assemblages and water quality data. Statistical tests of differences among groups of sites were conducted using the ANOSIM permutation test on macroinvertebrate presence–absence data using the Bray–Curtis similarity measure. A SIMPER analysis (Clarke & Gorley 2006) was used to explore potential differences in taxa between upstream (US), downstream (DS) and reference (Ref) sites.

The logged temperature data were compared using a running median smoothing (10% of data) using Sigmaplot Version 11.0.

3. Results

3.1 Water quality

3.1.1 General

The water quality results from the OEH Clarence Colliery study are provided in Appendix 2 and summarised in Table A2 in Appendix 1. Also included in Table A2 are the EPA licence limits, as well as the NHMRC (2013) drinking water and ANZECC/ARMCANZ (2000) guideline levels where applicable. Previous samples of water quality (Johnson 1982, Toyer & Main 1981 and OEH unpublished data) were used to assess background

[4] Both organisations used the NSW AusRivAS protocols for sampling so results should be broadly comparable.

[5] Where analytes were reported as being less than the detection level or practical quantification level (<D.L.) then they were assigned a value of 0.5×D.L. for graphical and statistical purposes.

levels for headwater streams on the Newnes Plateau in an attempt to define 'naturallevels' for the streams in these areas. In this case the 80th percentile values for concentrations were calculated for samples from the (upstream) Wollangambe River and nearby streams to define 'natural levels' for various analytes (Table A2, Appendix 1; see Table A1, Appendix 1 for sites used for this assessment). Cohen (2002) described the average concentration of a variety of analytes in the raw mine water (i.e. prior to any treatment process being applied) and these are also provided in Table A2, Appendix 1.

Relative to 'natural levels' in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002), the LDP002 discharge was found to have elevated levels of: dissolved and total barium; bicarbonate alkalinity; dissolved and total calcium; dissolved and total cobalt; conductivity; hardness; dissolved and total lithium; dissolved and total magnesium; dissolved and total manganese[6]; dissolved and total nickel; dissolved and total potassium; dissolved and total strontium; dissolved and total sulfur; sulfate; alkalinity, total dissolved solids; dissolved and total vanadium; and dissolved and total zinc. In contrast, relative to 'natural levels' in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002) the LDP002 discharge had lower levels of chloride. For a number of analytes the difference was an order of magnitude (10 times) greater than 'natural levels' in the streams of the Newnes Plateau and for some analytes (e.g. nickel, sulfur, sulfate, calcium) concentrations were 50 to 100 times greater.

The concentration of nickel in LDP002 discharge waters (median= 0.075 mg/L and 0.0425 mg/L for total and dissolved nickel, respectively; OEH data for the current study) in particular stand out since the concentrations measured were greater than the ANZECC/ARMCANZ (2000) water quality guideline (WQG) trigger value for nickel to protect 95% of species (0.011 mg/L). The concentrations of total and dissolved nickel (0.041 mg/L and 0.037 mg/L, respectively) measured in water samples collected ~2 km downstream from the discharge and within the GBMA (site W10) were also above the WQG for nickel. It is noted that the current licence (EPL726) for Clarence Colliery does not specify a limit for nickel.

The concentration of zinc in LDP002 water (median=0.087 mg/L and 0.0255 mg/L for total and dissolved zinc, respectively) also exceeded the ANZECC/ARMCANZ (2000) WQG trigger value for zinc (0.008 mg/L) to protect 95% of species, although they were below the EPL limit set by the EPA for this discharge (1.5 mg/L). It is noted that the EPL limit is almost 200 times the ANZECC/ARMCANZ (2000) guideline level for protection of 95% of species. The concentrations of total and dissolved zinc (0.025 mg/L and 0.019 mg/L, respectively) measured in water samples collected 2 km downstream and within the GBMA (W10) were also above the WQG for zinc.

3.1.2 Comparison with Clarence Colliery monitoring data and EPL limits

Clarence Colliery monitors a subset of the analytes which were measured by OEH in the current study. If the longer-term monitoring data supplied by Centennial Coal for the Clarence Colliery LDP002 are considered, however, it is clear that some of these measurements actually show an increasing trend in concentration over time. This was particularly true for conductivity and to a lesser extent dissolved manganese (Figure 2). Conductivity in the Wollangambe River upstream of LDP002 (at W1 and WGRUP) was measured at 32–34 µS/cm (OEH data). This is fairly typical of conductivity levels in natural streams on the Newnes Plateau (80th percentile=34.2 µS/cm; Table A2, Appendix 1). The conductivity of the LDP discharge (320–340 µS/cm; OEH data) is currently an order of

[6] The exception being manganese levels in the Wollangambe River upstream of the LDP002, which were similar to levels measured in the LDP002 discharge.

magnitude greater than upstream levels and, based on Clarence Colliery longer-term monitoring results, conductivity has previously been as high as 500 µS/cm[7]. There is currently no EPL licence limit set for conductivity even though current LDP002 levels are close to the ANZEC/ARMCANZ (2000) default trigger level for upland streams (350 µS/cm) and have exceeded this guideline level in the recent past. There is a clear effect of the discharge on conductivity downstream of the LDP002 discharge. Conductivity at W3, HAWK585, and W10 ranged from 310–320 µS/cm, indicating that very little dilution of the LDP002 discharge is occurring once it joins the Wollangambe River.

The EPA licence maximum concentration for filtered manganese for LDP002 is 0.5 mg/L. Filtered manganese concentrations supplied by Clarence Colliery for LDP002 ranged between 0.01 mg/L and 1.35 mg/L, although average levels were close to 0.188 mg/L and most samples were below the EPA licence level (Figure 2). Dissolved manganese levels in LDP002 samples measured by OEH ranged from 0.17–0.25 mg/L, and were similar to upstream levels measured at W1 and WGRUP (0.14–0.25 mg/L). These upstream levels are higher than other Newnes Plateau headwater streams (dissolved manganese 80th percentile=0.066 mg/L; Table A2, Appendix 1). It is noted that raw mine water[8] can have much higher concentrations of dissolved manganese[9] than what was found in the discharge (mean=2.36 mg/L, range=1.93–2.63 mg/L; Cohen 2002).

There is no EPA licence concentration for total manganese for LDP002. Total manganese levels supplied by Clarence Colliery for LDP002 ranged between 0.088 mg/L and 1.84 mg/L, although average concentrations were close to 0.3 mg/L and most total manganese sample concentrations were below the EPA licence level for filtered manganese of 0.5 mg/L. Total manganese concentrations in LDP002 samples measured by OEH ranged from 0.33–0.39 mg/L, which were higher than upstream concentrations measured at W1 and WGRUP (0.14–0.27 mg/L). These upstream concentrations were also higher than other Newnes Plateau headwater streams (total manganese 80th percentile = 0.076 mg/L; Table A2, Appendix 1). It is noted that Clarence Colliery raw mine water has very much higher concentrations of total manganese[10] (mean=2.35 mg/L, range=1.92–2.52 mg/L; Cohen 2002). Both the total and dissolved concentrations of manganese measured in LDP002 and downstream of this discharge were below WQG trigger values for manganese (1.9 mg/L[11]).

The EPA licence level for pH for LDP002 is between 6 and 8.5. The pH levels supplied by Clarence Colliery for LDP002 ranged between 5.7 and 9.1. Average levels were close to 7.2 and most samples fell between the upper and lower EPA licence levels. The pH levels in LDP002 samples measured by OEH ranged between 7.22 and 8.04 and were higher[12] than upstream levels measured at W1 and WGRUP (5.51–6.18). These upstream pH levels were similar to other Newnes Plateau headwater streams (pH 80th percentile =5.9; Table A2, Appendix 1). Typical Newnes Plateau headwater stream pH appears to be slightly acidic whereas the LDP002 discharge tends to be neutral to alkaline (and at times can be highly alkaline). It is noted that Clarence Colliery raw mine water on average had low pH values (mean=4.23 but varied from 3.6–7.2 depending on location within the mine; Cohen 2002).

The EPA licence level for total suspended solids (TSS) for LDP002 is 30 mg/L. TSS levels supplied by Clarence Colliery for LDP002 ranged between 1 and 46 mg/L. Average levels

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[7] During 2012. Values for 2013 were not provided and do not appear to have been publically reported.

[8] Prior to treatment.

[9] Cohen (2002) reported ‘filtered’ levels.

[10] Cohen (2002) reported ‘unfiltered’ levels.

[11] This figure may not protect key species from chronic toxicity.

[12] Note that pH is measured on a log-scale.

were close to 7 mg/L and most samples were well below the EPA licence level. TSS concentrations in LDP002 samples measured by OEH were 3 mg/L, and were similar to upstream levels measured at W1 and WGRUP (<3–5 mg/L). These levels were also similar to other Newnes Plateau headwater streams (TSS 80th percentile=5 mg/L; Table A2, Appendix 1).

The EPA licence level for total sulfate for LDP002 is 250 mg/L. The concentrations of total sulfate supplied by Clarence Colliery for LDP002 ranged between 77 and 223 mg/L, with average levels close to 158 mg/L. All reported levels were below the EPA licence level. Sulfate levels in LDP002 samples measured by OEH ranged from 120–130 mg/L, but were almost two orders of magnitude higher than upstream levels measured at W1 and WGRUP (1.1–1.7 mg/L).

The upstream levels were also similar to other Newnes Plateau headwater streams (sulfate 80th percentile=2.5 mg/L; Table A2, Appendix 1). Concentrations of total sulfate (and total sulfur) in the LDP002 discharge appear to be much higher than what is typical for Newnes Plateau headwater streams. The effect of the discharge on sulfate concentrations downstream of the LDP002 discharge is obvious with sulfate concentrations at W3, HAWK585, and W10 ranging from 110–120 mg/L. Again, this indicates very little dilution of the LDP002 discharge once it reaches the Wollangambe River. It is noted that raw mine water also had higher concentrations of sulfate (mean=91 mg/L; Cohen 2002).

The EPA licence level for total zinc for LDP002 is 1.5 mg/L. Notably this current EPL limit is almost 200 times higher than the WQG trigger value for zinc to protect 95% of species of 0.008 mg/L[13] (ANZECC/ARMCANZ 2000). Total concentrations of zinc supplied by Clarence Colliery for LDP002 ranged between 0.04 mg/L and 9.54[14] mg/L. Average levels (excluding the 9.54 mg/L result) were close to 0.237 mg/L and these levels were all below the EPA licence level. Total concentrations of zinc in LDP002 samples measured by OEH were 0.087 mg/L, and were much higher (an order of magnitude) than upstream levels measured at W1 and WGRUP (0.0049–0.0055 mg/L). These upstream levels were similar to total zinc concentrations in other Newnes Plateau headwater streams (total zinc 80th percentile=0.0055 mg/L; Table A2, Appendix 1). Note that raw mine water can have high concentrations of total zinc (mean=2.62 mg/L; Cohen 2002).

There is no EPA licence level for chloride for LDP002. The total concentrations of chloride supplied by Clarence Colliery for LDP002 ranged between 2 mg/L and 8 mg/L, although average levels were close to 3.9 mg/L. Total chloride concentrations in LDP002 samples measured by OEH ranged from 3.6– 3.7 mg/L, which were lower than upstream levels measured at W1 and WGRUP (7.1–7.5 mg/L). These upstream levels were similar to other Newnes Plateau headwater streams (total chloride 80th percentile=7.5 mg/L; Table A2, Appendix 1). Chloride was unusual in that the levels in the LDP002 discharge were approximately half of that recorded in natural surface waters of streams on the Newnes Plateau. Cohen (2002) did not report chloride levels for raw mine water.

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[13] ANZECC/ARMCANZ (2000) recommend that levels such as this be adjusted according to the site-specific hardness of the water; however, it also states that the values provided in ANZECC/ARMCANZ (2000) have been calculated using a hardness of 30 mg/L $CaCO_3$. Hardness at W1 and WGRUP was low – measured at 2.9–3.6 mg/L $CaCO_3$. These hardness levels are similar to other Newnes Plateau headwater streams (hardness 80th percentile=3 mg/L; Table 1). It is not considered appropriate to adjust the default zinc guideline value on the basis of the hardness of the discharge waters (median=145 mg/L $CaCO_3$).

[14] The 9.54 mg/L level may be erroneous and needs to be checked. Excluding this value yielded a maximum of 0.712 mg/L.

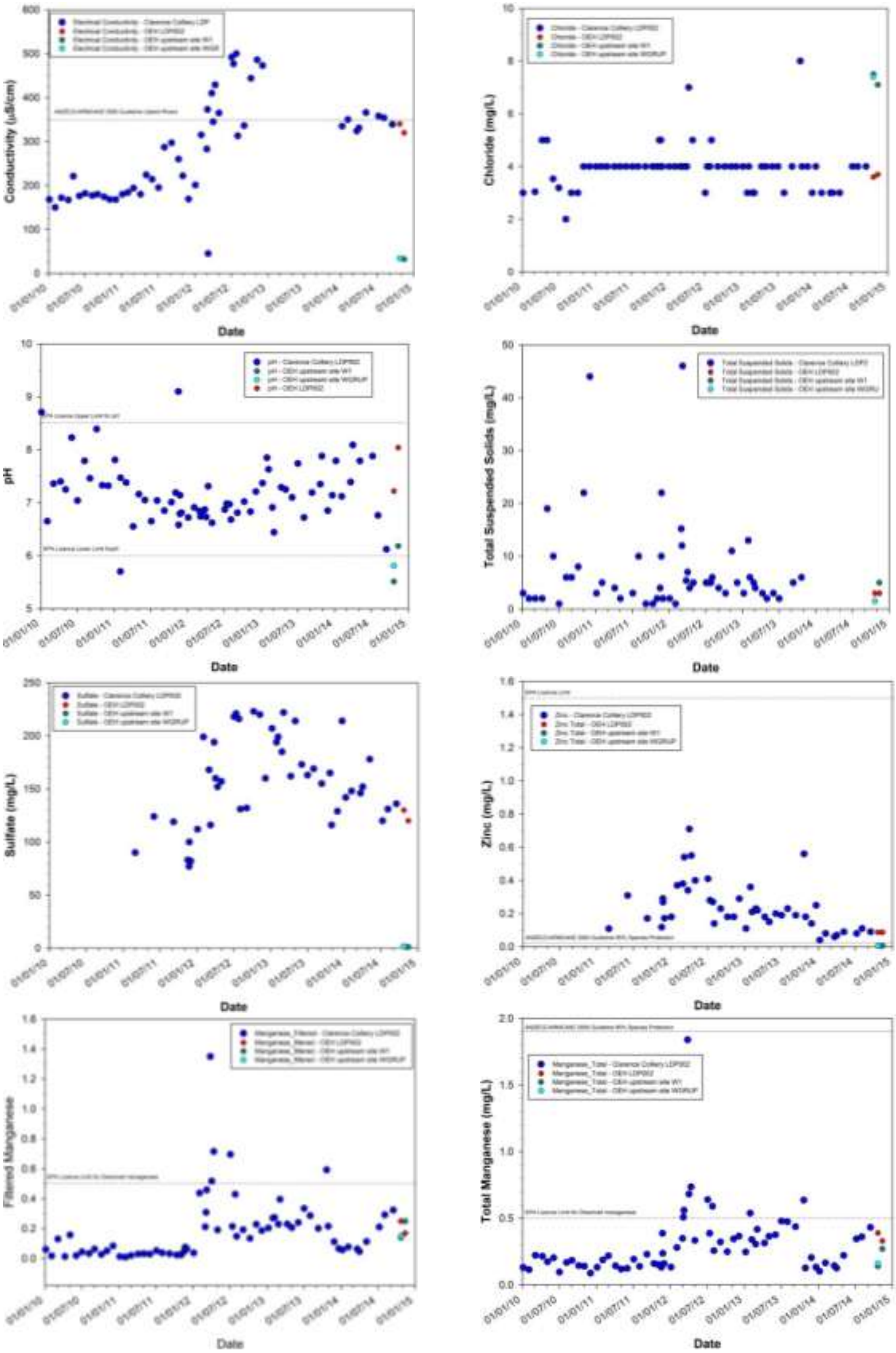

Figure 2: Long-term monitoring of LDP002

Data sources: Clarence Colliery (blue circles) and OEH (red circles). OEH data at upstream Wollangambe sites (light blue/green circles) included for context.

3.1.3 Ionic composition

A principal components analysis (PCA) of the sites and water quality data was undertaken using the PrimerE Version 6 software package. Initially the PCA was restricted to the ionic constituents (chloride, sulfate, bicarbonate alkalinity, total calcium, total potassium, total magnesium, total sodium, dissolved calcium, dissolved potassium, dissolved magnesium, dissolved sodium) and conductivity for the most recent OEH samples. The first two principal components accounted for 99.4% of the variation in the data (Figure 3).

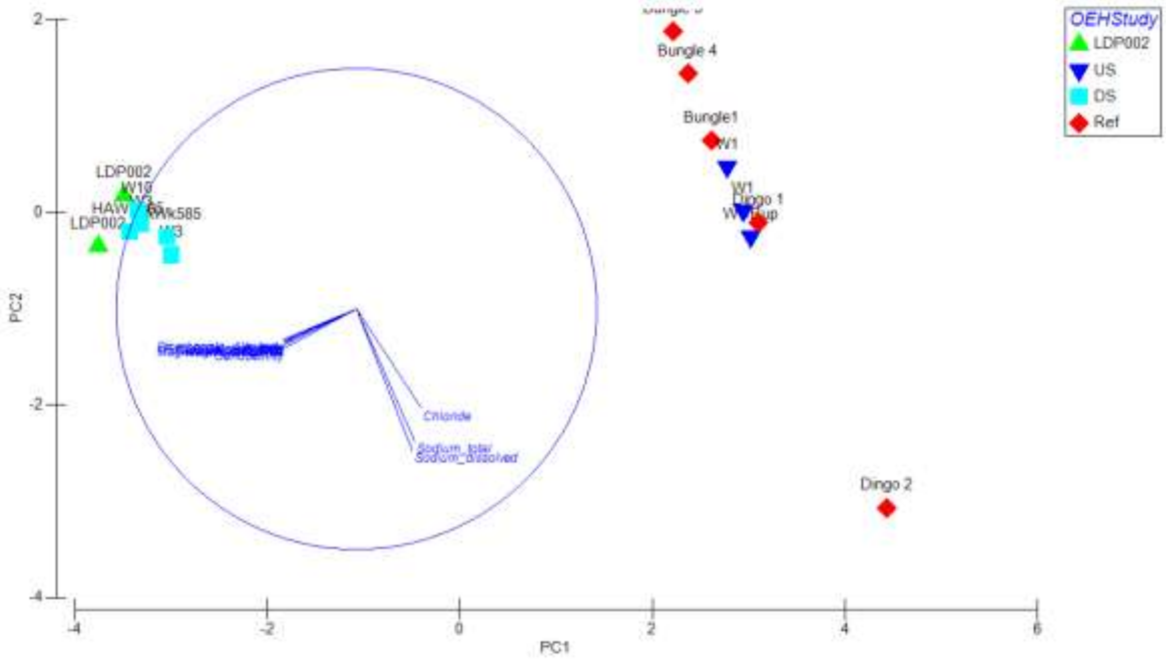

Figure 3: Principal components analysis with a correlation biplot projecting observations of sites and water quality (ionic constituents)
Data source: OEH 2014

When the data were grouped into upstream (US), downstream (DS), LDP002 and reference (Ref) sites and similarity calculated using the Gower metric, ANOSIM ($p<0.05$) identified significant differences between the groups. Pairwise comparisons also identified significant differences ($p=0.018$) between downstream and upstream sites, significant differences ($p=0.008$) between downstream and reference sites, but no significant difference ($p=0.5$) between upstream and reference sites.

If the samples collected in the current round of sampling are compared to previous data from sites on the Newnes Plateau using a PCA, the first two principal components accounted for 89.4% of the variation in the data (Figure 4).

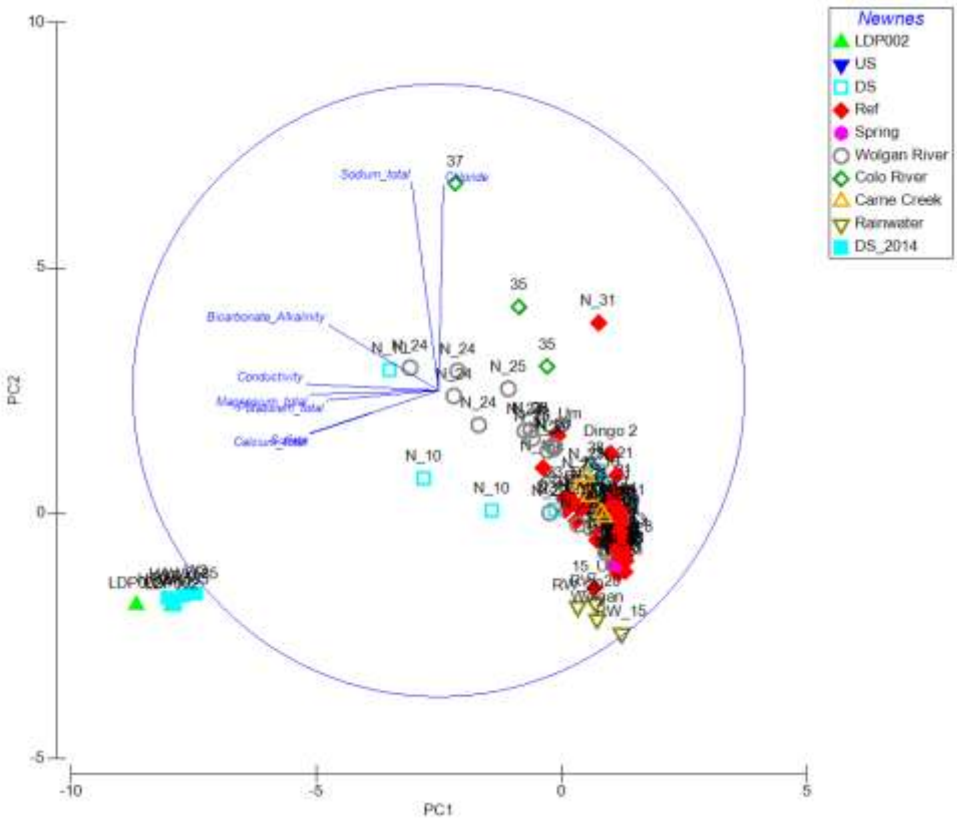

Figure 4: Principal components analysis with a correlation biplot projecting observations of sites and water quality (ionic constituents)
Data source: OEH 2012, 2014, Toyer & Main 1981, Johnson 1982

It is clear that in terms of water quality, the streams on the Newnes Plateau are very low in salts (only slightly elevated compared to salt levels measured in rainfall in the area; rainfall data from Toyer & Main 1981, Johnson 1982). Ionic composition of waters from the LDP002 and Wollangambe River downstream (DS) sites are very different to all other sites. The ionic composition of water samples from LDP002 and downstream of the dam (i.e. sites W3, HAWK585 and W10) is also very different to the ionic composition of Wollangambe water measured by Toyer and Main (1981) downstream of the storage dam (site N_10 in Figure 4). This difference in ionic composition is supported by Clarence Colliery monitoring data for conductivity which shows a distinct rise in conductivity since mid-2011, reaching 500 µS/cm in mid-2012 before falling to current levels of about 350 µS/cm (see Figure 2). The current conductivity levels are almost 10 times the conductivity measured upstream of the LDP002 discharge (and other natural streams on the Newnes Plateau). Overall, these analyses demonstrate a significant effect of the LDP002 discharge on the ionic composition of Wollangambe River waters downstream of the discharge.

3.1.4 Metals, metalloids and non-metallic inorganics

A PCA of the water quality data was undertaken on the total metal, metalloid and non-metallic inorganic data using the PrimerE Version 6 software package. This PCA was restricted to the metals, metalloids and non-metallic inorganics which were consistently measured above detection limits and exhibited variation between sites (lithium, manganese, cobalt, nickel, zinc, strontium, barium, thallium, lead, aluminium, iron, sulfur and silicon). The first two principal components explained 86% of the variation in the data.

Relative to other sites, LDP002 discharge waters and Wollangambe River samples from sites downstream of the discharge had elevated total levels of zinc, strontium, barium, sulfur, cobalt and nickel.

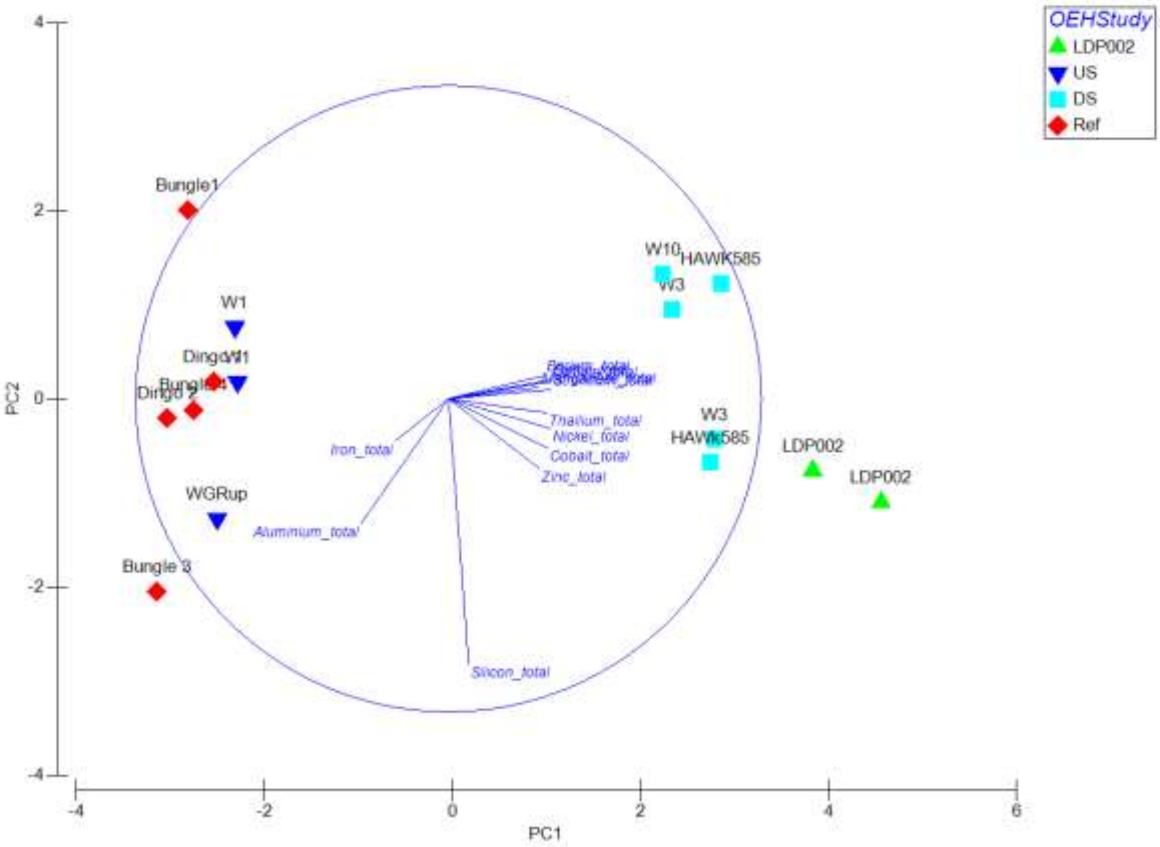

Figure 5: Principal components analysis with a correlation biplot projecting observations of sites and water quality (total metal, metalloid and non-metallic inorganic constituents)
Data source: OEH 2014

When the data were grouped into upstream (US), downstream (DS), LDP002 and reference (Ref) sites and similarity calculated using the Gower metric, ANOSIM ($p<0.05$) identified significant differences between the groups. Pairwise differences among groups were also significant ($p<0.05$).

A PCA of the water quality data was also undertaken on the dissolved metal, metalloid and non-metallic inorganic data using the PrimerE Version 6 software package (Figure 6). This PCA was also restricted to the dissolved metals, metalloids and non-metallic inorganics which were consistently measured above detection limits and exhibited variation between sites (lithium, manganese, cobalt, nickel, zinc, strontium, barium, thallium, lead, aluminium, iron, sulfur and silicon). The first two principal components explained 90.7% of the variation in the data. Relative to other sites, LDP002 discharge waters and Wollangambe River samples from sites downstream of the discharge had elevated dissolved levels of zinc, strontium, barium, sulfur, cobalt and nickel.

When the data were grouped into upstream (US), downstream (DS), LDP002 and reference (Ref) sites and similarity calculated using the Gower metric, ANOSIM again identified significant differences between the groups ($p<0.05$). Pairwise differences among groups were also significant ($p<0.05$), except for LDP002 and DS groups ($p=0.429$).

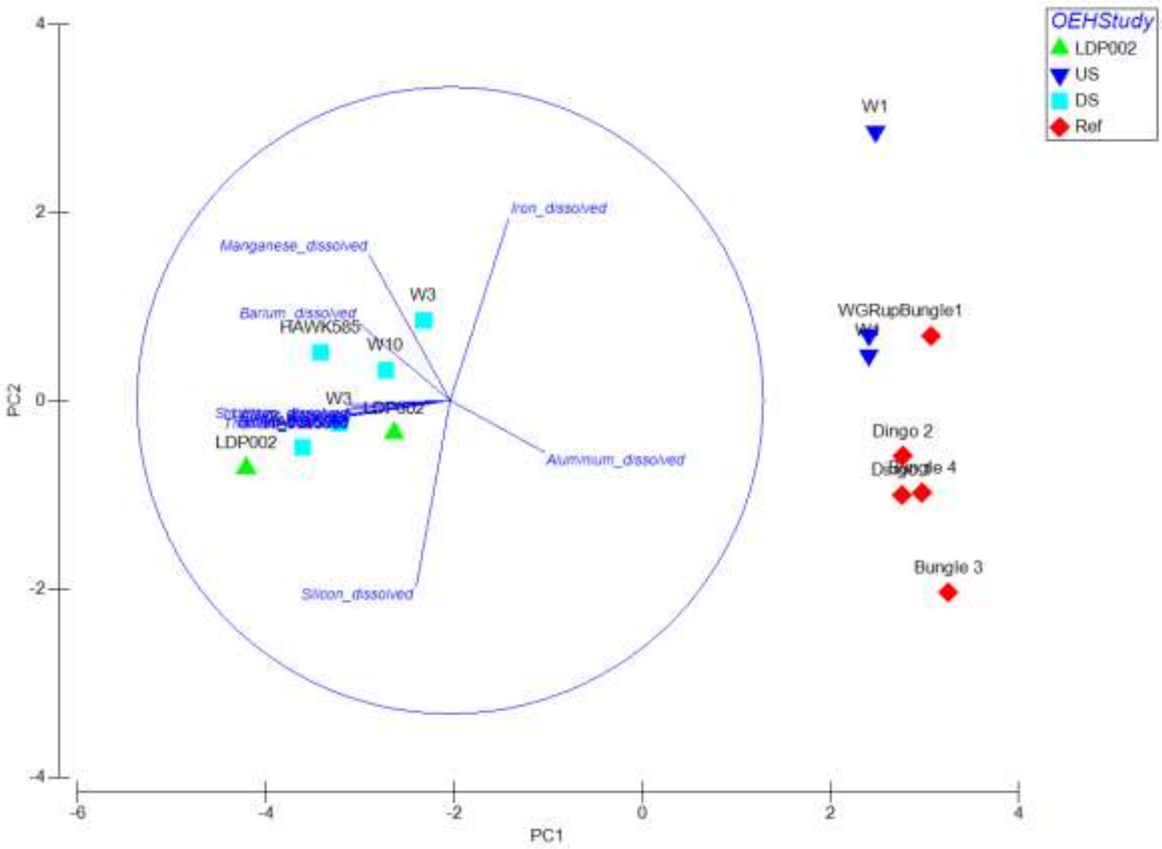

Figure 6: Principal components analysis with a correlation biplot projecting observations of sites and water quality (dissolved metal, metalloid and non-metallic inorganic constituents)
Data source: OEH 2014

When the sample sites were broadened to the Newnes Plateau[15] more generally, and the PCA restricted to the metals, metalloids and non-metallic inorganics which were consistently measured above detection limits (lithium, manganese, cobalt, nickel, zinc, strontium, barium, thallium, lead, aluminium, iron, sulfur and silicon):

- the first two principal components for total metals, metalloids and non-metallic inorganics explained 80.4% of the variation in the data (Figure 7)
- the first two principal components for dissolved metals, metalloids and non-metallic inorganics explained 73.5% of the variation in the data (Figure 7).

Relative to other sites on the Newnes Plateau, LDP002 discharge waters and Wollangambe River samples downstream of the discharge had elevated total and dissolved levels of zinc, strontium, barium, sulfur, cobalt, nickel and manganese. It is clear that in addition to the ionic composition of Wollangambe River waters, the LDP002 discharge is also significantly altering the concentrations of a number of metal, metalloid and non-metallic inorganic levels in the Wollangambe River.

[15] Apart from individual measurements of iron and aluminium, Johnson (1982) and Toyer and Main (1981) did not measure metals within the surface waters of the Newnes Plateau. Broader comparisons of metals were therefore made with Newnes Plateau water quality based on other OEH results (OEH unpublished data; see Table A2, Appendix 1).

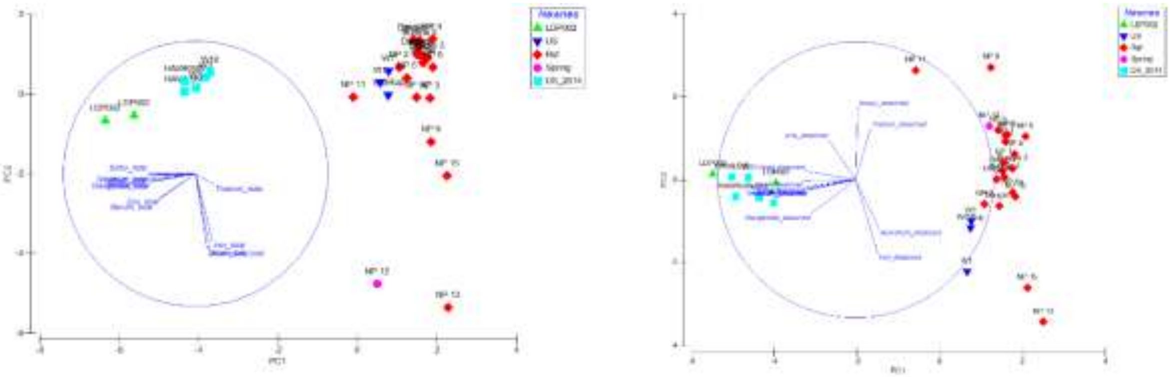

Figure 7: Principal components analysis of total (left) and filtered (right) metal, metalloid and non-metal constituents
Data source: OEH

3.2 Water temperatures

Water temperatures measured in the LDP002 discharge were 16.97°C on 22/10/14 and 17.59°C on 13/11/14. The HOBO Water Temperature Pro v2 data loggers were installed at the W3, Bungle3, Dingo1 and Dingo2 sites at the time of first visit and were collected again approximately two months later on 16 and 17 December 2014. There was significant diurnal variation in temperatures so the logged temperature data were compared using a running median smoothing (10% of data) using Sigmaplot Version 11.0. Plots of the smoothed data are provided in Figure 8 and compared to temperatures logged in a piezometer in Carne West Swamp, also located on the Newnes Plateau.

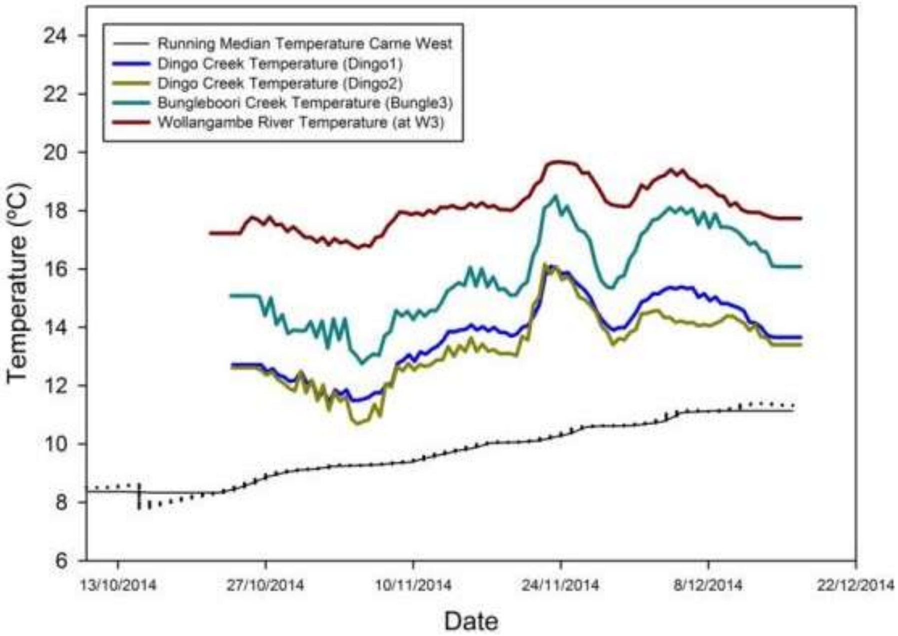

Figure 8: Smoothed temperature data for Carne West Swamp (black line), Dingo Creek (blue and dark yellow lines), Bungleboori Creek (turquoise line) and Wollangambe River downstream of LDP002 discharge (red line) for the period October to December 2014
Data source: OEH

The Carne West Swamp water temperatures (within the peat substrate) were much less variable but nevertheless indicated an increasing temperature regime from October to December 2014, which was broadly mirrored in the surface water temperatures of the monitored streams. Median temperatures in the Wollangambe River at site W3 (downstream of the discharge) were on average between 1°C to 5°C warmer than temperatures measured at the Dingo Creek and Bungleboori Creek sites. This component of the study was undertaken as a preliminary look at the issue of stream temperatures resulting from the licensed discharge. Further studies of stream temperatures (including temperatures in Wollangambe River upstream of the discharge) are required to provide a better context for the impact of the LDP002 discharge on water temperatures in the Wollangambe River. Nevertheless, these preliminary results suggest that the discharge could also be affecting (increasing) the temperature regime of the Wollangambe River downstream of where the discharge joins. This hypothesis requires further verification.

3.3 Flow

As identified earlier, the Clarence Colliery LDP002 discharge is covered by an EPA licence (EPL726) which specifies a volume/mass limit for LDP002 of 25 ML/day. This limit may be exceeded when there is greater than 10 mm of rainfall within a 24 hour period. According to the latest monitoring summary for December 2014 (Centennial Coal 2014), flows ranged from a minimum of 1.485 ML/day to a maximum of 20.891 ML/day, with an average of 13.885 ML/day between 1 December 2014 and 31 December 2014. A plot of the recorded flows over the last five years is provided in Figure 9. Rainfall from the Bureau of Meteorology (BoM) rainfall station at Bilpin[16] was included for an indication of rainfall at the time of discharge.

It is clear that flows are currently lower than in 2012 and 2013, but these flows are still significant given their magnitude and location in the catchment (i.e. close to the headwaters of the Wollangambe River). Scouring of the channel and undercutting of banks was observed downstream of the main dam on the Wollangambe River, but whether this is causally related to the continuous release of high volumes of mine water needs further assessment.

[16] Bilpin (Station 063118), approximately 24 km distant from Clarence, was chosen since it had the most complete rainfall record of nearby stations. It should be recognised that localised variations in rainfall amount and intensity can occur.

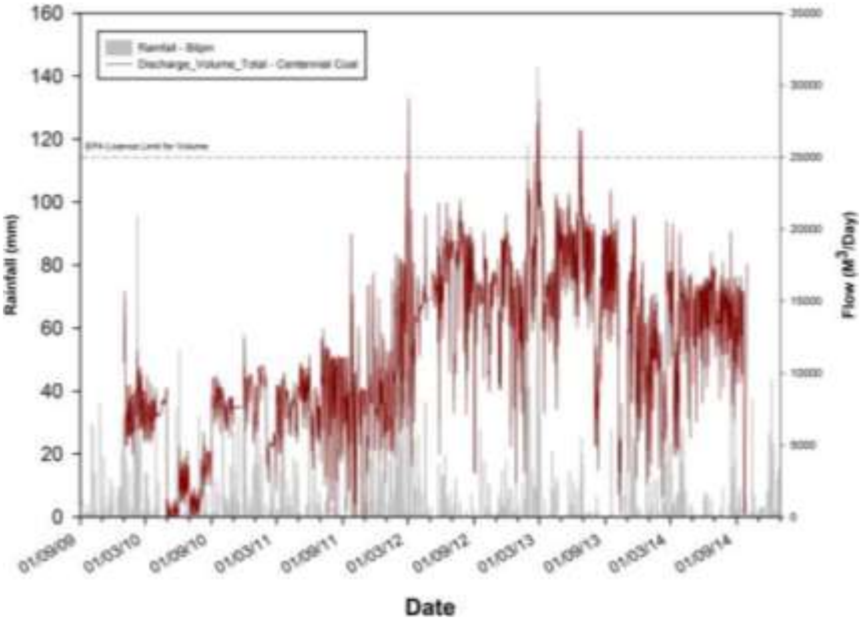

Figure 9: Flows from LDP002 for the period 2010 to 2014
Data source: Clarence Colliery and BoM

3.4 Loads

Based on concentrations measured in the LDP002 discharge and current average flow records (mean=13.885 ML/day), loads of various constituents to the environment were calculated (see Table 2). The current LDP002 discharge adds annually, on average, 1140 tonnes of salt[17], 195 tonnes of sulfur, 3 tonnes of iron, 1.8 tonnes of manganese, 440 kg of zinc and 380 kg of nickel to the Wollangambe River.

Table 2: Estimated contaminant loads from LDP002

Analyte	LDP002_Median (mg/L)	Kg/day	Tonnes/annum
Cobalt total	0.0275	0.38	0.14
Iron total	0.6200	8.61	3.14
Manganese total	0.3600	5.00	1.82
Nickel total	0.0750	1.04	0.38
Strontium total	0.0800	1.11	0.41
Sulfur total	38.5000	534.57	195.12
Total dissolved solids	225.0000	3124.13	1140.31
Zinc total	0.0870	1.21	0.44

3.5 Ecotoxicity

The full ecotoxicology test results are provided in Appendix 2. Two sample runs were conducted; the first collection of samples (Run 1) occurred on 21/10/14 and 22/10/14, with the second set of samples (Run 2) collected on 13/11/14. Ecotoxicity testing of algae and

[17] Based on total dissolved solid levels.

chronic toxicity testing of cladocerans were only conducted on samples collected on 13/11/14.

3.5.1 Cladoceran (waterflea) Run 1 – acute toxicity

Undiluted (100%) water samples from LDP002, W1, W3, HAWK585 and Bungle4 (samples 201402201, 201402203, 201402204, 201402205 and 201402207, collected 22/10/14 and 23/10/14) caused observable acute effects in *Ceriodaphnia dubia* (60–75% immobilisation). Following conductivity adjustment to 200 µS/cm, water samples from W1 (upstream of discharge) and Bungle4 (reference stream) had minimal observable effect on *C. dubia*, in that immobilisation in exposed *C. dubia* was not statistically different to that occurring in the conductivity control group.

LDP002 (sample 201402201 collected 22/10/14) caused significant immobilisation in exposed *C. dubia* at concentrations down to 50%, the lowest concentration tested. The percentages of *C. dubia* immobilised after 48 hours of exposure were 35% and 70% for 50% and 100% concentrations, respectively. The 48-hour EC50 (immobilisation) concentration was calculated to be 71% of sample.

Water from W3, 1.2 km downstream of the discharge (sample 201402204 collected 21/10/14), caused significant immobilisation in exposed *C. dubia* at a concentration of 100%, the only concentration tested, with 90% of *C. dubia* immobilised after 48-hour exposure.

The sample collected from HAWK585, downstream of the discharge (sample 201402205 collected 22/10/14), caused significant immobilisation in exposed *C. dubia* at concentrations down to 25%. The percentages of *C. dubia* immobilised after 48 hours of exposure were 50%, 90% and 70% for 25%, 50% and 100% concentrations, respectively. The sample would need to be diluted approximately eight times to avoid these acute toxic effects on *C. dubia* (based on the tested concentrations). The 48-hour EC50 (immobilisation) concentration was calculated to be 27% of sample.

3.5.2 Cladoceran (waterflea) Run 2 – acute toxicity

Undiluted water samples from LDP002, HAWK585, W10 and W1 (samples 201402355, 201402356, 201402358 and 201402359 collected on 13/11/14) caused observable acute effects in *Ceriodaphnia dubia* (15–55% immobilisation). When the conductivity of the water sample from W1 (upstream of discharge) was increased to 230 µS/cm, no toxic effects were evident in exposed *C. dubia*.

LDP002 (sample 201402355 collected 13/11/14) caused statistically significant immobilisation in exposed *C. dubia* at concentrations down to 25%, though it is noted at 25% there was only 10% immobilisation. Fifty-five per cent of *C. dubia* were immobilised after 48 hours of exposure in undiluted sample. The 48-hour EC50 (immobilisation) concentration was calculated to be 90% of sample.

Water from HAWK585, downstream of the discharge (sample 201402356 collected 13/11/14), caused significant immobilisation in exposed *C. dubia* at a concentration of 100%, with 45% of *C. dubia* immobilised after 48-hour exposure. No toxic effects were observed in concentrations at and below 25%.

Water from W10, downstream of the discharge and inside the Blue Mountains National Park (sample 201402358 collected 13/11/14), caused significant immobilisation in exposed *C. dubia* at a concentration of 100%, with 15% of *C. dubia* immobilised after 48-hour exposure. No acute toxic effects were observed in concentrations below 25%.

3.5.3 Cladoceran (waterflea) Run 2 – chronic toxicity

Undiluted water samples from LDP002, HAWK585, W10 and W1 (samples 201402355, 201402356, 201402358 and 201402359 collected on 13/11/14) caused observable chronic effects in *Ceriodaphnia dubia.* When the conductivity of the water sample from W1 (upstream of discharge) was increased to 230 µS/cm, no impairment in reproduction or other toxic effects were evident in exposed animals.

The water sample collected from LDP002 (sample 201402355 collected 13/11/14) caused significant reproductive impairment in exposed *C. dubia* at concentrations down to 12.5%. The average number of young produced in undiluted LDP002 was four, an 80% reduction relative to the conductivity control group (18 young). The average number of young produced in 12.5% and 25% concentrations of LDP002 was 10 and 12, respectively, a 40% and 30% reduction relative to the conductivity control group. No reproductive impairment was observed in a 5% concentration of LDP002. LDP002 would need to be diluted approximately 20 times to avoid these sub-lethal toxic effects on *C. dubia* (based on the tested concentrations).

The 7-day IC25 (inhibition concentration of sample calculated to cause a 25% reduction in reproduction in *C. dubia*) was calculated to be 4.5% of LDP002 and the IC50 (inhibition concentration of sample calculated to cause a 50% reduction in reproduction in *C. dubia*) was calculated to be 34% of LDP002.

The water sample collected from HAWK585, downstream of the discharge (sample 201402356 collected 13/11/14), caused significant parental mortality and reproductive impairment in exposed *C. dubia* at a concentration of 100%. The average number of young produced in undiluted HAWK585 was six, a 70% reduction relative to the conductivity control group (18 young). A lack of dose response was evident in the lower test concentrations. No significant reproductive impairment was observed in 5% and 25% concentrations of HAWK585, however a 40% reduction in reproductive output was observed at 12.5%.

The 7-day IC25 of HAWK585 was calculated to be 4.0% of sample and the IC50 was calculated to be 38% of sample.

The undiluted sample collected from W10, downstream of discharge and inside the Blue Mountains National Park (sample 201402358 collected 13/11/14), caused significant reproductive impairment in exposed *C. dubia* at concentrations down to 12.5% (the lowest tested concentration). The average number of young produced in undiluted W10 was eight, a 70% reduction relative to the conductivity control group (18 young). The average number of young produced in 12.5% and 25% concentrations of W10 was 11 and 12, respectively, a 40% and 30% reduction relative to the conductivity control group.

The 7-day IC25 for W10 was calculated to be 5.0% of sample and IC50 was calculated to be 65% of sample.

3.5.4 Rainbowfish Run 1

Undiluted water samples collected from LDP002, HAWK585, W3 and Bungle4 (reference stream) caused minimal effects in *Melanotaenia duboulayi.*

Sample from W1 (upstream of LDP002) caused significant acute effects in exposed *M. duboulayi* at a concentration of 100% of sample, with 30% of fish imbalanced after 72 hours. When the conductivity of this sample was increased to 230 µS/cm, although the degree of fish imbalance was reduced (20%), significant effects in exposed *M. duboulayi* were observed.

3.5.5 Rainbowfish Run 2

Samples collected from LDP002, HAWK585, W10 and W1 on 13/11/14 (samples 201402355, 201402356, 201402358 and 201402359) had minimal observable effect on *M. duboulayi*, in that imbalance in exposed *M. duboulayi* was not statistically different to that occurring in the control group.

3.5.6 Algae Run

LDP002 (sample 201402355 collected 13/11/14) caused significant inhibitory effect on growth of *Pseudokirchneriella subcapitata* with an estimated 72-hour IC50 (the sample concentration causing 50% inhibition of algal growth) of 46%. The sample would need to be diluted approximately four times to avoid these toxic effects on *P. subcapitata* (estimated based on tested concentrations).

Water sampled from HAWK585, downstream of the discharge (sample 201402356 collected 13/11/14), caused some inhibitory effect on growth of *P. subcapitata* in that the per cent inhibitory effect was limited to 61% when exposed to undiluted sample. When diluted, the sample caused stimulation of algal growth.

Water sampled from W10, downstream of the discharge and inside the Greater Blue Mountains World Heritage Area (sample 201402358 collected 13/11/14), generally stimulated or did not affect the growth of *P. subcapitata*, i.e. cell yield of exposed algae was higher than or not significantly different from the cell yield of the control group.

When the electrical conductivity of water sampled from W1, upstream of discharge (sample 201402359 collected 13/11/14), was adjusted to match the conductivity of the algal medium, this sample caused an inhibitory effect on growth of *P. subcapitata* in that the per cent inhibitory effect was 37% when exposed to undiluted sample, although this effect was not statistically significant. When diluted the sample caused stimulation of algal growth.

When this sample was tested as-received (i.e. at the sample conductivity of 34 µS/cm) and not supplemented with nutrients for algal growth, the sample caused some inhibitory effect on growth of *P. subcapitata* in that the per cent inhibitory effect was 61% when exposed to undiluted sample. Chemical analysis of this sample suggests that the observed inhibition was due (at least in part) to limited nutrients. When diluted the sample caused stimulation of algal growth.

3.5.7 Ecotoxicity summary

Cladoceran (waterflea)

The LDP002 discharge samples were found to cause significant immobilisation in exposed *C. dubia*. Samples from sites downstream of the discharge (HAWK585, W3, W10) also caused significant immobilisation in exposed *C. dubia.*

The LDP002 discharge samples were also found to cause significant reproductive impairment in exposed *C. dubia* at a variety of dilutions. The LDP002 sample would need to be diluted approximately 20 times to avoid these sub-lethal toxic effects on *C. dubia* (based on the tested concentrations). Samples from sites downstream of the discharge (HAWK585, W3, W10) also caused significant reproductive impairment in exposed *C. dubia*.

Significant immobilisation and reproductive impairment in exposed *C. dubia* also occurred at the upstream (W1) and reference (Bungle4[18]) sites; however, this appeared to be

[18] Reproductive impairment not tested for this sample.

attributable to the very low conductivity levels in the samples from these sites. Following conductivity adjustment to 200–230 μS/cm, the W1 and Bungle4 samples were found to have minimal observable effects on *C. dubia*.

Rainbowfish

The LDP002 and downstream site (HAWK585, W3, W10) samples caused no or minimal (statistically non-significant) imbalance in exposed *M. duboulayi.* Only sample 201402203 (W1 sample collected 22/10/14 – upstream of discharge) caused statistically significant imbalance in exposed *M. duboulayi* at a concentration of 100% of sample. It is likely that this is attributable to the very low conductivity levels at this site. The second W1 sample (201402359) collected on 13/11/14 had minimal observable effect on *M. duboulayi*.

Algae

The LDP002 sample caused significant inhibitory effect on growth of *P. subcapitata*. Some inhibitory effect on growth of *P. subcapitata* was found a short distance downstream of the discharge (HAWK585), but not at W10 approximately 2 km downstream of the discharge. The sample tested from W1 (upstream of the LDP002 discharge) caused some inhibitory effect on growth of *P. subcapitata*. Based on chemical analysis of the W1 sample the observed inhibition is likely to be caused by limited available nutrients.

3.6 Macroinvertebrates

Ten sites (see Table 1) were sampled for macroinvertebrates in accordance with the NSW AusRivAS protocols (Turak et al. 2004). Similarities in the macroinvertebrate community composition at each site were assessed using non-metric multi-dimensional scaling (nMDS) ordinations using the Bray–Curtis similarity measure based on presence–absence data (Figure 10). There was a clear difference between the community composition at sites in the Wollangambe River downstream of the LDP002 discharge compared to upstream Wollangambe River and reference stream sites.

When the presence–absence data were grouped into upstream (US), downstream (DS) and reference (Ref) sites and similarity calculated using the Bray–Curtis similarity measure, ANOSIM ($p=0.004$) identified significant differences between the groups. Pairwise comparisons also identified significant differences ($p=0.012$) between reference and downstream sites but no significant differences ($p=0.107$) between upstream and reference sites. Insufficient sites were available to undertake a significance test at the $\alpha=0.05$ level for comparison of upstream and downstream sites.

Overall, the downstream sites exhibited much lower diversity of taxa (upstream range=14–15 taxa; reference site range=18–29 taxa; downstream range=4–7 taxa) and much lower numbers than other sites. These differences were observable at the time of field sorting and picking. When the downstream sites (W3 and HAWK585) were sampled (on 21/10/14 and 22/10/14 respectively) there was a bluish tinge to the water[19] and at W3 there was a noticeable surface film which caused air bubbles to remain at the surface for long periods of time. These phenomena were not observed when the sites were revisited on 13/11/14 and 17/12/14.

[19] This bluish tinge to the water was also observed in the main dam.

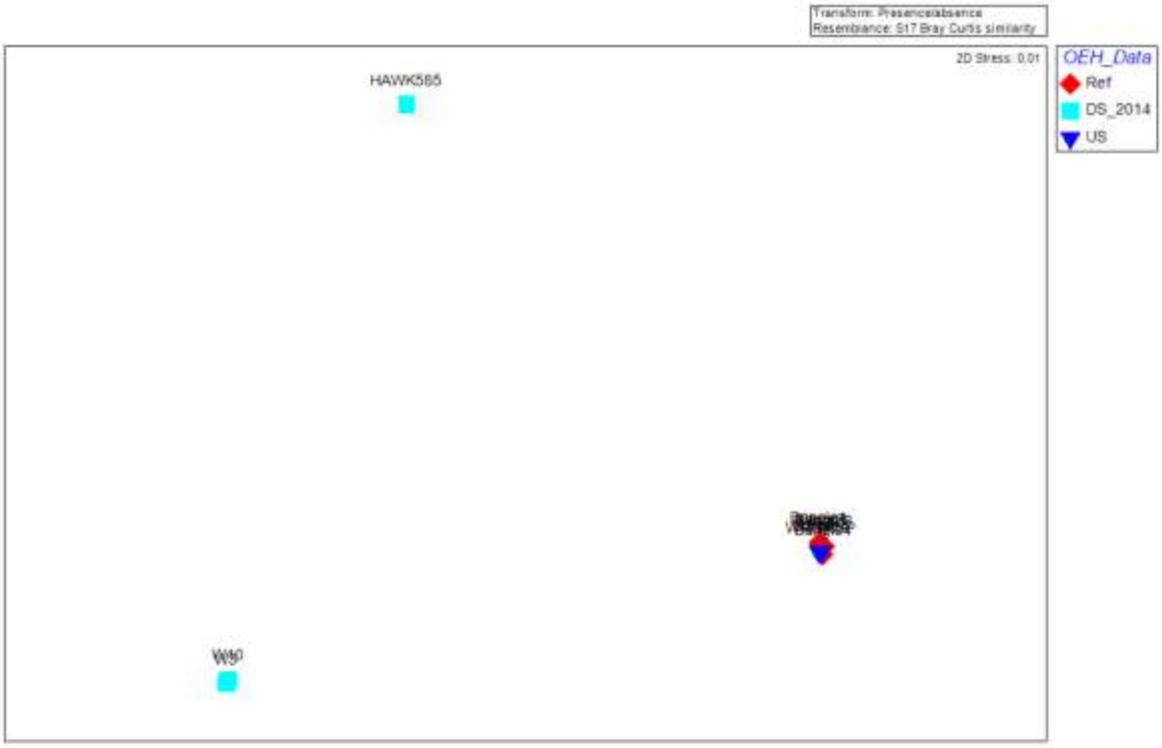

Figure 10: Non-metric multidimensional scaling ordination of macroinvertebrate data comparing upstream (US), downstream (DS) and reference (Ref) sites
Data source: OEH 2014

If the macroinvertebrate data are compared to previous data in and around the Newnes Plateau using nMDS then it is clear that the community composition downstream of the discharge is quite different to community composition at other Newnes Plateau and Blue Mountains streams (Figure 11). The Wollangambe Exit site is highlighted in pink (in Figure 11) because it is downstream of the LDP002 discharge and yet groups with the other reference stream sites. This site was sampled on 15/5/2009 and is approximately 20 km downstream of the colliery main dam. While the Wollangambe Exit site result may be suggestive of recovery/amelioration of macroinvertebrate community impacts, it is important to note that this is based on only one sample and sampling occurred prior to the major increase in salinity at Clarence Colliery in 2011–12 (see Figure 2 above). At the time of sampling (15/5/2009), electrical conductivity at site 23129 was measured at 95 µS/cm. It is noted that Belmer et al. (2014) recently recorded electrical conductivity at site W4 (upstream of the Wollangambe Exit site) at 231 µS/cm.

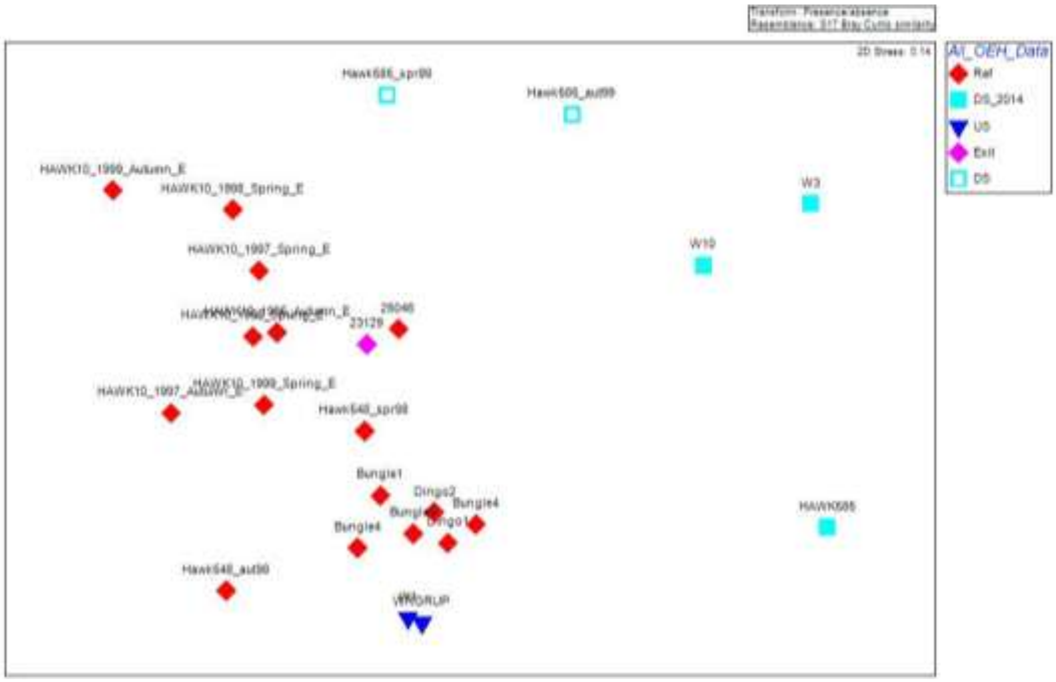

Figure 11: Non-metric multidimensional scaling ordination of macroinvertebrate data comparing upstream (US), downstream (DS) and reference (Ref) sites
Data source: OEH

When the presence–absence data were grouped into upstream (US), downstream (DS) and reference (Ref) sites[20] and similarity calculated using the Bray–Curtis similarity measure, ANOSIM (p=0.001) identified significant differences between the groups. Significant pairwise differences were found between reference and downstream sites (p=0.001), upstream and downstream sites (p=0.048), but no significant difference between upstream and reference sites (p=0.327). When a SIMPER analysis was used to explore potential differences between upstream (US), downstream (DS) and reference (Ref) sites the following results were obtained:

- The major taxa contributing to the difference between reference sites and the downstream Wollangambe sites sampled in 2014 were the families Leptophlebiidae (mayfly), Tanypodinae (non-biting midge), Scirtidae (marsh beetle), Gripopterygidae (stonefly), Hydracarina (water mite), Leptoceridae (stick caddis), and Aeshnidae (dragonfly) accounting for approximately 27% of the difference between reference sites and the downstream Wollangambe sites.
- The major taxa contributing to the difference between upstream sites and the downstream Wollangambe sites sampled in 2014 were the families Leptophlebiidae (mayfly), Synthemistidae (dragonfly), Scirtidae (marsh beetle), Philorheithridae (caddis fly), Ceratopogonidae (biting midge), Hydracarina (water mite), Tanypodinae (non-biting midge) and Tipulidae (crane fly) accounting for approximately 55% of the difference between upstream sites and the downstream Wollangambe sites. Replication of upstream sites was low (n=2) however, and further spatial and temporal sampling is required to be certain that these apparent taxa differences are persistent over time and space.

[20] The Wollangambe Exit site was excluded from this comparison.

MPR (MPR 2012, 2103a, 2013b, 2014a, 2014b) do not appear to have analysed their data statistically. Macroinvertebrate data[21] reported were therefore entered into Primer V6 and a comparison made between upstream (US), dam, downstream swamp (Swamp), downstream (DS), downstream national park (DS_NP) and reference (Ref) sites using presence–absence data and a Bray–Curtis similarity measure, and compared in an nMDS ordination (Figure 12). ANOSIM was used to test for significant differences among sites.

A significant difference among all sites was found (ANOSIM, p=0.001). Significant pairwise differences (see Table 3) were also found between the upstream and downstream sites (p=0.016); upstream and swamp sites (p=0.024); upstream and downstream national park sites (p=0.006); and upstream and dam sites (p=0.008). Significant pairwise differences were also found between the reference and downstream sites (p=0.001); reference and swamp sites (p=0.003); reference and downstream national park sites (p=0.002); and reference and dam sites (p=0.001). No significant difference was found between the upstream and reference sites (p=0.347); or swamp and downstream sites (p=0.302).

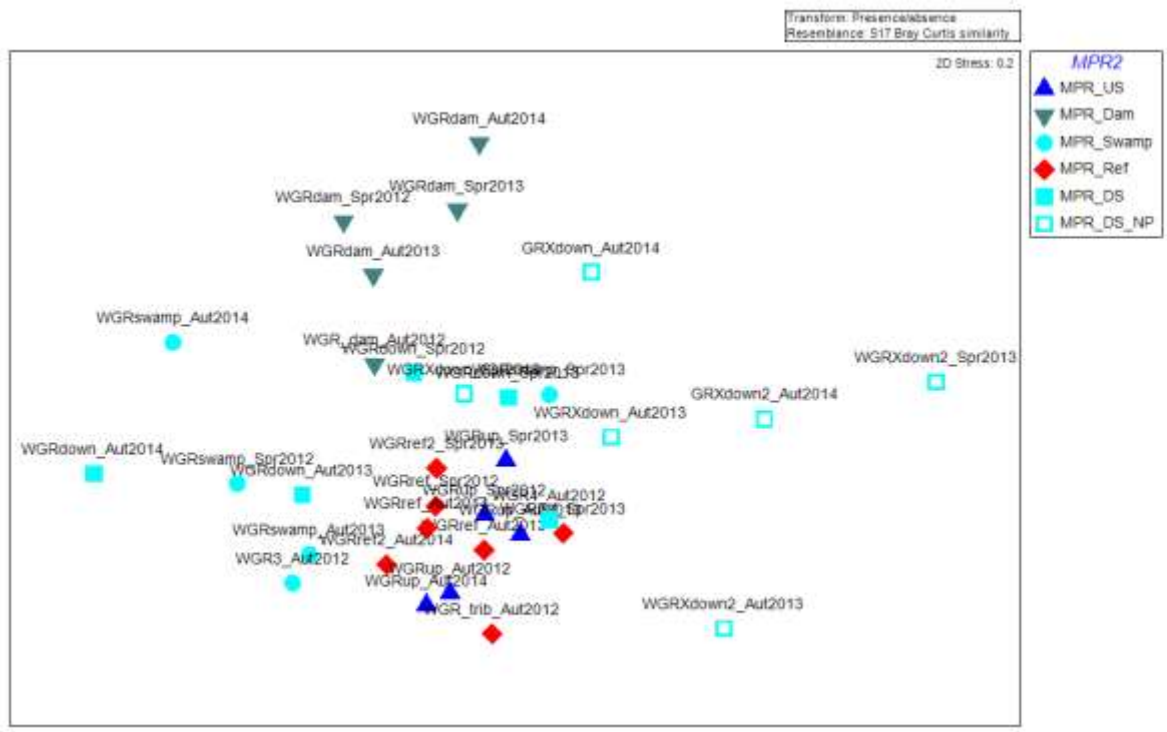

Figure 12: Non-metric multidimensional scaling ordination of macroinvertebrate data comparing upstream (US), dam, downstream swamp (Swamp), downstream (DS), downstream national park (DS_NP) and reference (Ref) sites
Data source: MPR

[21] To align the MPR taxonomy with OEH's taxonomy, taxa identified by MPR as Telephlebiidae were grouped with the Aeshnidae and MPR taxa Hemicorduliidae were grouped with the Corduliidae.

Pairwise tests

Table 3: Pairwise ANOSIM tests for macroinvertebrates at upstream (US), dam, downstream swamp (Swamp), downstream (DS), downstream national park (DS_NP) and reference (Ref) sites
Data source: MPR

Groups	R statistic	Significance level %	Possible permutations	Actual permutations	Number ≥ observed
MPR_US, MPR_Dam	0.946	0.8	126	126	1
MPR_US, MPR_Swamp	0.462	2.4	126	126	3
MPR_US, MPR_Ref	0.029	39.8	792	792	315
MPR_US, MPR_DS	0.308	1.6	126	126	2
MPR_US, MPR_DS_NP	0.479	0.9	462	462	4
MPR_Dam, MPR_Swamp	0.572	0.8	126	126	1
MPR_Dam, MPR_Ref	0.877	0.1	792	792	1
MPR_Dam, MPR_DS	0.392	0.8	126	126	1
MPR_Dam, MPR_DS_NP	0.616	0.4	462	462	2
MPR_Swamp, MPR_Ref	0.539	0.3	792	792	2
MPR_Swamp, MPR_DS	0.052	30.2	126	126	38
MPR_Swamp, MPR_DS_NP	0.356	1.5	462	462	7
MPR_Ref, MPR_DS	0.383	0.1	792	792	1
MPR_Ref, MPR_DS_NP	0.632	0.2	1716	999	1
MPR_DS, MPR_DS_NP	0.329	1.9	462	462	9

When the MPR data were combined with the OEH data, many of these differences among sites were reinforced. Again, analyses were based on presence–absence data and a Bray–Curtis similarity measure and compared in an nMDS ordination (Figure 13).

It is apparent from Figure 13 that MPR upstream and reference sites group together with OEH upstream and reference sites. Downstream sites group in a different area of the nMDS space with the latest OEH samples (light blue squares) showing the clearest departure from reference and upstream macroinvertebrate communities[22].

[22] Statistical hypothesis tests among sites were not undertaken due to the different operators involved, large number of pairwise tests involved (and increased potential for Type 1 errors) and the low levels of replication at some individual sites (e.g. LDP002d, Wollangambe Exit, and Wollangambe upstream sites). Further sampling over time at these sites would enable such tests to be undertaken if warranted.

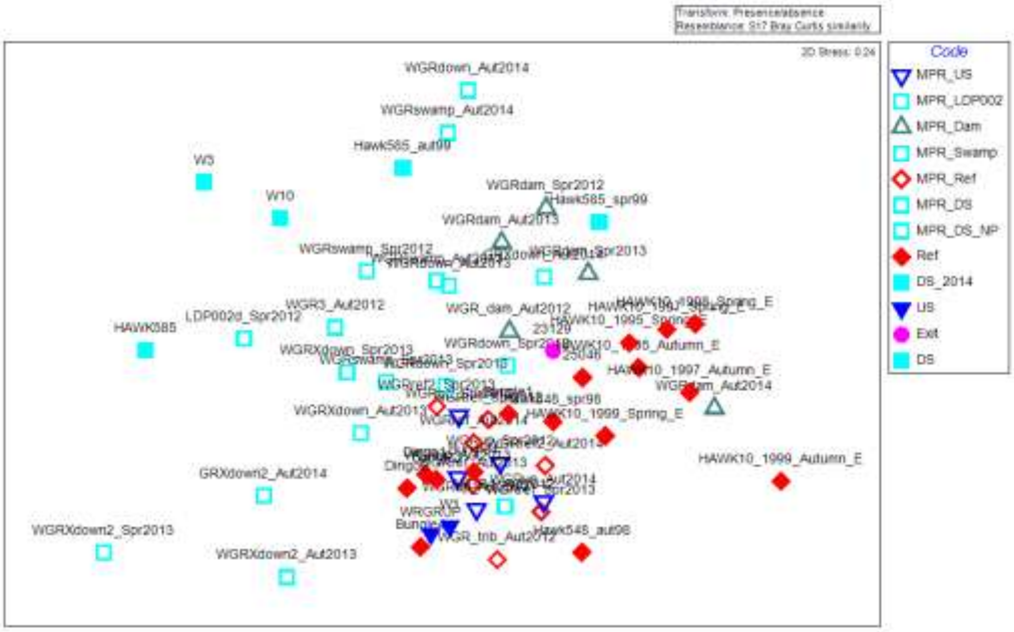

Figure 13: Non-metric multidimensional scaling ordination of macroinvertebrate data comparing upstream (US), downstream (DS) and reference (Ref) sites
Data source: OEH (closed symbols) and MPR (open symbols)

4. Discussion

4.1 History

After the submission of an environmental impact statement in 1975 and subsequent development approval, construction of Clarence Colliery commenced in September 1976. Construction of a large water storage dam, drainage controls and other site works were carried out early in the phase of the development. Coal storage and transport from the site by rail commenced in 1980 and a coal preparation plant was brought into production in July 1981 (Toyer & Main 1981). During construction of the water storage and polishing dam on the Wollangambe River, problems were experienced in controlling siltation of the river. Coalex Pty Ltd was successfully prosecuted by the State Pollution Control Commission (SPCC) for failing to prevent pollution of the Wollangambe River[23] (Toyer & Main 1981).

For the first part of the water quality sampling program undertaken by the Minerals Department (Toyer & Main 1981), the colliery was found to have had little effect on the chemical composition[24] of the Wollangambe River. Towards the end of their period of sampling however, the inflowing colliery drainage was found to be higher in bicarbonate, calcium and sodium than previously, as a result of the addition of water pumped from underground after the coal seam had been intersected. This change was reflected in the main colliery dam and downstream in the Wollangambe River (Toyer & Main 1981). On many sampling occasions the suspended solids levels at a number of sites were above

[23] Toyer and Main (1981) refer to Wollangambe Creek but the correct terminology is Wollangambe River (see Geographical Names Board).

[24] Toyer and Main (1981) primarily considered ionic constituents and did not consider the broad suite of metals, metalloids and non-metal inorganics analysed in the current OEH study.

the SPCC's generally accepted level for effluent discharge of 30 mg/L. During this period, water in the main dam remained turbid and water flowing over the spillway into Wollangambe River also had elevated suspended solid levels. After the initial construction phase of mining, Toyer and Main (1981) claimed that '*The mine, now under full production, is having no adverse effect on water quality*'.

In 1995 the Colong Foundation for Wilderness wrote to the EPA reporting a black sludge on the bed of the Wollangambe River for about 1.5 kilometres downstream of Clarence Colliery. The EPA confirmed it was a biofilm, which was naturally occurring but derived its black colour and growth from accumulating manganese oxides, and the entrapment of microfine coal (RJ Whyte pers. comm.). The EPA commenced addressing the high manganese concentration in the mine water, which was well above the Protected Waters (Class P) limit of Schedule 2 of the Clean Waters Regulations 1972. The filterable manganese in the mine water ranged from 1.35 to 2.24 milligrams per litre (mg/L); whereas, the Schedule 2 limit for filterable manganese was 0.05 mg/L (RJ Whyte pers. comm.).

The biofilm issue prompted further studies by CSIRO (Jones & Eames 1995) who found concentrations of several metals (aluminium, cobalt, iron, manganese, nickel, zinc and sulfur) in Wollangambe River sediments downstream of the colliery to be elevated significantly over levels found in the Wollangambe River above the discharge site (see discussion in Cohen 2002). The addition of alum during the treatment process employed in the mine water treatment plant was considered to be the major contributing factor to aluminium being high in the sediments of the Wollangambe River (Cohen 2002). Concentrations of cobalt, manganese, nickel and zinc were also higher in treated mine water than in the Wollangambe River above the water release point (Jones & Eames 1995; Cohen 2002). Cohen's (2002) study also found that biofilm samples collected 23 km downstream showed particularly high manganese contents, indicating that manganese may be concentrating in the biofilm layers for some distance below the Clarence Colliery discharge point.

Cohen (2002) found that there was a sharp increase in metal content directly below the Clarence Colliery release site compared to the background levels experienced at two sites above the discharge point. Nickel and zinc had the highest metal concentrations directly below the Clarence Colliery discharge point. Cobalt and manganese had the highest metal concentrations three kilometres downstream[25] of the Clarence Colliery discharge point. The metal content in sediments 12 km and 23 km downstream of the colliery dropped off significantly for all metals considered in the study. The last site examined exhibited metal contents comparable to those encountered at sites above the Clarence Colliery discharge point. Cobalt was found to exhibit the greatest increase over background levels at the last (23 km downstream) site monitored. Cohen (2002) suggested that metal content was likely to decrease even further thereafter based on the decreasing trends found in his study, the gradual removal of metal loading from the water column and the dilution by tributary streams and groundwater inflows along the course of the river.

Cohen (2002) concluded that discharge of treated mine water from Clarence Colliery was having an impact on the Wollangambe River and that the impact remained significant for some distance downstream ('*around 20 kilometres*'). Manganese in particular was building to levels that warranted concern. Cohen (2002) suggested that this was most likely attributable to the poor performance of the mine water treatment plant in removing manganese.

[25] This would place this site inside the GBMA boundary.

In 2000–01, with Clarence Colliery applying to convert tenements into mining leases to continue mining without an increase in production, the EPA attached a pollution reduction program (PRP) to EPL726 for the design of a trial for a daily release of 5 ML of mine water into Farmers Creek (RJ Whyte pers. comm.). This option was considered as a way to remove some of the mine water from the Wollangambe River, but it also had the potential to demonstrate a way of removing all of the mine water from the Wollangambe River. The trial did not proceed because it lacked support from the Department of Land and Water Conservation, Sydney Catchment Authority[26] and Lithgow Council. The Colong Foundation for Wilderness also raised concerns about the manganese and biofilms in the Wollangambe River with the potential for the trial to shift the biofilm problem from one catchment to another (RJ Whyte pers. comm.).

In April 2002, following the failure of the trial, the EPA attached another PRP setting July 2004 as the date when Clarence Colliery must meet Class P standards for filterable manganese of 0.05 mg/L and filterable iron of 0.3 mg/L (RJ Whyte pers. comm.).

In July 2004 Clarence Colliery complied with its PRP, and in June 2004, in accordance with Schedule 2, the EPA varied the EPL to add filterable manganese, filterable iron, arsenic, boron, cadmium, chloride, copper, lead, mercury, selenium, silver, sulfate, zinc, chromium (hexavalent), and fluoride. Salinity (EC) and nickel were not added at this time because they were not on Schedule 2[27] (RJ Whyte pers. comm.).

In November 2004 the EPA issued Clarence with a penalty notice and $1500 fine for breaching the filterable manganese limit of its EPL on 18 October 2004 (RJ Whyte pers. comm.). This action followed Clarence not being in compliance when the EPA collected (unannounced) samples on 18 August 2004 and warned Clarence to achieve compliance, even taking into account the time needed to achieve optimal performance of the treatment plant (RJ Whyte pers. comm.). Another round of unannounced sampling on 28 April 2005 indicated Clarence was complying with the filterable manganese limit (RJ Whyte pers. comm.).

Between 2004 and 2007 Clarence had difficulty consistently meeting the 0.05 mg/L standard (100th percentile) and had to report non-compliances. In 2006 the *Clean Waters Act 1970* and the Clean Waters Regulations 1972 (and Schedule 2) were repealed. In September 2007, Clarence applied for a variation of the filterable manganese limit because even though the treatment plant was working properly, there was still a difficulty in precision dosing because of the variable manganese in the raw water (with the risk of unused potassium permanganate being in the discharge; RJ Whyte pers. comm.). In October 2007 the EPA varied the EPL to a 50th and 100th percentile of 0.05 mg/L and 0.1 mg/L for filterable manganese, respectively (RJ Whyte pers. comm.). Both levels were below the ANZECC/ARMCANZ (2000) manganese guideline level to protect 99% of species (1.2 mg/L). The 100th percentile for filterable manganese became 0.5 mg/L on 5 July 2010 and the 50th percentile limit was removed (RJ Whyte pers. comm.).

On 26 March 2012 Clarence breached its manganese limit because of the treatment plant being unable to cope with an increased inflow of raw mine water and the EPA fined Clarence Colliery $1500 for this breach (RJ Whyte pers. comm.). Centennial Coal (2012b) reported that on 26 March 2012 there was an exceedance of EPL726 at LDP002 for filterable manganese (1.35 mg/L recorded, limit of 0.5 mg/L). There were also exceedances at LDP002 for filterable manganese on 2 April, 12 April and 3 July 2012, with results of 0.52 mg/L, 0.72 mg/L and 0.70 mg/L respectively. Centennial Coal (2012b)

[26] At the time it was proposed that this mine water would flow through Farmers Creek Swamp, a Newnes Plateau Shrub Swamp, now listed as an endangered ecological community (EEC) under the TSC and EPBC Acts.

[27] Schedule 2 was largely based on the old British drinking water standards of the 1950-60s and were not specifically targeted to in-stream water quality or potential environmental impact (RJ Whyte pers. comm.).

stated that the samples taken on 3 July 2012 were a re-sample for those collected in June 2012, which appeared erroneous and conflicted with on-site monitoring at the time. With the likelihood of an error in the sampling and analysis process, Centennial Coal (2012b) considered that the June 2012 results were not representative of water discharged and re-sampling was undertaken. Exceedances of the filterable manganese concentration limit at LDP002 were a result of the Clarence water treatment plant not performing to required levels (Centennial Coal 2012b). There has been an ongoing review of the Clarence water treatment plant, resulting in optimisation of the treatment process and upgrades to dosing infrastructure (Centennial Coal 2012b).

In the annual return for 2013 Clarence Colliery reported one exceedance of filterable manganese, which was considered minor and did not result in the EPA taking any action (RJ Whyte pers. comm.).

4.2 Current situation

4.2.1 Water quality

The surface water in streams on the Newnes Plateau generally has excellent water quality, with very low concentrations of dissolved and total salts, and very low concentrations of most metals, metalloids and non-metallic inorganics (excepting iron and aluminium). The very low levels of dissolved salts lead to the very low conductivity levels usually recorded in these streams (median=28 µS/cm, 80^{th} percentile=34.2 µS/cm; see Table A2 in Appendix 1). The chemical composition of waters on the Newnes Plateau is very similar to the composition of rainfall falling in the area, with very low concentrations of dissolved and total salts (see Toyer & Main 1981). The pH levels of Newnes Plateau surface waters tend to be slightly acidic (median=5.5, 80^{th} percentile=5.9: see Table A2) and have a low level of alkalinity with little buffering (neutralising) capacity (Toyer & Main 1981).

Based on the results of OEH's most recent sampling, relative to 'natural levels' in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002), the LDP002 discharge has elevated levels of: dissolved and total barium; bicarbonate alkalinity; dissolved and total calcium; dissolved and total cobalt; conductivity; hardness; dissolved and total lithium; dissolved and total magnesium; dissolved and total nickel; dissolved and total potassium; dissolved and total strontium; dissolved and total sulfur; sulfate; alkalinity, total dissolved solids; and dissolved and total zinc. Relative to 'natural levels' in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002) the LDP002 discharge has lower levels of chloride.

For a number of the analytes measured the concentration measured in LDP002 waters was an order of magnitude (10 times) greater than 'natural levels' in the headwater streams of the Newnes Plateau, and for some analytes (e.g. nickel, sulfur, sulfate, calcium) it was 50 to 100 times greater. Nickel concentrations (total and dissolved) in LDP002 discharge waters in particular stand out since the levels recorded were greater than the ANZECC/ARMCANZ (2000) default water quality guideline trigger value (0.011 mg/L) for the protection of 95% of species, and greater than the NHMRC (2013) Australian drinking water guideline level (0.02 mg/L). It is noted that the current licence (EPL726) for Clarence Colliery does not specify a limit for nickel. The total nickel concentrations found in the current study downstream of the discharge (0.041–0.053 mg/L) were slightly lower than the concentrations recorded by Belmer et al. 2014 (0.083–0.132 mg/L). Centennial Coal monitoring data indicated similar total nickel concentrations in the main dam (0.048 mg/L; n=1) and at the Wollangambe River downstream site (mean=0.0744 mg/L; maximum=0.142 mg/L; n=13). Much lower total nickel concentrations were measured at the Wollangambe River upstream site (mean=0.00085 mg/L; maximum=0.005 mg/L; n=40) and Wollangambe Tributary site (mean<DL; maximum<DL; n=12). Nickel concentrations in Clarence Colliery raw mine water can be much higher (mean=0.89 mg/L, range=0.78–1.02 mg/L; Cohen 2002).

Zinc concentrations in LDP002 water (and downstream) exceed the ANZECC/ARMCANZ (2000) water quality guideline (WQG) trigger value (0.008 mg/L) for protection of 95% of species, although they are below the EPL limit currently set by the EPA for this discharge (1.5 mg/L). It is noted that the EPL limit is set at nearly 200 times the ANZECC/ARMCANZ (2000) guideline level for the protection of 95% of species. The total zinc concentrations found in the current study downstream of the discharge (0.025–0.04 mg/L) were lower than the concentrations recorded by Belmer et al. in 2014 (0.101–0.136 mg/L), but still well above the ANZECC/ARMCANZ (2000) guideline level (0.008 mg/L) for protection of 95% of species. In addition to total zinc, dissolved zinc concentrations in downstream waters (0.019–0.033 mg/L), that is the form that is more bioavailable to organisms, also exceeded the WQG trigger value for zinc. Centennial monitoring data indicated high total zinc concentrations in the main dam (mean=0.140 mg/L; maximum=0.440 mg/L; n=37) and at the Wollangambe River downstream site (mean=0.082 mg/L; maximum=0.166 mg/L; n=15). Much lower total zinc concentrations were measured at the Wollangambe River upstream site (mean=0.011 mg/L; maximum=0.076 mg/L; n=69) and Wollangambe Tributary site (mean=0.003 mg/L; maximum=0.006[28]; n=12). Zinc concentrations in Clarence Colliery raw mine water can be much higher than discharge levels (mean=2.62 mg/L, range=2.38–3.06 mg/L; Cohen 2002).

In the current study, conductivity levels in the Wollangambe River upstream of LDP002 were measured at 32–34 µS/cm. This is fairly typical of conductivity levels in natural headwater streams on the Newnes Plateau (80th percentile=34.2 µS/cm; Table A2). The conductivity of the LDP discharge (320–340 µS/cm; OEH sample results) is currently an order of magnitude greater than upstream levels and, based on Clarence Colliery longer-term monitoring results, conductivity has previously been as high as 500 µS/cm. This agrees with the findings of Belmer at al. 2014 who found conductivity levels of 30 µS/cm upstream of the discharge and 342 µS/cm downstream. There is currently no EPL licence limit set for conductivity, although current LDP002 levels are close to the upper ANZEC/ARMCANZ (2000) default guideline level for upland streams (350 µS/cm) and have exceeded this guideline level in the recent past. The effect of the discharge on conductivity downstream of the LDP002 discharge is obvious with conductivity levels at W3, HAWK585, and W10 ranging from 310–320 µS/cm, indicating very little dilution of the LDP002 discharge once it joins the Wollangambe River. The average conductivity of raw mine water has previously been reported at approximately 240–281 µS/cm (see Cohen 2002[29] and IEC 1999; maximum reported conductivity=330 µS/cm).

The increasing salinisation of NSW freshwater rivers and streams as a result of high volume, high salt content waste water has been demonstrated in a number of areas, including the Hunter River, Upper Georges River, Upper Coxs River, Upper Nepean River and Wingecarribee River (e.g. Krogh et al. 2013, Cardno Ecology Lab Pty Ltd 2010, OEH 2012, Krogh & Miller 2011). A direct assessment of mine water salinity impacts can be found in the ACARP study on the effects of mine water salinity on freshwater biota (Cardno Ecology Lab Pty Ltd 2010). Cardno Ecology Lab Pty Ltd (2010) found that discharge waters from mines in the Hunter and Illawarra/Macarthur regions induced deleterious responses in a range of aquatic biota. Arthropods were the most sensitive

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[28] Recorded levels for Dissolved Zinc were often higher than Total Zinc levels which were mostly < D.L. One record of dissolved zinc=0.05 mg/L with corresponding total zinc level < D.L. is potentially an error.

[29] Cohen (2002) gives an average of 154 mg/L (range 88–197 mg/L) for total dissolved solids and conductivity has been calculated assuming a conversation factor of EC (µS/cm) × 0.64 = TDS (mg/L). It should be noted that the factor used to convert conductivity to TDS can vary according to the specific ionic composition of the water. IEC (1999) reported conductivity of raw mine water ranging from 210–330 µS/cm (mean=281 µS/cm) for the period 21/10/98 to 25/2/99.

organisms tested, with the mayfly *Atalophlebia* spp. being the most sensitive of these. The salinity levels at which effects occurred were below those reported in the literature for sodium chloride (NaCl) based solutions and highlighted the need for site-specific toxicity information that takes into account the variable composition of saline mine waters, including the consideration of other constituents (Cardno Ecology Lab Pty Ltd 2010). Different ions (sodium [Na^+], calcium [Ca^{2+}], magnesium [Mg^{2+}], potassium [K^+], chloride [Cl^-], bicarbonate [HCO_3^-], sulfate [SO_4^{2-}] and the salts they form) can induce varying degrees of toxicity to aquatic life (e.g. Young 1923; Mossier 1971; Nelson 1968; Held & Peterka 1974; Rawson & Moore 1944; Farag & Harper 2012). There are a number of recent scientific publications that suggest increased levels of salinity can adversely affect aquatic communities (e.g. Kefford et al. 2006, 2007a, 2007b, 2010; Cardno Ecology Lab Pty Ltd 2010; Dunlop et al. 2008, 2011; Cañedo Argüelles et al. 2013).

More recently Farag and Harper (2012) constructed a database of toxicity evaluations of sodium bicarbonate ($NaHCO_3$) on aquatic life and used these data to establish acute and chronic criteria for the protection of aquatic life[30]. Chronic toxicity was observed at concentrations that ranged from 450 to 800 milligrams $NaHCO_3$ per litre (also defined as 430 to 657 milligrams HCO_3^- per litre or total alkalinity expressed as 354 to 539 milligrams $CaCO_3$ per litre) and the specific concentration depended on the sensitivity of the four species of invertebrates and fish exposed. Acute and chronic criteria of 459 and 381 milligrams $NaHCO_3$ per litre, respectively, were calculated to protect 95% of the most sensitive species (Farag & Harper 2012). It is noted that the bicarbonate alkalinity in LDP002 waters measured in the current study (32 mg/L) is well below the acute and chronic criteria of Farag and Harper (2012) and bicarbonate concentrations may therefore not be an issue for this particular discharge, as it potentially has been for other mine water discharges (e.g. OEH 2012). Nevertheless, electrical conductivity levels in the LDP002 discharge are still an order of magnitude greater than natural headwater streams on the Newnes Plateau and it would be unrealistic to suggest that such a large change is not affecting the river’s ecology in some way. It is noted that the ecotoxicology and macroinvertebrate community results, discussed further below, indicate impacts as a result of the LDP002 discharge, although whether this is due to salinity or a combination of factors including salinity is yet to be determined.

On the basis of current and previous monitoring, it can be concluded that the LDP002 discharge significantly alters the water chemistry (pH, conductivity, alkalinity, ionic composition[31], and suite of metals, metalloids, non-metallic inorganics) of the receiving waters close to where the discharge joins the Wollangambe River and for a considerable distance downstream (including at sites sampled within the Greater Blue Mountains World Heritage Area). Because of the volume and concentrations of the discharge and its location high in the headwaters of the Wollangambe River, very little dilution is achieved once the discharge joins the Wollangambe River. The very high flows (on average ~14 ML/day) could also potentially be contributing to scouring and bank undercutting downstream of the discharge. In addition, the discharge may also be affecting average stream temperatures, although this requires more detailed monitoring and assessment.

4.2.2 Ecotoxicology

The LDP002 discharge caused acute and chronic toxicity to *Ceriodaphnia dubia* at a variety of dilutions. It caused significant inhibitory effects on growth of the alga

[30] This was for US species, but see also OEH (2012). The ACARP report (Cardno Ecology Lab Pty Ltd 2010) on impacts of mine water salinity also investigated toxicity issues associated with saline mine water discharges.

[31] It is likely that at least some of the differences in ionic composition might also be due to the treatment processes used to increase pH and reduce metal levels in raw mine water, since the ionic proportions of raw mine water appears to be closer to ambient surface water ionic proportions than the treated discharge waters.

Pseudokirchneriella subcapitata but caused no or minimal effects in *Melanotaenia duboulayi.* Adverse effects in *C. dubia* and *P. subcapitata* were also observed in waters sampled downstream of the discharge. The LDP002 discharge therefore has the potential to be inducing toxicity and/or reproductive impairment effects on sensitive invertebrate and algal species that reside in the receiving environment of the Wollangambe River, including at sites within the Greater Blue Mountains World Heritage Area. Further investigations are needed to determine exactly which components of the LDP002 discharge waters are causing the observed acute and chronic toxicity. In addition to standard test species, future assessments should also consider toxicity testing of taxa endemic to the area.

4.2.3 Macroinvertebrate community structure

In the current study, there were clear differences between the community composition at sites in the Wollangambe River downstream of the LDP002 discharge compared to upstream Wollangambe River and reference stream sites. Overall, the downstream sites exhibited much lower diversity of taxa and much lower numbers than other sites, which was noticeable at the time of field sorting and picking. The site sampled by OEH within the Greater Blue Mountains World Heritage Area (W10) was found to be very similar to the 1.2 km downstream site (W3) in terms of macroinvertebrate community composition. These results support the findings of Belmer et al. (2014) who found decreased macroinvertebrate family richness (by 65%) and decreased abundance (by 90%) downstream of the discharge.

When the macroinvertebrate communities from the current study were compared with data collected at nearby sites (EPA/OEH unpublished data) there was a clear difference between most sites downstream of the discharge and reference sites. DECC (2008) discussed the sampling of the Wollangambe River immediately downstream of Clarence Colliery (site HAWK585 in the current OEH study) in autumn and spring 1999 for the National River Health Program. They found this site to be in much poorer condition than the reference condition, suggesting that the aquatic biota was severely impaired by discharges from the coal mine (DECC 2008). Based on the recent OEH sampling, the macroinvertebrate community at this site does not appear to have improved since the 1999 sampling took place.

Also of interest is the sampling of the Wollangambe Exit site which suggested little difference in macroinvertebrate communities between this site and reference sites, despite it being downstream of the discharge[32]. It is important to note, however, that sampling at this site occurred prior to the observed increase in salinity in the LDP002 discharge in 2011–12. The Wollangambe Exit site is located in a pool downstream of the gorge. As such there is habitat that provides refuge from the constant fast flow of the mine discharge waters.

MPR (2012) assessed the aquatic habitat condition of the Wollangambe River and aquatic macroinvertebrates were collected, sorted and identified using the AusRivAS methods. Fish were trapped using bait traps set over the short time the macroinvertebrate sampling was undertaken. MPR (2012) concluded:

- The survey also showed that the two downstream of dam river sites had aquatic ecology attributes similar to Newnes Plateau reference sites with one difference,

[32] Below Cohen's (2002) site W6 and Belmer et al.'s (2014) site W4. Sites W6 and W4 are reasonably close together (near Mt Wilson) but Cohen suggests W6 is 23 km downstream whereas Belmer et al. 2014 suggest W4 is 16 km downstream. These discrepancies are likely to be due at least in part to the sinuous path of the Wollangambe River and different methods of distance estimation.

that the two sites were subjected to a more or less constant water flow (arising from the main dam discharge).

- Much of the pattern can be attributed to physical attributes of the sampling sites and as responses to the main dam overflow at the time of sampling. The presence of the main dam alters the actual habitats available for aquatic macroinvertebrates and limits invertebrate drift, and the more or less continuous flow rate of the discharge alters the ability of aquatic macroinvertebrates to colonise some sites downstream.
- The net result is that at site WGRdown some 980 m downstream from the main dam spillway and 540 m upstream of the national park boundary the river supports a macroinvertebrate fauna similar to pristine Newnes Plateau Shrub Swamp monitoring sites.
- With regard to potential impacts of the existing Clarence Colliery mining operations on the aquatic ecology of Wollangambe River within the Blue Mountains National Park, it is clear from the results provided in this snapshot survey that there are unlikely to be measurable impacts beyond the park boundary.

Whilst the potential effects of high flow and the dam upstream of the sampling sites (W3, HAWK585 and W10) are acknowledged as potential factors influencing community composition, the macroinvertebrate community findings of MPR (2012) are at significant odds to the current study (and the findings of Belmer et al. 2014). They are also at significant odds with earlier sampling downstream of the discharge undertaken in 1999 (e.g. see DECC 2008 and Figure 11).

When the MPR data from subsequent assessments were statistically analysed, significant differences among all sample sites were found. Significant pairwise differences were also found between: the upstream and downstream sites; upstream and swamp sites; upstream and downstream national park sites; and upstream and dam sites. Significant pairwise differences were also found between the reference and downstream sites; reference and swamp sites; reference and downstream national park sites; and reference and dam sites. No significant differences were found between the upstream and reference sites; or swamp and downstream sites.

The MPR data and OEH's latest sampling suggests that the macroinvertebrate community downstream of the discharge is significantly different to pristine headwater streams of the Newnes Plateau. Further, the difference in macroinvertebrate communities extends to sites (OEH site W10 and MPR site WGRX) located within the Greater Blue Mountains World Heritage Area. One problem in basing impact assessments purely on presence–absence of taxa is that it does not necessarily identify changes in abundance. At the time of field sorting and picking for the OEH study, it was obvious that diversity and abundance was unusually low at the sites downstream of the LDP002 discharge. This was also the case for Belmer et al.'s (2014) study. Further studies are required to determine the full longitudinal extent of the discharge impact on macroinvertebrate communities in the Wollangambe River.

In the mid 1990s the Clarence Colliery discharge was implicated in the development of black biofilms in the Wollangambe River (Cohen 2002). This would likely have affected macroinvertebrate communities at the time, but no macroinvertebrate community sampling was undertaken. Cohen (2002) discussed the biofilm with accumulated manganese oxides and entrapment of microfine coal. A similar black biofilm was noted at two of the downstream sites during sampling in October 2014; however, it did not appear to be as extensive as that investigated by the EPA in 1995 (see Photo 1 below). MPR (2013b) also reported a mat-like silt/algae matrix that was smothering submerged surfaces at downstream sites (WGRdam, WGRswamp, WGRdown and to a lesser extent WGRXdown). When the downstream sites (W3 and HAWK585) were sampled by OEH (on 21/10/14 and 22/10/14 respectively) there was also a bluish tinge to the water (see Photo 2 below) and at W3 there was a noticeable surface film which caused air bubbles to remain at the surface for long periods of time. These phenomena were not observed when the sites were revisited on 13/11/14 and 17/12/14 when water clarity had improved. The cause/origin of the bluish tinge and surface film could not be traced.

Photo 1: Biofilm with accumulated manganese oxides and entrapment of microfine coal
Source: Courtesy R Mann (formerly EPA)

Photo 2: Wollangambe River at site W3
Source: OEH

4.3 ANZECC/ARMCANZ reference condition assessment

The ANZECC guidelines acknowledge that different levels of protection may be appropriate for different water bodies. The guidelines specify three levels of protection, from stringent to flexible, corresponding to whether the condition of the particular ecosystem is:

- of high conservation value
- slightly to moderately disturbed, or
- highly disturbed.

The policy in NSW is that the level of protection applied to most waterways is the one suggested for ‘slightly to moderately disturbed’ ecosystems; however, waterways that mainly flow through relatively undisturbed national parks, World Heritage Areas or wetlands of outstanding ecological significance are designated as being of ‘high conservation value’ (DEC 2006). On this basis, the Wollangambe River is considered to be a river of ‘high conservation value’.

ANZECC/ ARMCANZ (2000) noted that for high conservation/ecological value systems (condition 1):

‘*The present Guidelines recommend that for condition 1 ecosystems* [high conservation/ ecological value] *the values of the indicators of biological diversity should not change markedly. To meet this goal, the decision criteria for detecting a change should be ecologically conservative and based on sound ecological principles. Moreover, a precautionary approach is recommended — management action should be considered for any apparent trend away from a baseline, or once an agreed threshold has been reached. Any decision to relax the physical and chemical guidelines for condition 1 ecosystems should only be made if it is known that such a degradation in water quality will not compromise the objective of maintaining biological diversity in the system. Therefore,* *considerable biological assessment data would be required for the system in question, including biological effects and an ongoing monitoring program based on sufficient baseline data. The nature of contaminants expected in the receiving waters might also affect decisions on this issue. Where there are few biological assessment data available for the system, the management objective should be to ensure no change in the concentrations of the physical and chemical water quality variables beyond natural variation.*'

It is noted that a number of analytes in the LDP002 and downstream site samples are well above the ANZECC/ARMCANZ (2000) default guideline trigger levels for protection of 95% and 99% of species (e.g. nickel and zinc). If a lower level of protection than condition 1 was to be applied to the Wollangambe River, the ANZECC/ARMCANZ (2000) guidelines identify that for some water quality indicators, users will need to define a *reference condition* that provides both a target for management actions to aim for and a meaningful comparison for use in a monitoring or assessment program. The reference condition is particularly appropriate for slightly–moderately and highly disturbed ecosystems and is a key component of the ANZECC framework for applying the guidelines. The reference condition must be chosen using information about the physical and biological characteristics of both the catchment and aquatic environments to ensure the sites are relevant and represent suitable target conditions.

Locally appropriate trigger values can be derived to take into account local geology or other natural process that might be relevant. The ANZECC guidelines provided detailed instruction on how local trigger values should be derived. Local trigger values do not reflect the degraded nature of a waterway. Where it is relevant to take disturbance into account this is done as a part of the calculation of the relevant trigger values. This approach includes the use of reference sites, which are sites that broadly reflect the natural state of the relevant waterway. It is clear that under the current levels of treatment, the LDP002 discharge is unable to meet condition 1 (high conservation/ ecological value) targets and is highly unlikely to satisfy locally derived water quality trigger values for many contaminants.

In terms of licensing discharges, the EPA (2013) identifies that it is the responsibility of licence holders to:

- be aware of the pollutants that are discharged to waters from their premises
- be aware of the environmental impacts that pollutants discharged from their premises have on the environment
- ensure that their licence specifically regulates the discharge from their premises of all those pollutants that pose a risk of non-trivial harm to human health or the environment – where the premises discharges a pollutant that is not regulated by the licence, the licence holder does not have a defence against the pollution of waters offence by that pollutant.

Based on the results of the current study:

1. There is a need to review EPL726 licence conditions for nickel and conductivity in LDP002 discharge waters because the impact of those pollutants on the environment may not be trivial.
2. It is noted that the EPL726 limit for zinc (1.5 mg/L) is set at nearly 200 times the ANZECC/ ARMCANZ (2000) guideline level for the protection of 95% of species. The EPL726 limit for zinc should be reviewed.

3. The EPA licence level for total sulfate (250 mg/L) is currently almost two orders of magnitude higher than upstream levels. The EPL726 limit for total sulfate should also be reviewed.
4. Consideration should also be given to setting EPL licence limits for other contaminants (eg barium, cobalt, lithium, strontium and sulphur), since they are significantly higher in the LDP002 discharge waters than background levels in the upstream Wollangambe River and Newnes Plateau headwater streams. Little is known of the potential effects of elevated levels of barium, cobalt, lithium, strontium and sulfur on aquatic organisms or ecosystems in this area. Whilst ANZECC/ ARMCANZ (2000) do not specify guideline levels for these elements, they do advocate the setting of guideline levels on the basis of 80th percentiles derived from reference site sampling.

4.3.1 Impacts on the Greater Blue Mountains World Heritage Area (GBMA)

Very little dilution of the LDP002 discharge (and contained contaminants) is achieved once it joins the Wollangambe River. This is largely due to the volume of the discharge, together with its location high in the headwaters of the Wollangambe River. Based on the results of the current study, water quality impacts from the Clarence Colliery discharge are measurable for a considerable distance downstream, including at sites within the GBMA. The discharge (and downstream waters) also caused acute and chronic toxicity to a range of test species.

In the mid to late 1990s while nickel and zinc had the highest metal concentrations in sediments directly below the Clarence Colliery discharge point, cobalt and manganese were reported to have the highest metal concentrations three kilometres downstream of the Clarence Colliery discharge point (Cohen 2002). The metal content in sediments 12 km and 23 km downstream of the colliery dropped off significantly; however, cobalt was found to exhibit the greatest increase over background levels at the last (23 km downstream) site monitored. Cohen's (2002) study also found that biofilm samples collected 23 km downstream showed particularly high manganese contents, indicating that manganese may be concentrating in the biofilm layers for some distance below the Clarence Colliery discharge point. All these latter sites are within the Greater Blue Mountains World Heritage Area.

More recently, Belmer et al. (2012) recorded levels of zinc and nickel in Wollangambe River surface waters above the ANZECC/ARMCANZ (2000) guideline level for the protection of freshwater species at site W4 (upstream of Bell Creek), close to the commencement of the Wollangambe Canyon[33]. OEH's current study identified water quality and macroinvertebrate community impacts at a site (W10) just inside the GBMA. The MPR data were also indicative of impacts at site WGRX (downstream of OEH site W10). OEH's sampling suggests that the macroinvertebrate community downstream of the discharge is demonstrably different to pristine headwater streams of the Newnes Plateau with significantly decreased diversity and abundance. These differences are likely to be a direct effect of mining in the catchment and the discharge of waters significantly higher in barium; bicarbonate alkalinity; calcium; cobalt; conductivity; hardness; lithium; magnesium; nickel; potassium; strontium; sulfur; sulfate; alkalinity, total dissolved solids; and zinc. Further studies are required to determine whether impacts are due primarily to a single contaminant or a mixture of contaminants in the discharge. Physical changes such as constant high flows, higher pH levels, temperature increases and the physical effect of

[33] The Wollangambe Canyon is probably the most visited canyon in the Blue Mountains area, with up to 150 canyoners on a peak summer day (DECC 2008).

the main dam itself may also be contributing to altered freshwater aquatic communities in the Wollangambe River.

Whilst the black biofilms of the mid 1990s no longer appear to be as obvious a problem, the toxicity of the LDP002 discharge waters is of current concern. In addition to the LDP002 discharge waters exhibiting toxicity to test organisms, water samples from sites downstream of the discharge (HAWK585, W3, W10) also caused acute toxicity (significant immobilisation) in exposed *Ceriodaphnia dubia* at the concentrations tested. In addition, these samples caused chronic toxicity (significant reproductive impairment) in exposed *C. dubia* at the concentrations tested. The full extent of the LDP002 discharge impact is yet to be clearly defined, but it obviously extends well within the Greater Blue Mountains World Heritage Area boundary.

Given that the LDP002 discharge flows into a near-pristine Newnes Plateau headwater stream which subsequently flows into the Greater Blue Mountains World Heritage Area, it is recommended that any review of EPL limits be based on ANZECC/ARMCANZ (2000) guideline levels for the protection of freshwater species. This would likely require a significant review of current treatment processes at Clarence Colliery, including consideration of improved treatment processes such as reverse osmosis to significantly reduce the levels of salt in the discharge to levels consistent with background and upstream levels. It is likely that this would also assist in reducing high metal concentrations (see WA Department of Health 2009). If such a process were introduced, it could turn what is currently a significant waste stream into a significant resource for use within the local or nearby areas, whilst at the same time addressing a significant point source that is currently impacting on the values of the Greater Blue Mountains World Heritage Area.

4.4 Conclusions

While caution needs to be exercised in being definitive about impacts based on one small study, the weight of evidence from this and previous studies shows:

- The surface waters of the Newnes Plateau generally have excellent water quality with very low concentrations of dissolved and total salts and very low concentrations of most metals, metalloids and non-metallic inorganics (excepting iron and aluminium).
- Clarence Colliery LDP002 introduces a high volume point source of pollution to the Wollangambe River.
- Very little dilution of the LDP002 discharge (and contained contaminants) is achieved once it joins the Wollangambe River. This is largely due to the volume of the discharge, together with its location high in the headwaters of the Wollangambe River.
- Relative to ‘natural levels’ in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002), the LDP002 discharge has elevated levels of: dissolved and total barium; bicarbonate alkalinity; dissolved and total calcium; dissolved and total cobalt; conductivity; hardness; dissolved and total lithium; dissolved and total magnesium; dissolved and total nickel; dissolved and total potassium; dissolved and total strontium; dissolved and total sulfur; sulfate; alkalinity, total dissolved solids; and dissolved and total zinc.
- Relative to ‘natural levels’ in the streams of the Newnes Plateau (including the Wollangambe River upstream of LDP002) the LDP002 discharge had lower levels of chloride.

- For a number of analytes measured the difference in concentration was an order of magnitude (10 times) greater than 'natural levels' in the streams of the Newnes Plateau and for some analytes (e.g. nickel, sulfur, sulfate, calcium) it was 50 to 100 times greater.
- Nickel concentrations in LDP002 discharge waters were greater than the ANZECC/ARMCANZ (2000) default guideline trigger value for the protection of 95% of species and greater than the NHMRC (2013) Australian drinking water guideline value. The current licence (EPL726) for Clarence Colliery does not specify a limit for nickel.
- Zinc levels in LDP002 water (and downstream) also exceed the ANZECC/ARMCANZ (2000) guideline trigger value for protection of 95% of species, although they were below the EPL limit set by the EPA for this discharge.
- The LDP002 alters the water chemistry (pH, conductivity, alkalinity, ionic composition, suite of metals, metalloids, non-metallic inorganics) of the receiving waters close to where the discharge joins the Wollangambe River and for a considerable distance downstream (including at sites sampled within the Greater Blue Mountains World Heritage Area).
- The LDP002 discharge caused acute and chronic toxicity to the cladoceran *Ceriodaphnia dubia* at a variety of dilutions. It also caused significant inhibitory effects on growth of the alga *Pseudokirchneriella subcapitata.*
- The LDP002 discharge has the potential to be inducing toxicity and/or reproductive impairment effects on sensitive invertebrate and algal species in the receiving environment of the Wollangambe River, including at sites within the Greater Blue Mountains World Heritage Area.
- Further investigations would be needed to determine exactly which components of the LDP002 discharge waters are causing the observed acute and chronic toxicity effects.
- OEH's latest sampling suggests that the macroinvertebrate community downstream of the discharge is demonstrably different to pristine headwater streams of the Newnes Plateau. Further, the difference in macroinvertebrate communities extended to the sample site located within the Greater Blue Mountains World Heritage Area.
- Further studies are required to determine the full longitudinal extent of the discharge impacts on macroinvertebrate communities in the Wollangambe River.
- There is a clear need to review EPL licence conditions for nickel and conductivity (not currently on EPL724). The EPL limit for Zinc, currently set at nearly 200 times the ANZECC/ARMCANZ (2000) guideline level for the protection of 95% of species, should also be reviewed.
- Based on the results of the current study, consideration should also be given to setting EPL licence conditions for other contaminants in the discharge whose levels were found to be significantly higher than background levels in the Upper Wollangambe River and Newnes Plateau headwater streams.
- Given that the LDP002 discharge flows into a near-pristine Newnes Plateau headwater stream which subsequently flows into the Greater Blue Mountains World Heritage Area, it is recommended that any review of EPL limits is based on ANZECC/ARMCANZ (2000) guideline trigger values for the protection of freshwater species.

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