Berrima Colliery
Performance Monitoring Program
Scientific Report
Environment Protection Licence 608

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1. Abstract

Berrima Colliery is an underground coal mine located in the Southern Highlands of NSW. Originally commencing in the 1870's the mine operated continuously between 1926 and 2013. Since October 2013, the mine has been in the process of final closure. While operating, the mine pumped water to the surface for domestic use at the pit top as well as supplying the nearby Village of Medway. Excess water was discharged into the Wingecarribee River via a licensed discharge point. Prior to discharge, the underground water was pumped and settled multiple times which reduced, though did not eliminate a range of minerals that occurred naturally in the groundwater. Discharge from the mine has occurred for approximately 90 years.

During the final closure process, the mine was allowed to flood and free drain into the Wingecarribee River via the existing licensed discharge point. During the initial flooding of the mine workings, between August 2015 and December 2015, the mine discharge volume reduced significantly. The initial water free draining from the workings was of acceptable quality however in July 2016 the quality of water free draining from the mine deteriorated. Metal concentrations increased significantly, conductivity rose and pH fell.

During the two year period of free draining during 2016 and 2017, investigations of the mixing zone showed high deposition of Iron and Manganese. River flow was also very low, allowing the deposition to accumulate. In February 2018 Boral implemented an underground water treatment system to improve the water quality discharged into the Wingecarribee River. The treatment system was designed to increase the dissolved oxygen concentration and pH in order to precipitate Iron and Manganese. Precipitated metals are then removed by settlement prior to the water discharging off the site. The system proved effective and resulted in progressive removal of the metal concentrations at the discharge.

In May 2019, seven internal bulkheads were constructed in order to gather data on permeability of the strata within the mine. This will inform final closure options by determining the potential to seal or at least partially seal the mine workings. The completion of the installation of the bulkheads in May 2019 caused a significant reduction in the volume of the mine discharge. By December 2019 water had reached the final bulkhead and the mine had recommenced discharge via pumping through the underground treatment system. Data is currently being gathered on the permeability of the strata surrounding the bulkhead installations. It is anticipated that the water quality discharged in 2020 will be similar to the water quality discharged during the previous underground treatment phase during January 2018 up until March 2019. The amount of water to be pumped during 2020 will vary in order to determine inflow into the mine workings.

This report compiles four separate studies into the impacts on the Wingecarribee River, namely water quality, aquatic ecology, ecotoxicology and sediment analysis. These results can then be used to develop further strategies necessary to provide long term certainty of the potential impacts of the mine following permanent closure.

2. Introduction

2.1 Purpose

This report has been prepared in response to Special Condition E3.1 of Environment Protection Licence (EPL) 608.

2.2 Scope

Special Condition 8 of EPL 608 requires Berrima Colliery to develop and implement an action plan to prevent, control, abate and mitigate pollution of the Wingecarribee River. Special Condition 8 includes a set of sub-conditions (E1 to E3) which require assessment of background water quality, development of alternative water uses, specifies the scope of the underground water treatment methods, maintenance of the treatment system, performance monitoring and reporting requirements.

This report provides the results of the underground water treatment system available for the period ending 31st December 2019. This report does not deal with other activities undertaken at the colliery in relation to final closure, methods of closure or other environmental implications of the closure process. This information is contained separately in the Annual Environmental Management Reports for 2018 and 2019 and the Stage 1 Final Closure Mining Operations Plan (2019). This report brings together the environmental studies specific to Special Condition 8 of the EPL.

2.3 Study Area

The overall study area consists of Consolidated Coal Lease 748 shown on Plan 1 in Appendix A, but centres on the underground mine workings rather than the two surface sites referred to as the Pit Top and Loch Catherine. These sites were used for administration, coal handling and storage and do not contribute to the discharge of the mine.

The specific study area consists of the mixing zone of the mine discharge within the Wingecarribee River. This extends from the licensed discharge point downstream for a distance of approximately 6 km. Reference sites upstream of the discharge point and in the Medway Rivulet tributary form ambient sites for comparison. Historical ambient upstream and downstream sample locations are also included to provide a more comprehensive data set on river water quality data.

2.4 Aims and Objectives

The primary aim of the work is to assess the impacts of the water discharge from the mine on the receiving waters of the Wingecarribee River using the risk based methodology contained in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000). As the mine has historically discharged into the river, there is the need to assess the changes since the water quality deteriorated using the historic data as a baseline. The objectives specified by the EPA in Condition E3.1 of EPL608 require:

> *"To assess the gradient changes in composition and abundance of in-stream biota downstream of Berrima Colliery's adit discharge to the Wingecarribee River. To assess changes over time in the following installation of the water treatment system. To determine whether water quality in the Wingecarribee River at Biloela is less than trigger values for primary industries and recreational water quality and aesthetics (ANZECC 2000)."*

The hypothesis put forward by the EPA in Condition E3.1 is as follows:

> *"That the abundance and composition of aquatic biota will become more similar to reference sites following commissioning of the required water project. A specific bioindicator target is for % EPT at sites downstream of the discharge (Point 4, 5 and 6) are to be statistically similar to reference sites. The EPT index is used to calculate the relative abundance of pollution sensitive macroinvertebrates of the Ephemeroptera, Plecoptera and Trichoptera Orders. (Wright & Ryan, 2016)."*

This report covers the complete two years of the Performance Monitoring Program.

2.5 Methods

There are several components to this study, namely:

- ❒ Surface water quality within the receiving waters of the Wingecarribee River. This includes both the mixing zone and nominated reference sites.
- ❒ Groundwater quality within the mine workings prior to release into the Wingecarribee River. Although the water is naturally occurring and the discharge longstanding, the recent change in water quality following cessation of mining has created the need to undertake investigations into removing higher mineral content to better match long term discharge quality.
- ❒ Aquatic ecology studies within the receiving waters, including the mixing zone and nominated reference sites.
- ❒ Ecotoxicological investigations to determine changes in inhibitors within the mixing zone compared to nominated reference sites.
- ❒ Sediment analysis along the river to determine rate of transport, effects of geology and the ultimate fate of minerals discharged within the mixing zone.

The above studies were undertaken during the past two calendar years 2018 and 2019, however a similar set of studies were undertaken between 2011 and 2012, while ambient water quality within the Wingecarribee River has been undertaken continuously since 2010. An ANZECC assessment was completed for Berrima Colliery in February 2013 which provides a baseline to compare with studies undertaken in 2018 and 2019. Details of each study is provided in the following chapters.

The methods used in this study follow the risk-based process described in ANZECC (2000) and the Guidelines in ANZECC (DEC 2006). Details of the methods for each study component is separately provided in each of the following chapters, however there are some guiding principles provided by ANZECC (2000) which are observed.

In Section 2.2.1.9, ANZECC 2000 page 2-17 states:

> *"The Guidelines have not been designed for direct application in activities such as discharge consents, recycled water quality or stormwater quality, nor should they be used in this way. (The exception to this may be water quality in stormwater systems that are regarded as having some conservation value.) They have been derived to apply to the ambient waters that receive effluent or stormwater discharges, and protect the environmental values they support. In this respect, the Guidelines have not been designed to deal with mixing zones, explicitly defined areas around an effluent discharge where the water quality may still be below that required to protect the designated environmental values. As such, the application and management of mixing zones are independent but very important processes."*

The ANZECC guidelines are a risk-based process designed to allow for the development of appropriate triggers based on ambient water quality and ecological investigations. The default water quality concentrations quoted in ANZECC should not be taken as 'pass' or 'fail' criteria. As stated in 'Using the ANZECC Guidelines and Water Quality Objectives in NSW' (DECC 2006):

> *"Trigger values are fundamental to using the ANZECC guidelines. The trigger values for different indicators of water quality may be given as a threshold value or a range of desirable values. Trigger values are conservative assessment levels, not pass/fail' compliance criteria. Local conditions vary naturally between waterways and it may be necessary to tailor trigger values to local conditions or 'local guideline levels'. The guidelines provide a process for refining the trigger values and these protocols should always be followed.*

The ANZECC methodology outlines the following sequence to be followed to determine appropriate trigger values:

- ❒ Define the water body including scientific information, monitoring data and ecosystem type classification (ANZECC 2000, Section 3.1.2).
- ❒ Determine environmental values to be protected.
- ❒ Determine level of protection (ANZECC 2000, Section 3.1.3).
- ❒ Identify environmental concerns such as toxic effects, nuisance aquatic plant growth, maintenance of dissolved oxygen and changes in salinity.
- ❒ Determine major natural and anthropogenic factors affecting the ecosystem.
- ❒ Determine management goals.
- ❒ Determine a balance of indicator types (ANZECC 2000, Section 7.2.1).
- ❒ Select indicators relevant to concerns and goals.

- Determine appropriate guideline trigger vales.
- Determine environmental values.
- Determine Site Specific Trigger Values.
- Determine effects on ecosystem-specific modifying factors including biological assessment, physical and chemical stressors, toxicants and sediments.

Given the nature of this study, some components have been developed separately as part of regulatory authority responsibilities under the mining lease CCL748 (Mining Act) and Environment Protection Licence EPL608 (Protection of the Environment Operations Act). The two principle authorities are the Environment Protection Authority (EPA) and the NSW Resources Regulator.

In terms of study methodology, the EPA has specified that the study should *"determine whether water quality in the Wingecarribee River at Biloela is less than trigger values for primary industries and recreational water quality and aesthetics"* (EPL608 Condition E3.1). This is an appropriate environmental value. The EPA has also specified some aquatic ecology methods and has undertaken its own ecotoxicological testing which is included in this study along with data obtained from earlier studies when the mine was operational for comparison.

3. Water Quality

3.1 Introduction

The assessment of water quality has included two components. The first is long term monitoring of the mine discharge into the Wingecarribee River, and the second being the quality of the receiving waters of the Wingecarribee River. Discharge quality has been measured using a variety of analytes since the early 1980's, however river water quality monitoring commenced in 2010. The ambient water quality was supplemented by the Performance Monitoring Program in 2018 following the closure of the mine in response to poor water quality free draining from the Adit.

River water quality can fluctuate due to frequent water exchange occurring from agricultural runoff, drainage from residential and industry as well as recreational influences. Nevertheless, organisms that are reliant on the waterways for survival require a certain degree of stability within the water quality (State of Environment, Aust Commonwealth 2016). The health and quality of a river ecosystem can be measured through a range of parameters, namely level of nutrients, dissolved oxygen, metals, pH and electrical conductivity.

In this case, the Wingecarribee River is characteristically high in metals including Iron with a slightly lowered pH level. Berrima Colliery has been discharging into the Wingecarribee River since at least 1926 with no demonstrated negative effects on downstream ecosystems. The quality of the discharged water deteriorated during the closure process. This occurred when the mine flooded and commenced to free drain at the end of 2015 following. The Colliery installed a limestone and aeration water treatment system which improved water quality to close to the long term average. In May 2019, seven underground bulkheads were installed to determine strata permeability and to facilitate the determination of final closure arrangements. This resulted in the water discharge to reduce significantly for the majority of 2019. The mine has since recommenced discharge via pumping through the underground treatment system. The pumping rate will vary as necessary to keep the water level below the top of the highest bulkhead. This will enable the volume of groundwater entering the workings to be estimated.

The ANZECC 2000 water quality guidelines provides a methodology to assess the impacts on receiving water quality using a risk based approach. The methodology required long term investigations on receiving water quality including an analogue site in order to determine appropriate water quality goals that ensure there are no long term changes to the environmental values of the Wingecarribee River.

As part of the Performance Monitoring Program, the water quality of the discharge water and at intervals within the Wingecarribee River have been monitored monthly for two years in order to evaluate the health of the river in relation to the discharge from the mine. The aim of this Chapter is to assess the success of the underground treatment system and the installation of the bulkheads, in order to assist in making informed decisions for the final closure of the mine.

3.2 Methods

On a monthly basis, water samples are taken from eight sites along the Wingecarribee River (including reference sites) and from the Adit Discharge Point as part of the Performance Monitoring Program. Three additional ambient river sites are sampled bi-monthly. Water samples are collected in plastic bottles with required preservatives and taken to ALS Environmental Laboratories on the same day for analysis. Chain of Custody documentation is prepared, and records kept including details of the time of sampling, location, person collecting the sample, temperature, pH and conductivity of the sample at collection, time received at the laboratory, temperature of the sample received at the laboratory and cross checking of analytes to be tested. The analytes tested include but are not limited to: Total and Dissolved Metals, Alkalinity, Dissolved Cations, Ionic Balance, Nitrogen, pH, Conductivity and Dissolved Oxygen.

3.2.1 Underground Monitoring Locations

Sampling of four of the sites within the underground water treatment were discontinued in 2019 when the underground workings were drained for the installation of the bulkheads. The drain adit discharge is sampled monthly in conjunction with the river monitoring.

3.2.2 Performance Water Quality Monitoring Program

On 21st December 2017, the EPA varied EPL 608 to include additional conditions in relation to water treatment and management prior to discharge under a Performance Monitoring Program. The Resources Regulator has also requested additional monitoring activities during the closure process.

A key component of the Performance Monitoring Program is the resultant water quality discharged into the Wingecarribee River and the assessment of any changes in water quality occurring within the mixing zone. The program includes additional monitoring locations downstream of the discharge point as well as reference sites just upstream of the discharge point. The program also includes the historic monitoring locations both upstream and downstream of the mine discharge for comparison purposes.

Water quality monitoring is undertaken monthly within the Wingecarribee River both upstream of the adit discharge and at various locations downstream. A monthly sample is also taken from the Medway Rivulet which is a tributary of the Wingecarribee River with the confluence approximately 2km downstream of the mine adit. The adit discharge water is also routinely sampled as part of the monitoring program. The program commenced in January 2018 and continued until the end of 2019. The sampling design consists of three groups as described in the following sections and shown on the attached plan.

3.2.2.1 Discharge Monitoring Sites - Near

These sites represent the mixing zone within the Wingecarribee River as well as the discharge water from the drain adit and are numbered as follows:

- Site 1: Mine Adit - Naturally occurring groundwater is captured in the underground workings and is discharged into the Wingecarribee River. The monitoring point is referred to as the V Notch Weir (EPL Point 4).
- Site 3: WR 300 DN - This site is located in the Wingecarribee River approximately 300m downstream of the confluence with the mine discharge water.
- Site 4: WR 1km DN - This site is located in the Wingecarribee River approximately 1km downstream of the confluence with the mine discharge water.
- Site 5: WR 2km DN - This site is located in the Wingecarribee River approximately 2km downstream of the confluence with the mine discharge water.
- Site 7: WR 3km DN - This site is located in the Wingecarribee River approximately 3km downstream of the confluence with the mine discharge water.

Plate 1a WR1km dn in 2019

Plate 1b WR3km dn in 2019

3.2.2.2 Discharge Monitoring Sites - Far

This site represents the Wingecarribee River at the edge of the mixing zone downstream of the adit discharge.

This site is located in the Wingecarribee River at Biloela Camp Site approximately 6km downstream of the confluence with the mine discharge water. It is referred to as Site 8: Biloela. Plate 2 shows the site in 2019.

Plate 2 Biloela Sampling Site (2019)

3.2.2.3 Reference Sites

These reference sites indicate the ambient water quality within the Wingecarribee River immediately upstream of the adit discharge as well as within a tributary of the river within the same catchment.

- Site 2: WR Up - This site is located in the Wingecarribee River 100m upstream of the mine adit discharge.
- Site 6: Medway Rivulet - approximately 100m upstream of the confluence with the Wingecarribee River.

3.2.3 Ambient Water Quality Monitoring Program

EPL 608 also specifies ambient water quality monitoring in the Wingecarribee River. The timing of the river monitoring generally corresponds to the discharge monitoring. These sites are historical sites which continue to be used to determine background water quality. The original four monitoring locations within the Wingecarribee River are listed below.

- Upstream - Wingecarribee River upstream of the mine adit discharge at Old Hume Highway Crossing at Berrima (Licence Point 9).
- Macarthur's Crossing - Wingecarribee River upstream of the mine adit discharge at Macarthur's Crossing (Licence Point 10).
- Biloela - Wingecarribee River downstream of the mine adit discharge at Biloela Camp Site (Licence Point 11).
- Downstream - Wingecarribee River downstream of mine adit discharge at Black Bob's confluence (Licence Point 12).

Plate 3a Upstream Site 2019 **Plate 3b Downstream Site 2019**

3.3 Results and Discussion

The following section provides details of the discharge water quality since January 2015 and the quality of the receiving waters over the past two years. During this period beginning in 2015, there were four changes which have occurred during the closure process at Berrima Colliery. These changes are noted on each of the Adit Discharge graphs Section 3.1.1.

Prior to August 2015 the underground mine water management system produced a relatively consistent discharge quality which had little variability for at least 30 years. During this period the receiving waters of the Wingecarribee River had adapted to this discharge.

Between August 2015 and December 2015 the mine discharge volume reduced significantly, representing the period that the underground workings were flooding. In July 2016 the quality of water free draining from the mine deteriorated. Metal concentrations increased significantly, conductivity rose and pH fell. During this two year period, investigations of the mixing zone showed high deposition of Iron and Manganese. River flow was also very low, allowing the deposition to accumulate.

In January 2018 Boral implemented an underground water treatment system to improve the water quality discharged into the Wingecarribee River. The treatment system was designed to increase the dissolved oxygen concentration and pH in order to precipitate Iron and Manganese. Precipitated metals are then removed by settlement prior to the water discharging off the site via the drain adit. The system proved effective and resulted in progressive removal of the metal concentrations at the discharge.

In May 2019, seven internal bulkheads were constructed to gather data on the permeability of the strata within the mine. This will inform final closure options by determining the potential to seal or at least partially seal the mine workings. The completion of the installation of the bulkheads in May 2019 caused a significant reduction in the volume of the mine discharge. By December 2019 water had reached the seventh and final bulkhead, and the mine recommenced discharge via the underground treatment system. Data is currently being gathered on the permeability of the strata surrounding the bulkhead installations. It is anticipated that the water quality discharged in 2020 will be similar to the water quality discharged during the previous underground treatment phase during January 2018 up until March 2019.

3.3.1 Adit Discharge

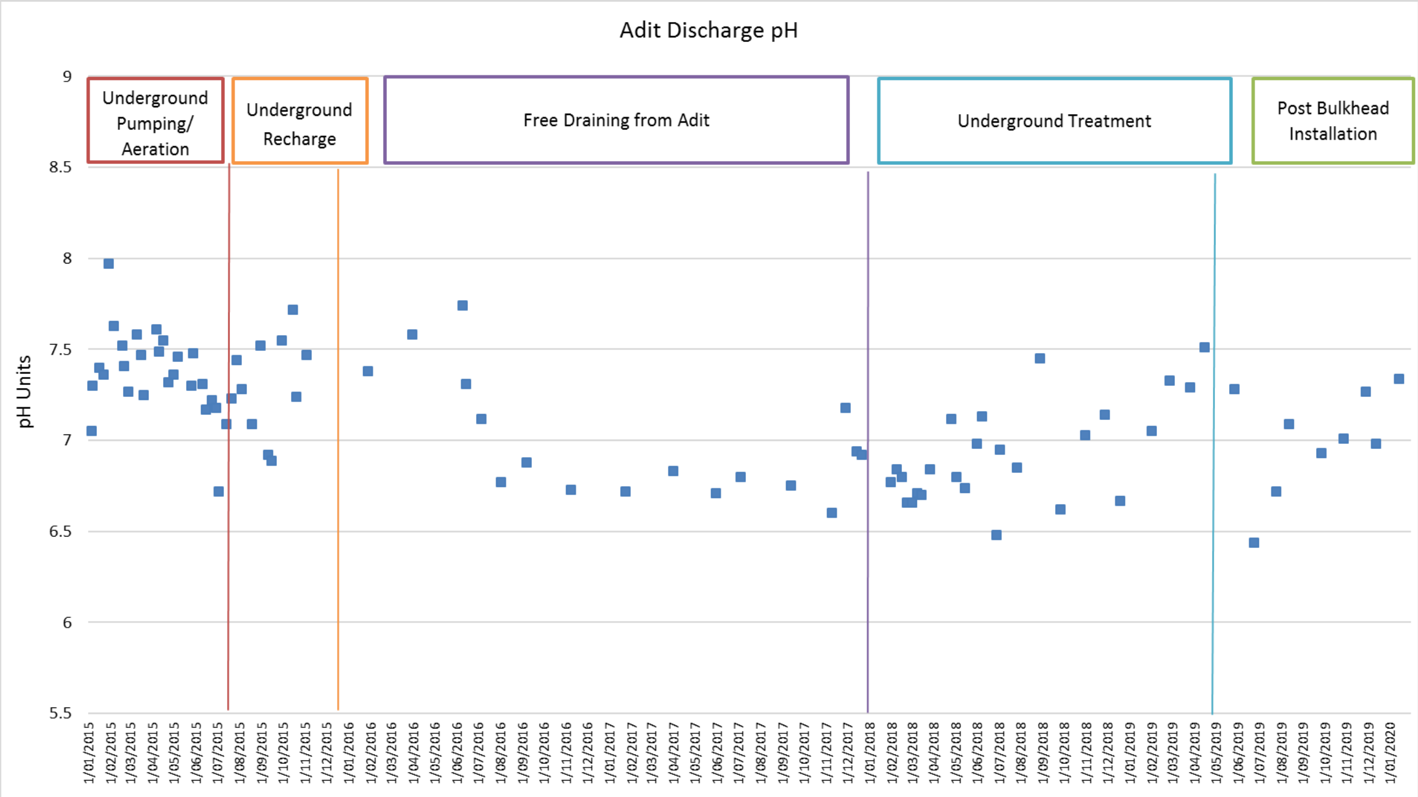
The following graphs provide a summary of discharge water quality from before closure, to post bulkhead installation. Noted on the graphs is the period immediately prior to the flooding of the mine, that is, when the original underground water management system was operating. The mine was allowed to flood in mid 2015 which involved the progressive removal of the internal pumping system. There was close to a 12 month period between the removal of the internal pumps and the commencement of free draining. This is the period when the mine was flooding up to the Pit Bottom Sump which overflowed into the Drain Adit and into the Wingecarribee River. The commencement of the underground treatment system in early 2018 and the installation of the bulkheads in May 2019 are also noted on the graphs.

Plate 4 Adit Discharge into River 2018

In late 2018, the volume of water pumped from the mine increased in order to reduce the standing water level sufficiently to install a set of seven bulkheads. The purpose of the bulkheads is to determine the permeability of the overlying strata which will assist in determining potential final closure options. The bulkhead installation resulted in a period of little or no discharge from the mine as the flooded section of the mine increased behind the bulkheads. The mine has recently recommenced pumping through the underground treatment system at a sufficient rate to ensure that free draining without treatment does not occur.

The results of the discharge water quality testing are shown on the following Graphs 3.1- 3.6.

Adit Discharge pH

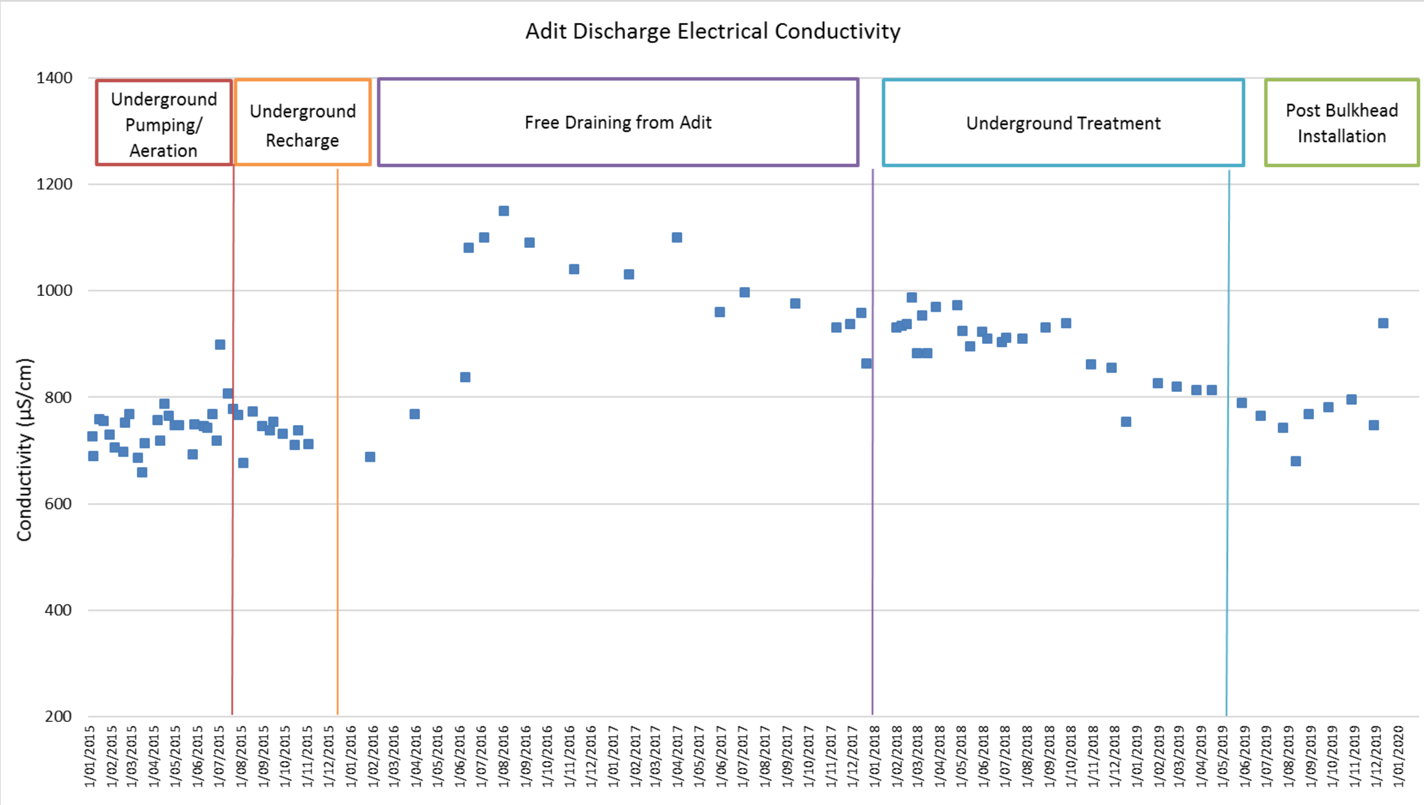


Graph 3.1 – Adit Discharge pH

As seen on Graph 3.1, there was a slight variation in discharge pH from mid-2018 as a result of the increased pumping. Although there has been a general increase in pH during the underground treatment, it is still slightly below the level achieved while the mine was operating.

Over the past 24 months, the pH has shown greater variability than occurred when the mine was operating. This is possibly the result of a combination of the variability within the treatment system, the influences of water which may bypass the treatment system, and variations to pumping regimes which included increased pumping rate prior to the installation of the bulkheads followed by no pumping as water built up behind the bulkheads.

It should also be noted that when the mine was recharging (flooding) there was very little discharge from the mine occurring. This happened in the second half of 2015 and the second half of 2019. Monitoring of discharge volume between May and July 2019 was at the limit of instrument detection, being 0.03 ML/day. Water samples were still taken during this time as part of the normal underground monitoring program however very little if any of this water was released from the mine.

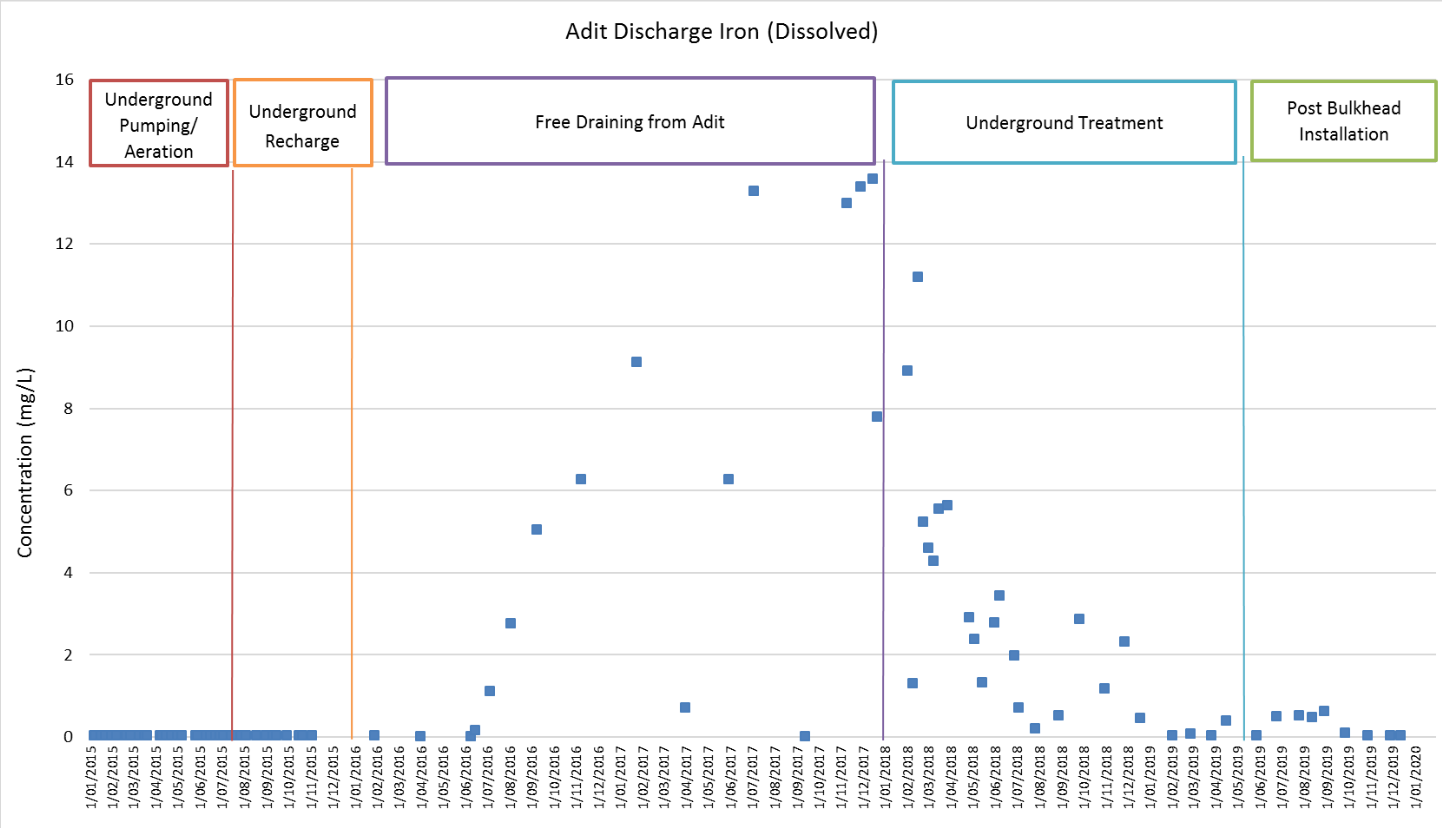


Graph 3.2 – Adit Discharge Conductivity

Graph 3.2 above shows the results for conductivity. This is generally a measure of salt but also other dissolved minerals. The cause of the initial increase in conductivity followed by a decrease while the mine was free draining is unknown but is likely a function of the change in dissolved solids loading of the water.

Although commonly linked with salt content, conductivity can also measure other dissolved solids such as Iron and Manganese. As such, any change in dissolved Iron and Manganese can also influence conductivity levels. Towards the end of this reporting period, conductivity levels approached the historic long-term average discharge from the mine, being below 800 µS/cm.

Although historically the mine discharged water with a conductivity below 900 µS/cm, it had on many occasions discharged water up to 1,000 µS/cm. This fluctuation in conductivity was considered to be caused by local geological conditions but groundwater recharge could also be a factor (Berrima Colliery Water Management Plan 2013).



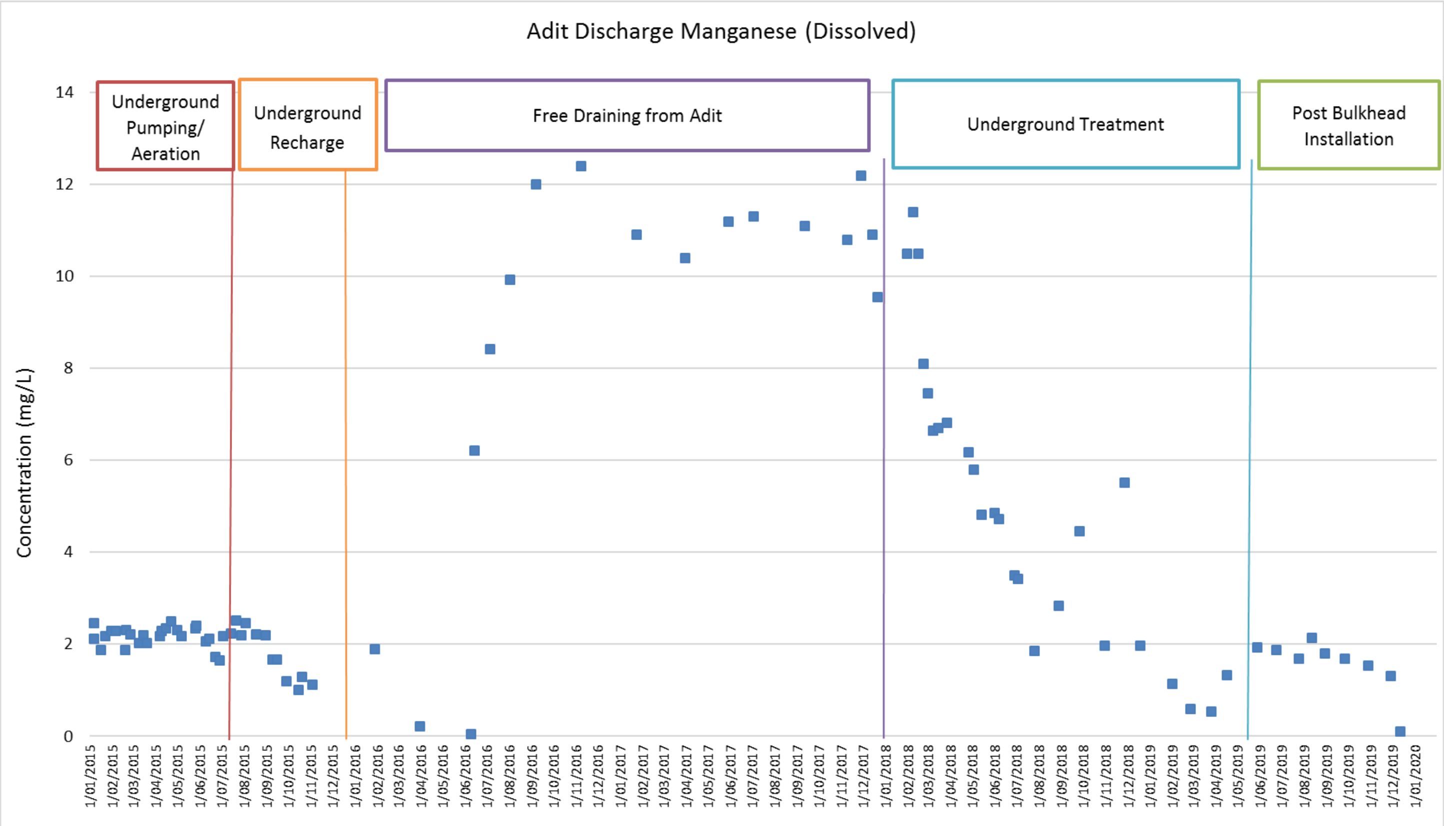
Graph 3.3 - Adit Discharge Iron Concentration

Graph 3.3 shows that the concentration of Iron prior to the mine free draining was very low. Once this previously treated water was removed during the free draining period, the concentration of Iron rapidly increased. When the underground treatment system was installed, the Iron concentration progressively reduced to near historic minimal concentrations. There was a slight increase in Iron concentration in mid-2019 as a lag to the increase in pumping rate, but the magnitude of the change was small. The Iron concentration has remained at low levels often below the detection limit following the bulkhead installation.

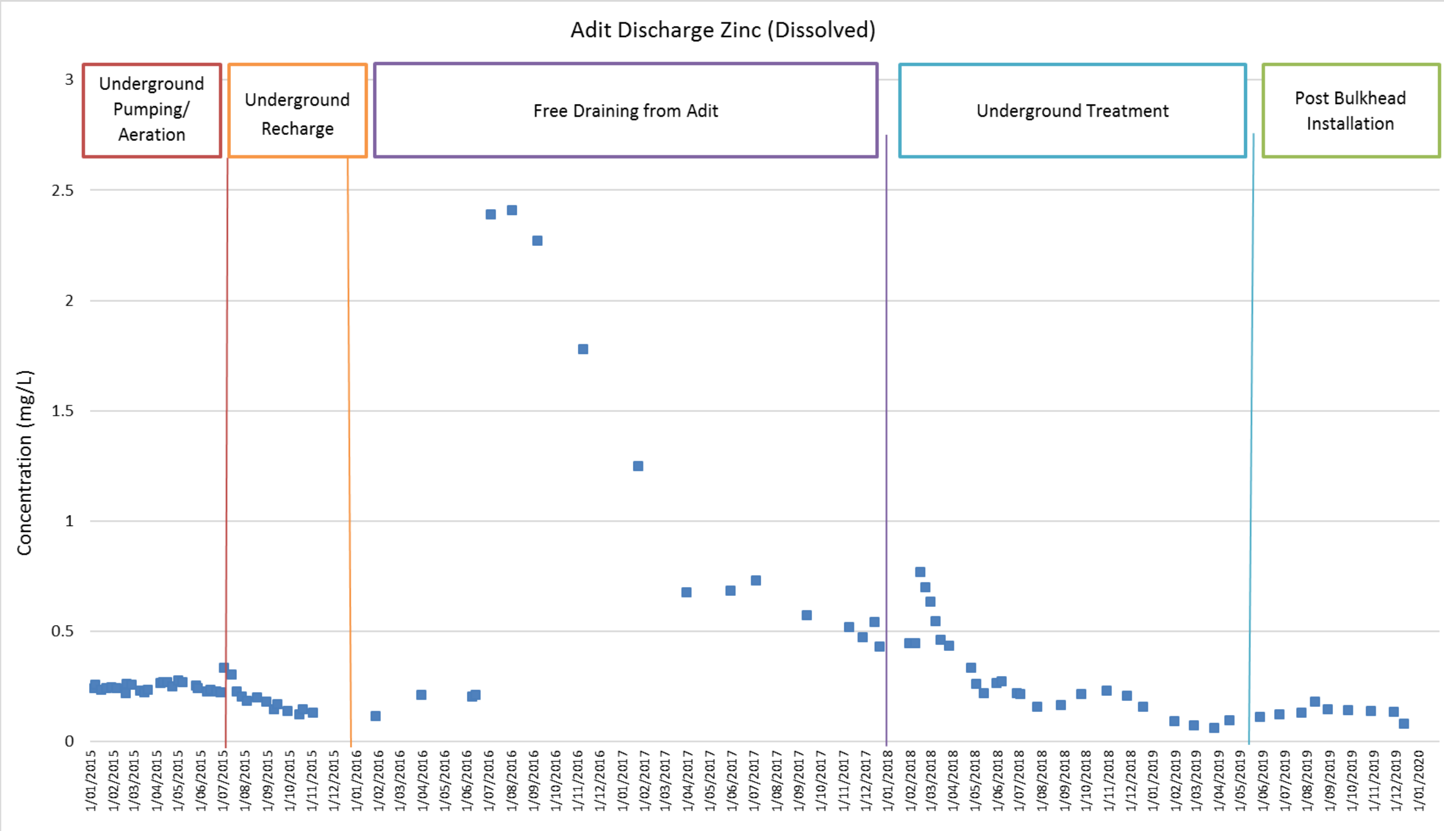
Manganese, Zinc and Nickel follow a similar trend of initial deterioration during free draining followed by progressive improvement following implementation of the underground treatment system. This is shown on Graphs 3.4 to 3.6. Despite these minerals being much harder to remove using a passive treatment system, the results just prior to the installation of the bulkheads were very similar to historic levels.

There was a marginal increase in metal concentration during the increased pumping undertaken in late 2018, however most results in 2019 were very close to the historic levels for Iron, Manganese, Zinc and Nickel. Levels of Manganese, Nickel and Zinc were often below the historic concentrations post bulkhead installation, with a further steep decline in December 2019.

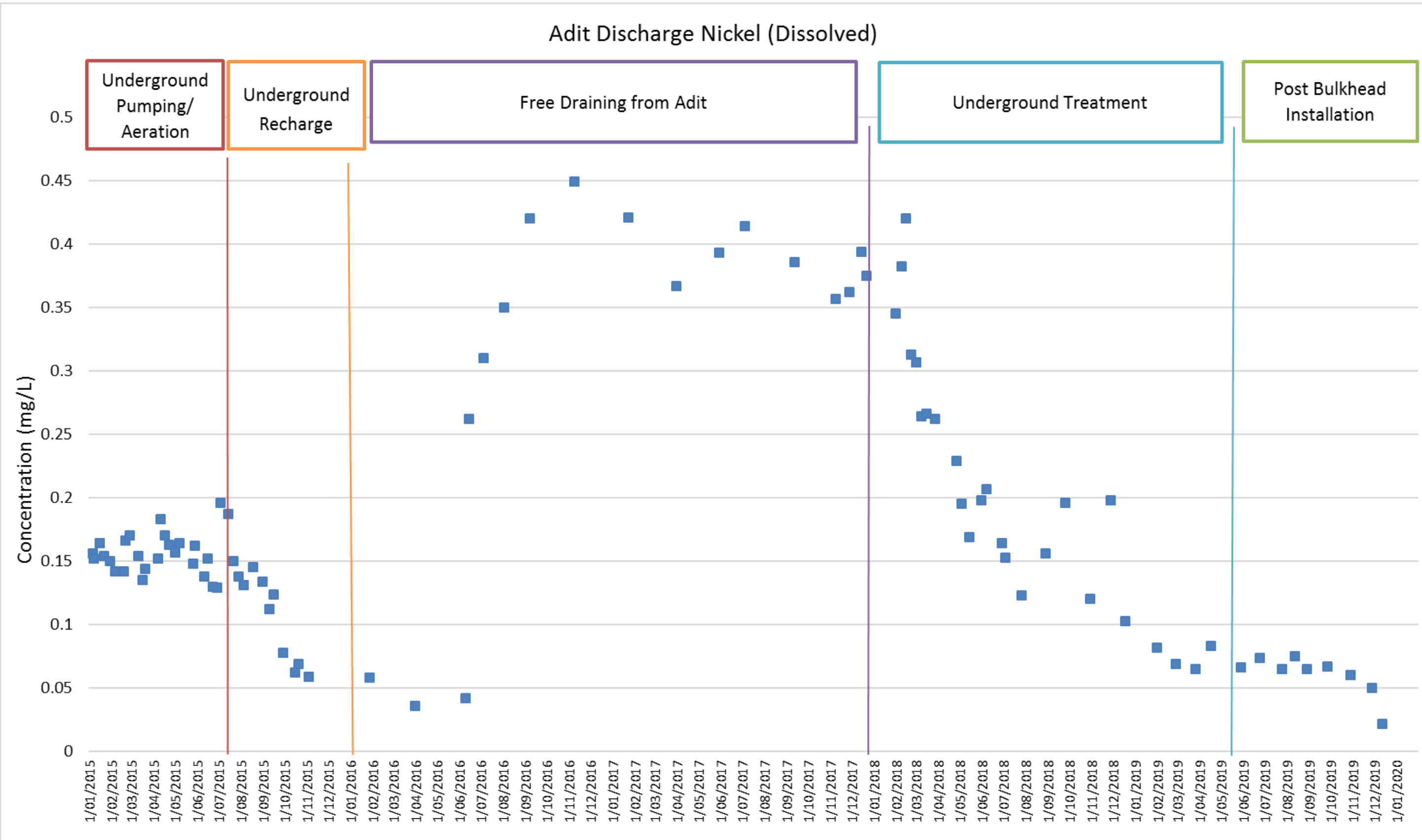
The results indicate that the underground treatment system was effective in returning discharge water quality to historic levels. This indicates that the recent reinstatement of the underground treatment system to cater for pumped water from behind the bulkheads will produce similar water quality to when the mine was operating.



Graph 3.4 – Adit Discharge Manganese Concentration



Graph 3.5 – Adit Discharge Zinc



Graph 3.6 – Adit Discharge Nickel

The results of the discharge monitoring demonstrate that water quality leaving the mine has significantly improved since the introduction of the underground treatment system. The discharge quality has now approached and in some instances is better than the long term average discharge from the mine. The results of the underground treatment system are provided in the following section.

3.3.2 Underground Treatment System

The underground treatment system was introduced as part of the Pollution Reduction Program conditioned on EPL608. Conditions E2.4 and E2.5 required Boral to carry out water treatment trials. The aim of the program is to reduce the mineral content in the discharge water. Iron is the main mineral that caused the discoloured discharge into the Wingecarribee River, however the concentration of other minerals also needs to be reduced to improve overall water quality. The initial pit top water treatment trials commenced at the beginning of 2018. These trials involved constructing a series of limestone channels to run tests on aeration and pH adjustment on a component of mine water delivered to the surface via the existing water supply line which runs up the drift.

The surface trials were successful with the removal of most of the Iron and approximately 25% of dissolved Manganese. The system was then extended to the underground workings in late January 2018. This included the installation of a separate pump line from the flooded section of the mine workings which discharged into a previously dry roadway within the old workings. The roadway was lined with limestone aggregate while aeration was provided by an intervening above ground metal sump. Venturis were installed in the pump line however these did not prove successful as adequate aeration occurred during the pumping process.

Changes were made to the underground water management system during the 4th Quarter of 2018. This involved pumping additional water from the mine in order to lower the flooded mine workings to enable access to construct additional internal bulkheads. The treatment system was discontinued for the majority of 2019 while the bulkheads were installed, and the water was building up behind them. The treatment system was recommissioned in December 2019 when the final bulkhead was reached. Water is currently pumped from an installed pipe through one of the bulkheads back into the underground limestone treatment system. Although the point of initial pumping has changed, the process of treatment prior to discharge has not been altered.

Underground water quality was monitored at three sample sites during 2018 including the 400 D12 Sump at the commencement of the system, 400 C8 at the return of the treatment and the Adit Discharge after final settlement in the Pit Bottom Sump. The water quality results from the underground trials are summarised below:

- The overall pH level at the end of the treatment system is within the range of historic discharge levels, however there is a drop between the end of the treatment system and the discharge point.

- Salinity levels are generally higher within the flooded mine section (400 D12 Sump) than treated water at 400 C8 and at the Adit Discharge.
- The treated water consistently has a higher concentration of dissolved oxygen than the untreated water, indicating that the oxygenation process at the commencement of the treatment system is effective.
- At the end of the treatment system (400 C8) nearly all detectable Iron has been removed. There is a reduction in total and dissolved Iron concentrations at the discharge point compared to before treatment.
- A similar trend - although not as pronounced - has occurred with Manganese, Nickel and Zinc, as concentrations at the discharge point are close to the historic averages and a significant improvement on the levels which occurred during the initial phase of free draining.
- The removal of approximately 9% of the free sulphate represents the largest proportion of the conductivity reduction achieved by the treatment system. Although there has been a slight decrease in the concentration of Sulphate at the discharge point, the reduction is too small to attribute this to any specific activity underground.

3.3.3 Wingecarribee River Water Quality Monitoring Results

The raw monitoring results are provided in Appendix C while a summary of the average results is provided in Graphs 3.7 to 3.12. The graphs show the individual monthly results along the Wingecarribee River grouped and colour coded according to sample sites. For each of these graphs, the mine discharge occurs between the results for WR Up and WR ~300m Dn. The years 2018 and 2019 are split into two graphs for each parameter for ease of interpretation. Also shown on the graphs as a line is the corresponding monthly Medway Rivulet concentration. This is important as it provides some context in relation to water quality results. Comparing the results of river water quality and the discharge water quality in Graphs 3.1 to 3.6 above provide useful information on both the river health and influence that the mine has on receiving water quality.

Plate 5 shows the Wingecarribee River taken at the confluence of the Medway Rivulet. The photo was taken in December 2018 at a time when the mine had temporarily stopped discharging but followed a storm event. The photo shows the visible difference in the quality of water from Medway Rivulet (relatively undisturbed catchment) compared with sediment load within the Wingecarribee River. It is this contrasting water quality that occurs during rainfall events that complicates the assessment of water quality impacts from the mine discharge. Conversely, there are periods of extremely dry conditions when the Wingecarribee River essentially stops flowing. During these periods, the mine discharge can make up a large percentage of the river flow.

The natural flushing of minerals and nutrients along the river from high flow events has been altered over time due to numerous farm dams, the water supply reservoir and the use of the Wingecarribee River as part of the water transfer system from the Tallowa Dam in the Shoalhaven sub-catchment.

Other factors such as nutrient inputs from agricultural land and the Bowral Sewage Treatment Plant and sediment inputs from towns and residential land also influence water quality along the river. Natural sediments also occur through erosion of geological strata through which the river passes. These sediments can build up over time but then mobilise during high flow events.

Plate 5 Wingecarribee River at the Confluence of the Medway Rivulet December 2018

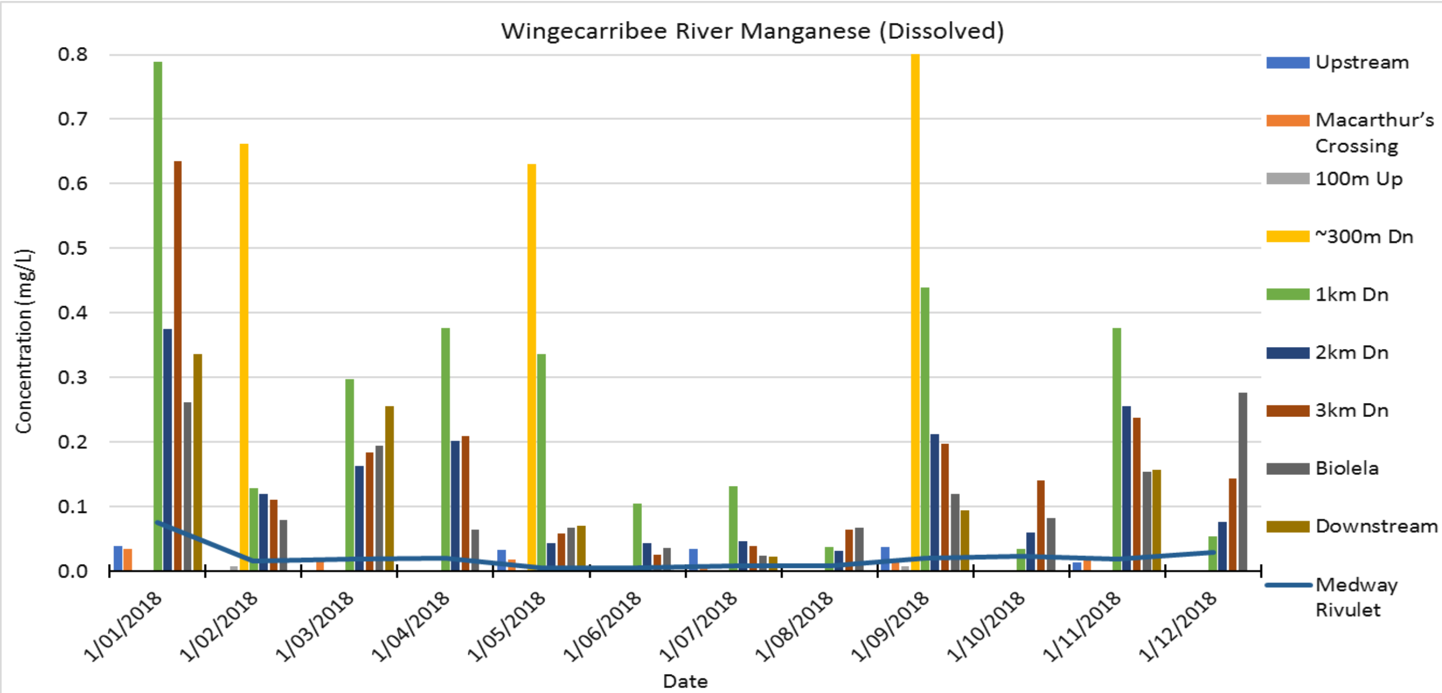
Other factors and natural variabilities occur such as increased salt content during low flow or high organic matter during high flow which can lead to eutrophication and acidification. Metal solubility and particle mobility increases with a lowered pH (Moore & Ramamoorthy 1984). This is important to note because metals which have built up in the sediment over many years can be released into the water with a reduction in pH (Lenntech 2020). Some metals including Manganese, Iron, Zinc and Copper are essential micronutrients, although high concentrations can become toxic to aquatic organisms. It is also important to control the heavy metal concentrations within the river because some algal species can become tolerant to polluted conditions. High metal concentrations can inhibit growth, reproduction and metabolism of freshwater organisms, and can also be hazardous for the functioning of natural ecosystems due to long persistence and bio-accumulative properties (Gheorghe *et al.* 2017). These impacts are associated with metal concentrations much greater than those recorded in the mixing zone during 2018 and 2019.

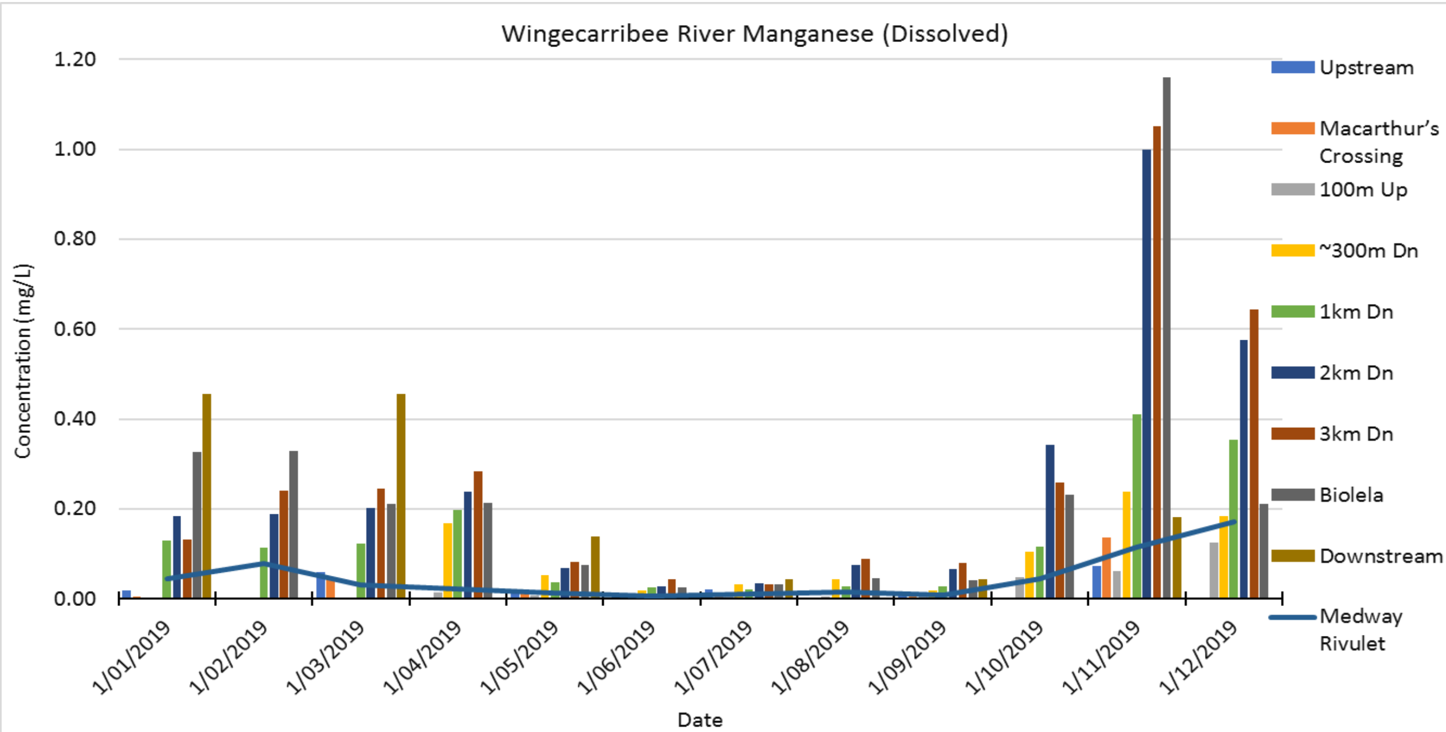
The Iron concentration within the Wingecarribee River has remained below 0.45 mg/L over the past two years. When the mine was discharging elevated Iron concentrations early in 2018, there were higher concentrations of Iron in the river upstream of the discharge. In high river flow periods such as December 2018, the concentration of Iron was elevated both upstream and downstream of the mine discharge. The annual average Iron concentration across all sites in 2018 was 0.11 mg/L, which rose to 0.17 mg/L in 2019. The highest average Iron concentration within the Wingecarribee River was at Macarthur's Crossing, with a combined annual average of 0.18 mg/L over the two years. Iron levels often fell below the detection limit at the end of 2019.

As seen on Graphs 3.7, the Iron concentration recorded in the Medway Rivulet is often higher than that recorded in the Wingecarribee River, with an average over 2018 and 2019 of 0.27 mg/L.

Graph 3.7 – Wingecarribee River Iron Concentration

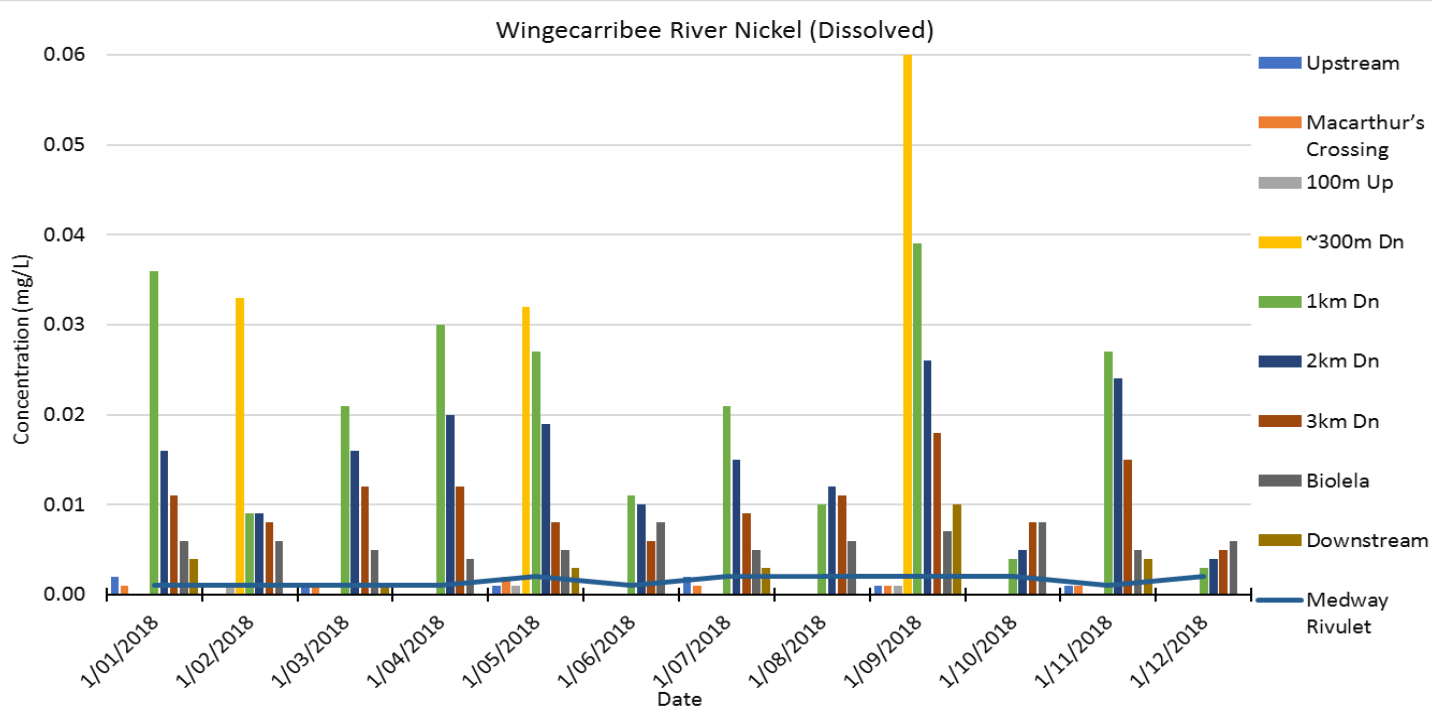
Graph 3.8 shows the Wingecarribee River dissolved Manganese concentrations over 2018 and 2019. The 2018 annual average Manganese concentration across all sites is 0.023 mg/L lower than that recorded for 2019, with averages of 0.139 mg/L and 0.162 mg/L respectively. The Manganese levels recorded in the Medway Rivulet are consistently well lower than the concentrations within the Wingecarribee River. The average Manganese concentration decreases rapidly through the mixing zone but remains slightly higher further downstream than at upstream sites. Manganese concentrations downstream from the adit discharge range from below detection limits to 0.42 mg/L. This is similar to the historical situation and concentrations downstream are all well below the 95% ANZECC default criteria of 1.9 mg/L. The elevated levels of Manganese recorded in November and December 2019 are a function of extremely dry conditions with minimal river flow.

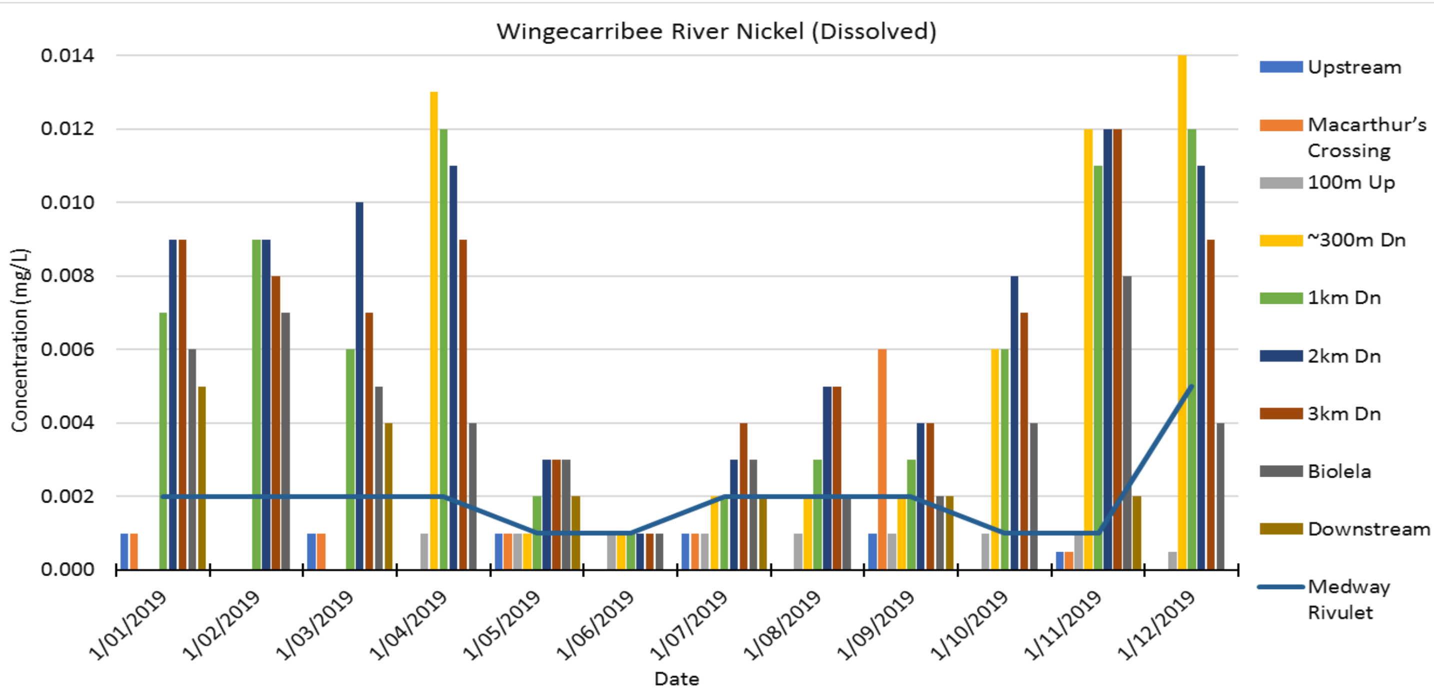




Graph 3.8 – Wingecarribee River Manganese Concentration

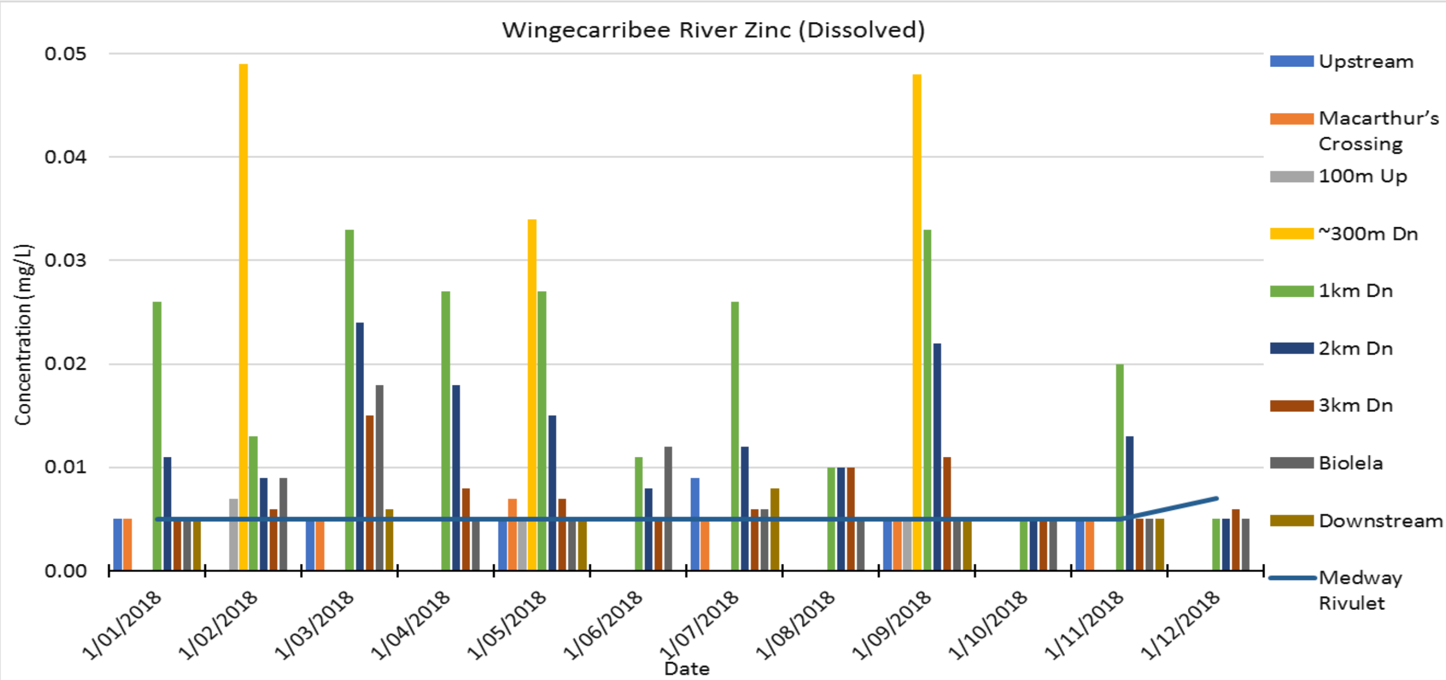
As with Manganese, Nickel concentrations in the river tend to follow river flow but with a greater influence registered from the mine discharge (Graph 3.9). The concentration of Nickel below the discharge point peaked in September 2018. This month corresponded to a relatively low concentration but an increased mine discharge volume at a time when the river flow was low. The Nickel concentrations were higher during 2018, with concentrations reaching 0.06 mg/L at the site WR~300m dn in September. Nickel levels remained below 0.014 mg/L throughout 2019. The concentrations of Nickel downstream rapidly reduce and fall below the ANZECC 2000 95% ecosystem protection default guideline value of 0.011 mg/L at the Biloela site. At the Medway Rivulet, the concentration of dissolved Nickel was lower than that in the Wingecarribee River and had an average of 0.0016 mg/L over the two years.

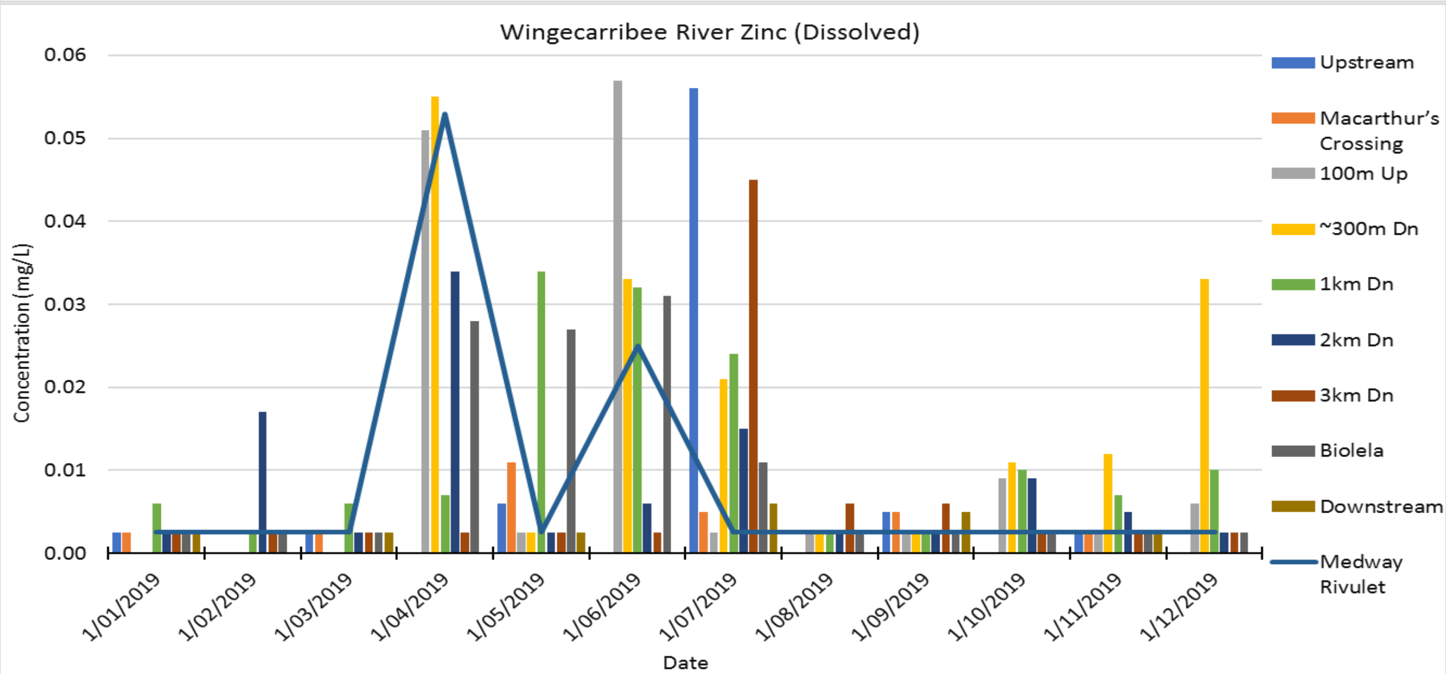




Graph 3.9 – Wingecarribee River Nickel Concentration

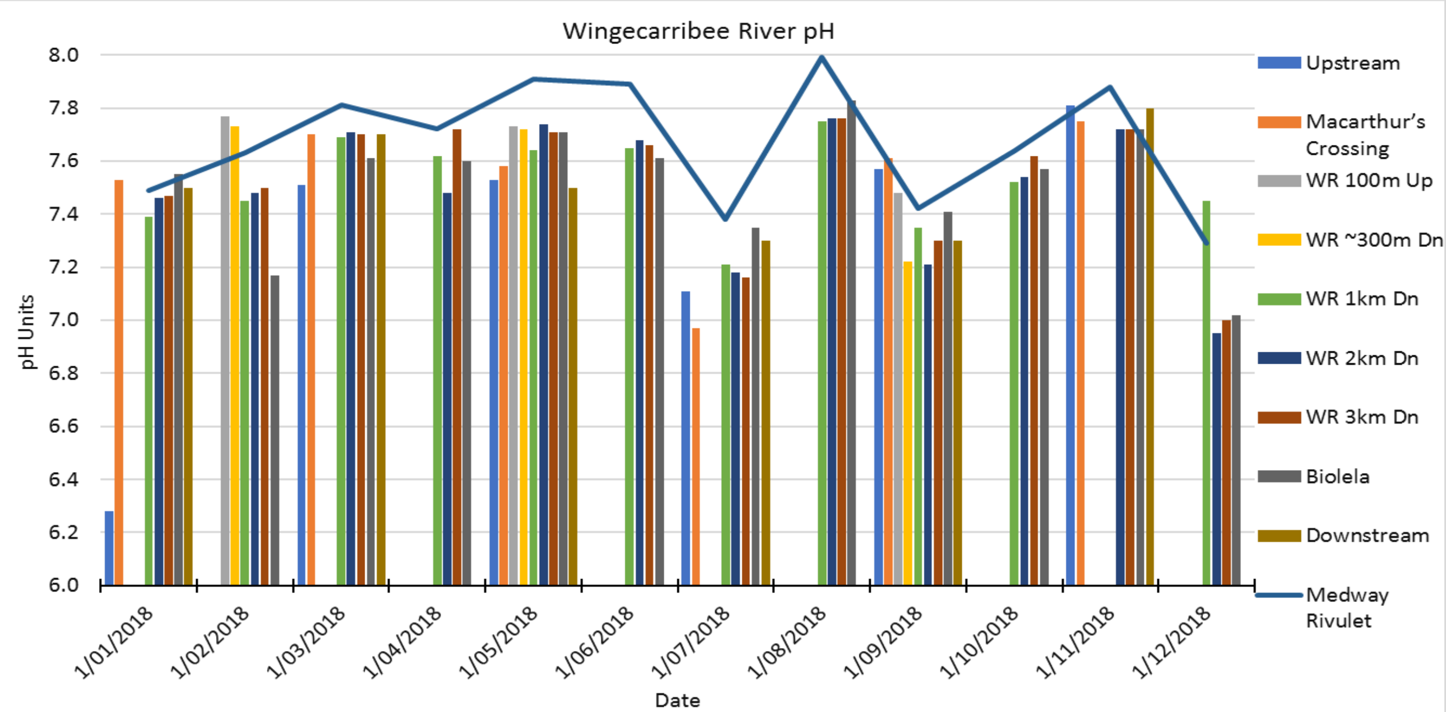
Graph 3.10 below shows that the levels of Zinc within the Wingecarribee River remain below 0.06 mg/L, with relatively stable concentrations over the past two years. The Zinc levels during 2018 show higher concentrations at the two immediate sites downstream of the discharge, being WR ~300m dn and WR 1km dn. Concentrations of dissolved Zinc were often below detection limits at the sites WR 3km dn, Biloela and Downstream during 2018 and 2019. The concentrations of Zinc downstream rapidly reduce and fall below the ANZECC 2000 95% ecosystem protection default guideline values of 0.008 mg/L at the Biloela site. There was sporadic fluctuation of Zinc levels from April to July 2019 which is not expected to be related to the mine discharge. The Zinc concentration at the Medway Rivulet is often below the detection limit of 0.005 mg/L, although it rose unexpectedly in April and June to levels of 0.053 mg/L and 0.025 mg/L respectively.

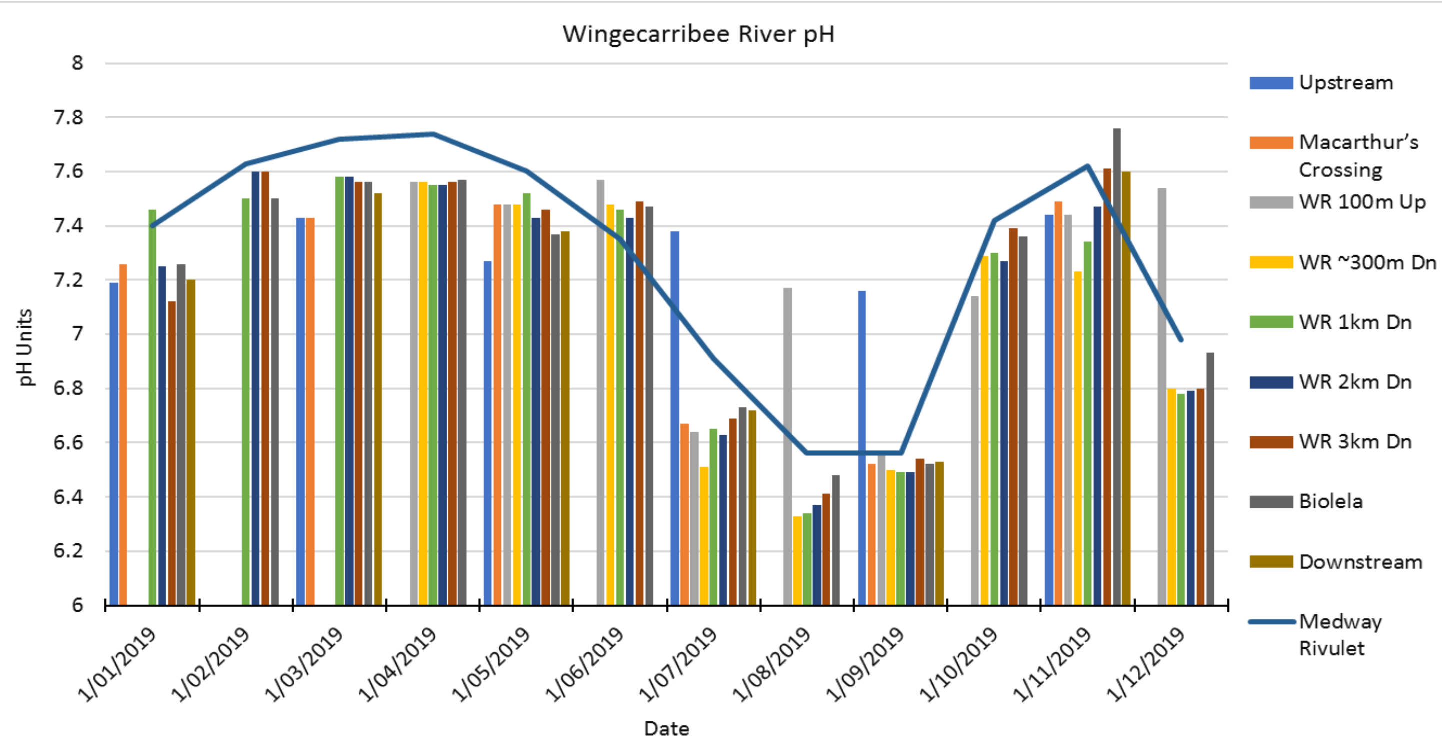




Graph 3.10 - Wingecarribee River Zinc Concentration

The pH drops from an annual average of 7.5 pH units in 2018 to 7.1 pH units in 2019. Graph 3.1 shows that there is little fluctuation of pH between sampling sites. Between August and October 2019 the pH of the river fell, however the pH was also lowered in the Medway Rivulet at this time. The mine was not discharging during this period and this indicated that other factors caused the reduction in pH. Often the pH at the Medway Rivulet was slightly higher than that in the Wingecarribee River, with the pH ranging from 6.56 to 7.99 pH units over the two years.





Graph 3.11 – Wingecarribee River Average pH

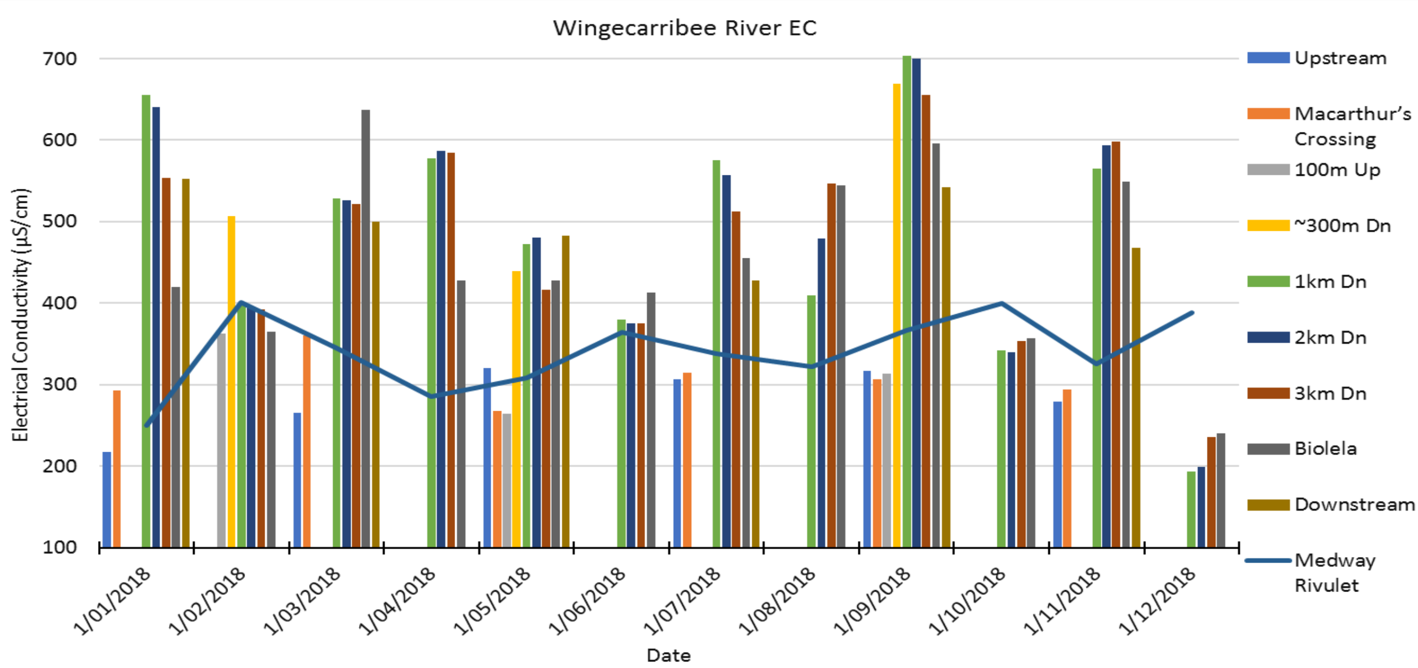
Natural river water generally has a pH between 6.5 and 8.5, with an optimum pH of 7.4 (Mattson 1999). The pH within the Wingecarribee River generally remains within a range safe for freshwater organisms. It is important to continue to monitor the pH levels within the river because extreme levels of pH outside of this range can be harmful to aquatic life, particularly immature fish and insects (SoE 2016).

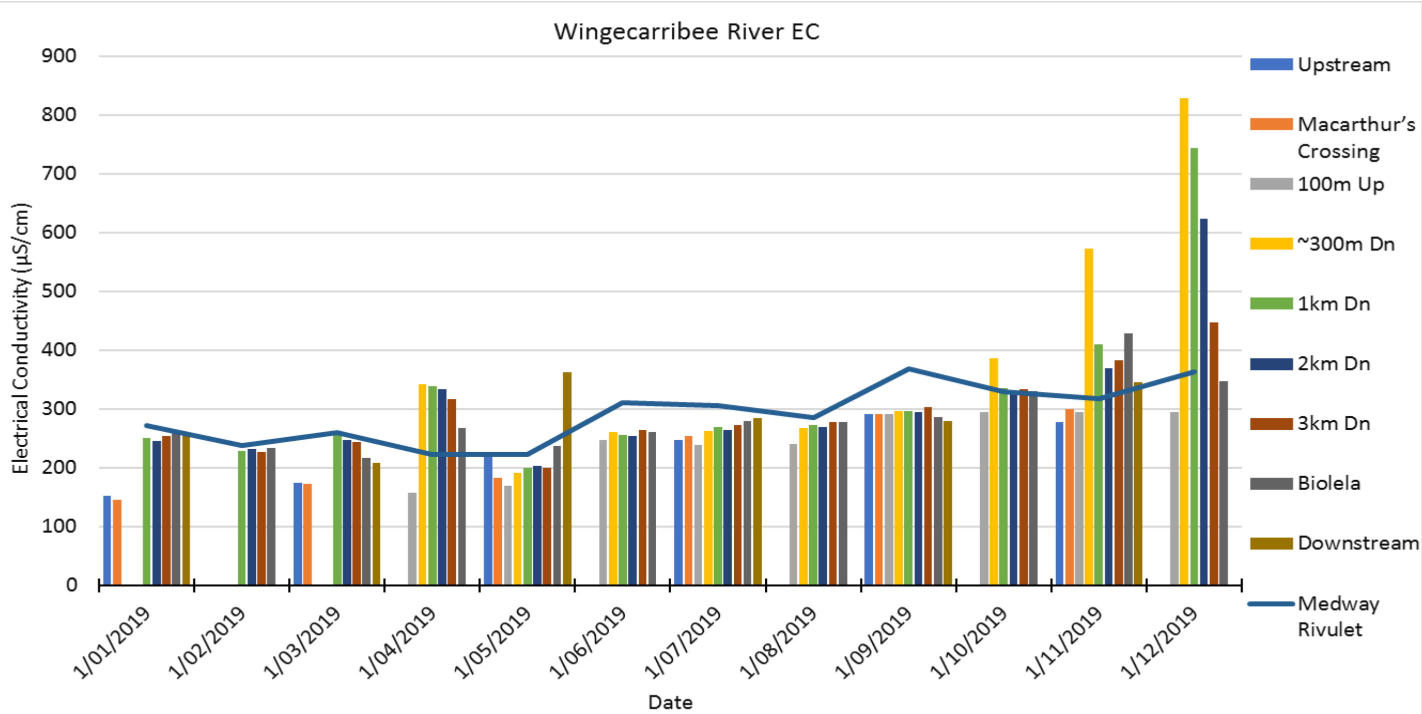
The harmful ecological effects of lowered pH levels include the invasion of pest planktonic and moss species; increased Aluminium ions stimulate mucous formation which clogs fishes' gills; and reduced Calcium levels prevent the production of fish eggs and causes abnormalities in larvae (EPA 1980). Acidic water increases the leaching of heavy metals.

There was a notable difference in Electrical Conductivity levels at upstream compared to downstream sites in 2018 as seen on Graph 3.12. The combined 2018 average for the upstream sites was 299 µS/cm, whereas downstream was higher at 481 µS/cm. The electrical conductivity concentration within the Medway Rivulet remained below the levels of the Wingecarribee River downstream sites in 2018 with an annual average of 341 µS/cm.

The difference between sites was less evident in 2019, as the average conductivity levels downstream of the discharge declined to 311 µS/cm. The Medway Rivulet conductivity concentration was slightly higher than the Wingecarribee River in 2019 with an annual average of 291 µS/cm. The conductivity is generally below 500 µS/cm across all sites which is considered fresh and non-saline.

As the river flow was extremely low in November and December 2019, the small volume of discharge from the mine represented an unusually high percentage of the river flow. Along with the effects of evaporation and contribution of groundwater baseflows these three processes are thought to have created an increased conductivity at the end of 2019. There was also an unusually high concentration of Sulphate in the river at the time which could account for the majority of the dissolved solids loading (conductivity).

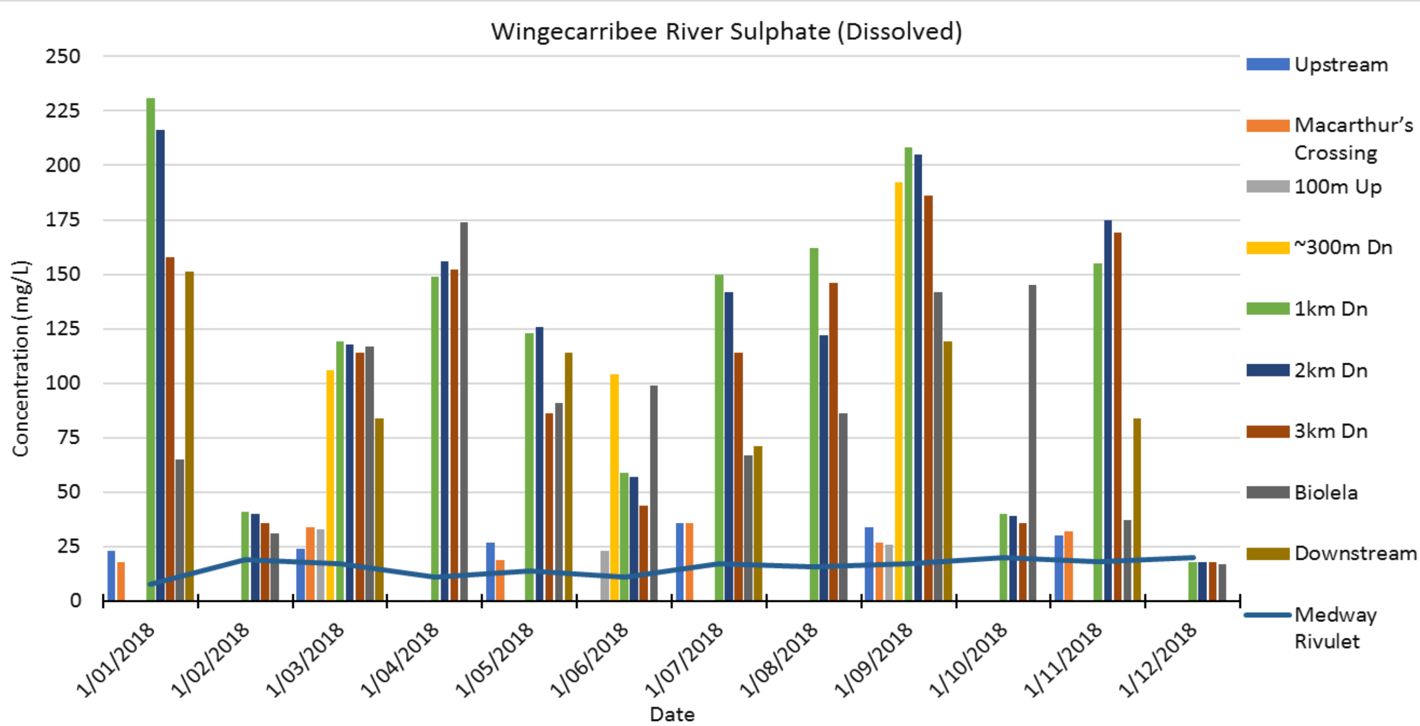


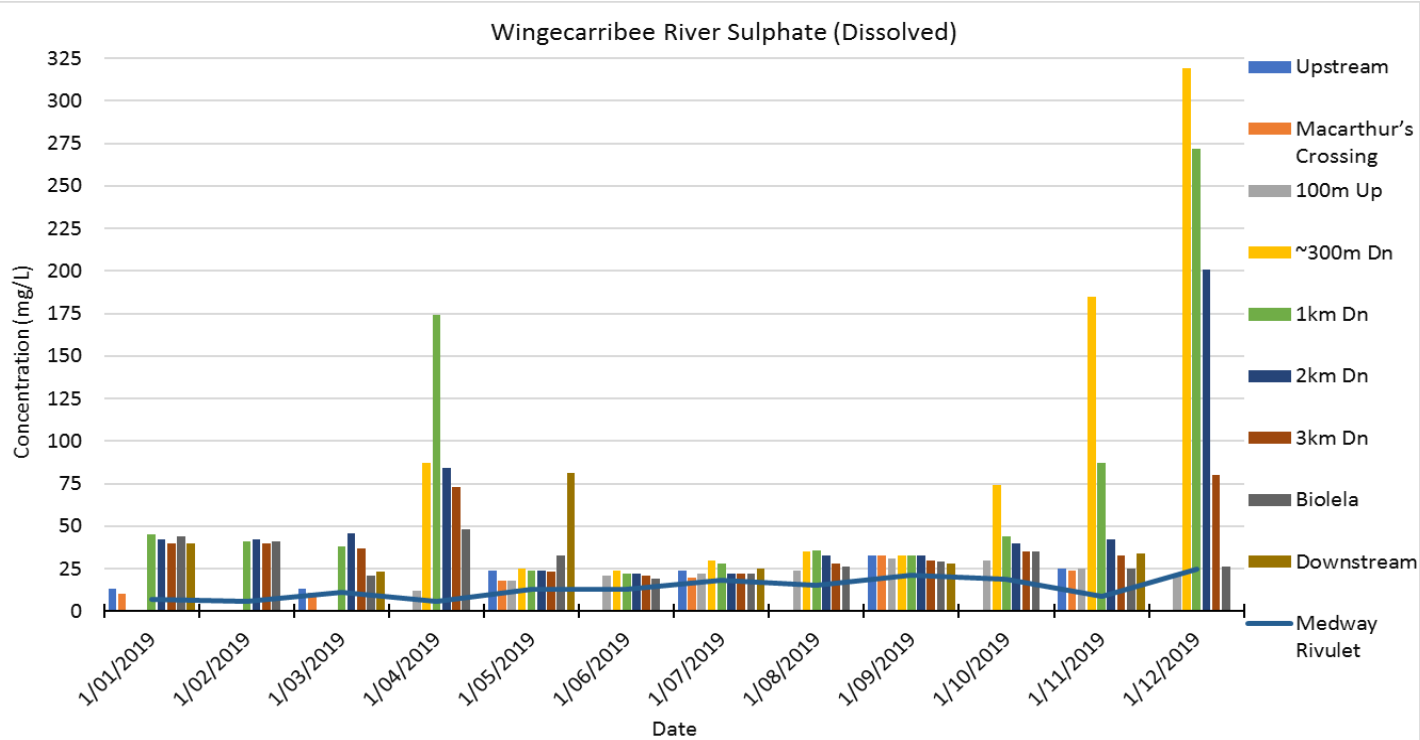


Graph 3.12 – Wingecarribee River Average Electrical Conductivity

Graph 3.13 shows the dissolved Sulphate levels during 2018 and 2019 which remain relatively constant downstream of the discharge point. The measured levels across all downstream sites in 2018 are generally around levels of 100 mg/L which is considered within the normal environmental range. The two upstream sites and the Medway Rivulet are significantly lower, with average sulphate concentrations of 28 mg/L and 16 mg/L respectively during 2018.

There is little fluctuation in Sulphate levels in 2019 despite increasing distance from the discharge point. The sulphate concentration during 2019 is substantially lower than 2018, with most sites remaining below 40 mg/L. Sites immediately downstream of the discharge recorded elevated sulphate levels from 185 mg/L to 319 mg/L during the last three months of 2019. The reason for this increase can be linked to factors associated with extended periods of low flow as the mine was not discharging during the latter half of 2019.

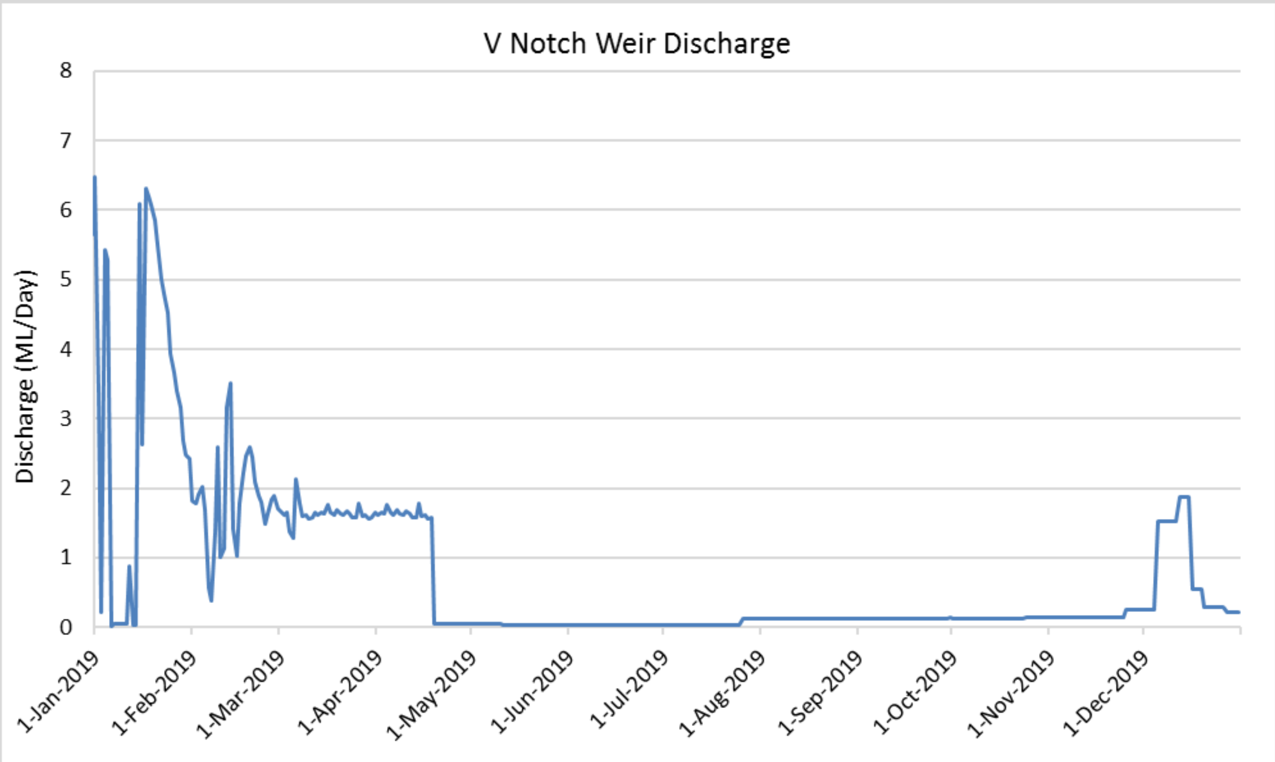




Graph 3.13 – Wingecarribee River Average Sulphate

3.3.4 Discharge Volumes

During 2018, the mine discharged an average of 2.5 ML/Day which is below the long term average of 2.7 ML/Day. From August 2018 until March 2019 the discharge volume was increased from 3ML/Day up to 5 ML/Day to drain the workings for the bulkheads to be installed. Pumping ceased in March 2019 for the construction to occur, which was completed by the end of May and the discharge volume during these months was at an average of 1.6 ML/Day. Once the bulkheads were installed, the discharge was minimal, with a range of 0.03 ML/Day to 1.53 ML/Day from June to December 2019. In mid-December the water level had reached the top of the seventh and final bulkhead, and pumping through the underground treatment system was restarted. Discharge volumes rose to an average of 0.81ML/Day for the last month of 2019. The daily discharge data is provided below in Graph 3.14.



Graph 3.14 – V Notch Weir Discharge

3.3.5 Weather Data and River Flow

Base water flow within the Wingecarribee River was previously measured at Macarthur's Crossing. This is the closest upstream location to the Colliery discharge point that is suitable for non-intrusive flow measurements. Approximately 6 years of data was gathered to understand the nature of river flow over time and its response to high rainfall events. This has been important to understand the dynamics of the river and potential sediment load and transport.

This data allowed the mixing zone length at the mine discharge point to be estimated. Based on previous water quality and aquatic ecology investigations within the mixing zone, it was established that in very low base river flow, the zone can extend down to the first downstream monitoring site at Biloela but in moderate to high river flow, the mixing zone various from 350 m to less than 100 m in length from the discharge point at the mine Adit.

The Wingecarribee River has been severely affected by extended low flow caused by prevailing drought conditions. The lowest flow recorded for the Wingecarribee River during the first half of 2019 was 1.4 ML/Day, the highest was 118 ML/Day with an annual average of 10.2 ML/Day. Due to sampling complications, the flow meter was discontinued at the end of June 2019, and an assumption was made of the average for the second half of the year based on the limited rainfall at 5 ML/Day.

Although the Wingecarribee River flow data is no longer available at Macarthur's Crossing, a photographic record has been used to discern differences in flow between months as seen in Plate 6a and Plate 6b below.

Despite some rainfall occurring and recent water transfers by WaterNSW, there has been no elevated flows which would result in flushing of the river. The high flow events, which see over 1,000 ML/Day, are essential to maintain a healthy river. There has been very little flow in the river since July 2017. In the past, large flushing events have resulted in excess of 2,000 ML/Day being passed down the river.

The Wingecarribee River is a highly regulated system with three water supply structures and many farm dams which starve the river of natural water flow. As a result, the river upstream of the mine suffers from long periods of little to no flow, sometimes despite rainfall occurring during these periods. This trend is observed to be worse over the past few years, with a lower average and fewer flushing events.

The consequence of low flow conditions is that the discharge from Berrima Colliery becomes the dominant water source for the river. Mixing becomes non-existent in very low flow conditions and other natural groundwater baseflow contributions can influence overall water quality.

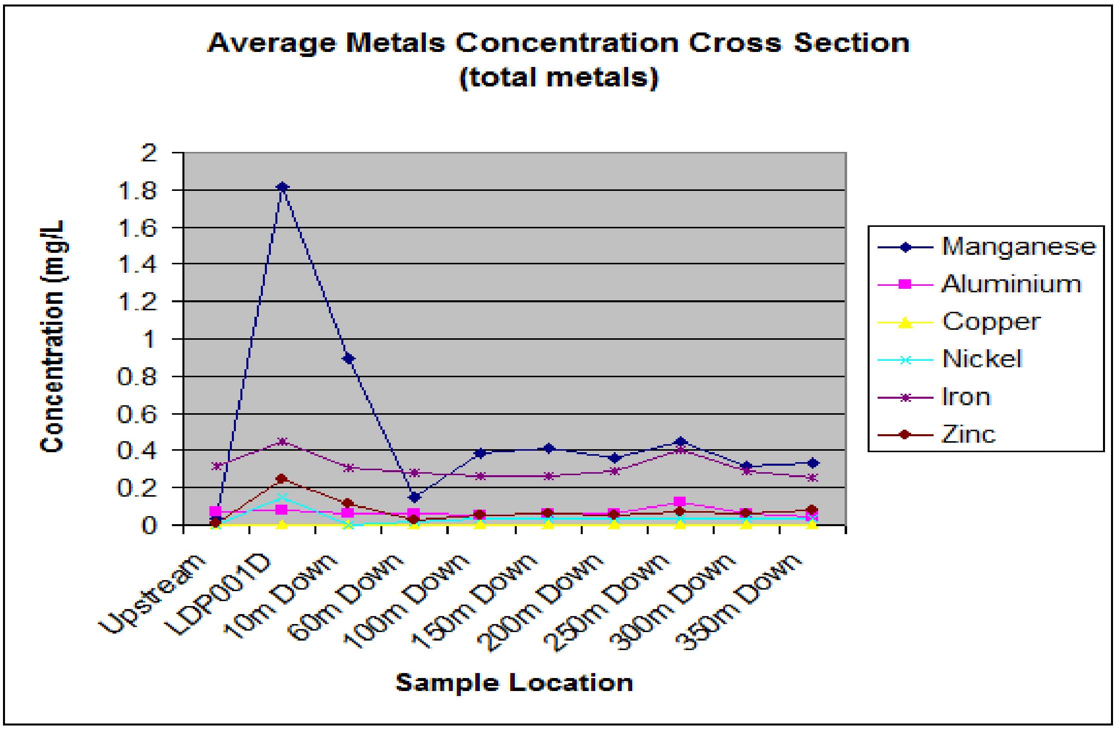
Plate 6a Macarthur's Crossing November 2019

Plate 6b Macarthur's Crossing February 2020

3.4 Summary of Mixing Zone Water Quality 2012

Graph 3.15 shows a summary of water quality data obtained from the mixing zone in 2012. The results are a summary of the data provided in the Berrima Colliery Water Management Plan 2012. The monitoring sites were slightly different in 2012 and included sites closer to the adit discharge but also include the 300m downstream site as well as data from Biloela.

This data was taken at a time when the mine was fully operational, and the discharge quality was typical of the long term averages. The flow in the Wingecarribee River at the time these samples were taken were also low and between flushing events.



Graph 3.15 – Wingecarribee River Quality Mixing Zone 2012

A comparison of 2012 data with 2018 and 2019 average data is provided in Table 3.1 below.

Table 3.1 – Annual Average Water Quality Concentrations in 2012, 2018 and 2019

Parameter (mg/L)	300m Downstream 2012	300m Downstream 2018	300m Downstream 2019
Iron	0.29	0.76	0.15
Manganese	0.32	0.87	0.096
Nickel	0.0345	0.0325	0.006
Zinc	0.465	0.057	0.019
	Downstream 2012	**Downstream 2018**	**Downstream 2019**
Iron	0.48	0.27	0.15
Manganese	0.076	0.23	0.22
Nickel	0.0049	0.0036	0.003
Zinc	0.01	0.006	<0.005

From the above data, the concentration of Iron and Manganese 300 m below the discharge point is higher in 2018 compared with 2012, although it then drops below the 2012 concentration in

2019. The concentration of Nickel and Zinc are very similar in 2012 and 2018 but are lower in 2019.

Further downstream, the data shows a gradual drop in Iron levels over time. Levels of Manganese, Nickel and Zinc are all similar in 2018 compared to 2019, which have shown a reduction since 2012.

3.5 ANZECC 2000 Assessment

Table 3.2 shows the established Site Specific Trigger Values (SSTV) for the receiving waters of the Wingecarribee River. This has been established using the 80th percentile Biloela results taken over 24 months up until 2013 in accordance with the ANZECC Water Quality Guidelines. The edge of the mixing zone is taken at the Biloela Camp Site downstream of the mine discharge. This site is also specified on the Performance Monitoring Program objectives as needing to meet the trigger values for primary industries and recreational water quality and aesthetics. Water quality data prior to 2013 represents the period when the mine was operational which is appropriate to use given that this represented the long term discharge quality into the river. The 2013 data set has been adopted as the benchmark for determining the impact of the mine closure as well as the assessment of discharge quality and the need to implement further underground treatment.

The table below also provides the current 80th percentile values for the upstream site and downstream site. These sites represent long term monitoring points which were originally intended to provide a comparison between water entering the mixing zone with water far enough downstream to not be influenced by the discharge. These results are still valuable for comparative purposes. Table 3.2 also includes a new site referred to as Medway Rivulet. This site is taken from a tributary just downstream of the mixing zone that was included in the Performance Monitoring Program. Monitoring commenced at this site in January 2018 which has only recently been able to gather sufficient data to determine an 80th percentile over a 2 year period.

The majority of the Medway Rivulet catchment covers the farmland of Sutton Forest and Moss Vale, which drains towards the Medway Rivulet water supply dam. Downstream of the Medway water supply dam, the Rivulet flows through an area of undisturbed forest and sandstone cliff areas prior to entering the Wingecarribee River. As the volume of water entering the Wingecarribee River from the Rivulet is highly constrained due to the water supply dam, the water quality within the lower reaches of the Rivulet will be more representative of the sandstone geology which exists within the mixing zone. However, given the reduced natural flow of the Rivulet, water quality is still not entirely representative of the natural system due to the lack of flushing events and consistent flow.

The ANZECC 95% default guideline is based on calculations of a probability distribution of aquatic toxicity endpoints. The 95% default guideline is designed to apply to ecosystems defined as slightly to moderately disturbed and attempts to protect a pre-determined 95% of existing species. The Wingecarribee River falls under this guideline as it is classified as a moderately disturbed ecosystem. A moderately disturbed ecosystem is defined by the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 as 'the biological integrity of an aquatic ecosystem that is adversely affected by human activity to a relatively small but measurable degree', with a management intent to maintain or improve indicator levels to achieve water quality objectives.

The ANZECC 95% default guideline is useful for comparative purposes only and should only be used if Site Specific Trigger Values have not been established. This is because the ANZECC guidelines recognise that every river system is different and has therefore established a hierarchy of assessments and analyses which should be used to determine water quality goals for a specific site.

Table 3.2 – Edge of Mixing Zone ANZECC Assessment

Parameter	Upstream Site (80th percentile)	Medway Rivulet (80th percentile)	Downstream Site (80th percentile)	ANZECC 95% Default / EPA	Recreation guidelines ANZECC	Mixing Zone 2013	Biloela SSTV	Biloela 2018 Average	Biloela 2019 Average
pH	7.7	7.73	7.63	6.5 to 8.5	6.5 to 8.5	7.5	7.5	7.5	7.2
EC (uS/cm)	299	364.5	448	350	1,500 *	430	350	460	285
TSS	11	5	6.5	50	<20% of natural	12	12	4.2	3.9
Total Nitrogen (mg/L)	0.465	0.07	0.27	0.25	10 **	0.2	0.2	n/a	0.17
Total Phosphorus (mg/L)	0.065	-	-	0.02	0.02	0.04	0.04	<0.01	<0.01
Sulphate (mg/L)	29	18.5	82.5	-	400	63	63	93.5	31
Manganese (mg/L)	0.038	0.039	0.17	1.9	0.1	0.52	0.3	0.132	0.242
Iron (mg/L)	0.24	0.34	0.275	N/A	0.3	0.31	0.7	0.11	0.133
Nickel (mg/L)	0.001	0.002	0.006	0.011	0.1	0.04	0.03	0.006	0.004
Zinc (mg/L)	0.0055	0.005	0.0085	0.008	5.0	0.08	0.02	0.007	0.018
Aluminium (mg/L)	0.185	0.01	0.065	0.055	0.2	0.07	0.07	<0.01	0.023
Copper (mg/L)	0.001	0.001	0.001	0.0014	1.0	0.0008	0.001	<0.001	<0.001

The above results confirm that the levels at the edge of the mixing zone ANZECC trigger point was not exceeded for any analyte. It should be noted that the average records at Biloela in 2019 for most analytes for the Wingecarribee River are actually lower than the Downstream site 80th percentile trigger. These values are calculated using the 80th percentile of 24 monthly samples from 2018 and 2019, that is, the level below which 80% of the readings fall. This is important to note because it means that water quality in the river itself, irrespective of the discharge from the Colliery, will exceed the SSTV for about 20% of the time.

For the Wingecarribee River, exceedances of the trigger value generally occur each time the river experiences very high flow and, in some cases, very low flow during drought periods. During high flow events, the dilution of water from the Colliery discharge is over 1,000 times, in low flow periods in the river however, dilution may only be 1 or 2 times the discharge volume.

As previously discussed, there was a deterioration in water quality leaving the mine which caused Iron staining in the river just below the discharge point in 2018. The water monitoring results indicate that the elevated mineral concentration has not impacted the river at the Biloela site compared to historic discharge.

Based on water quality averages, the environmental values at Biloela have seen a slight improvement in some analytes in 2019. However, the higher mineral content discharged for a short period when the mine commenced free draining are still impacting the immediate mixing zone below the mine discharge.

These results may change following the next flushing event which may mobilise the mineral rich sediments within the mixing zone. Such an event occurred in February 2020 however the results may take some time to register downstream.

3.6 Findings and Conclusion

The volume of the river flow can create a number of dynamic processes which influence the water quality within the Wingecarribee River.

- The influence of the volume and quality of the mine discharge is relative to the flow within the river. During drought periods when the Wingecarribee River flow is low, the dominant influence is the discharge from the mine even under low discharge situations. The effect of the discharge in low flow conditions can extend as far as Biloela. In high flow conditions the influence of the mine discharge is a significantly shorter distance.
- When the river is experiencing low flow, parameters such as conductivity and dissolved metals can naturally increase through a greater contribution of groundwater baseflows. Areas of stagnant water within the river can also be influenced by the quality of the sediments and processes such as eutrophication.
- As river flow volume increase due to rainfall, the water quality can be affected by surface runoff and flushing of river sediments. This can increase total metal concentrations as well as sediment loads. There can also be an increase in nutrients depending on the intensity and duration of rainfall. Water quality can noticeably change during a storm event as farm dams within the catchment progressively overflow into the river.
- Regional influences such as water supply dams, sewerage treatment plant discharges and runoff from urban areas can influence water quality. These influences can occur at various times during all weather patterns.
- The Bowral sewerage treatment plant discharge is relatively constant at 3 ML/Day, irrespective of flow volume in the river and therefore can register an influence near the mine during extended dry periods. There are also artificial flows from the Wingecarribee Reservoir including water transfers from a completely different catchment in the Shoalhaven River system.
- Runoff from urban areas tends to be more polluted during the first flush following an extended dry period. This can cause pollutants to enter the river in the early stages of high rainfall events.
- Runoff from agriculture and is more complex. During dry periods the numerous farm dams within the Wingecarribee River catchment require extended wet weather to fill. Contained

nutrients and metals will therefore only enter the river following extended wet weather. Under normal rainfall patterns this would generally occur seasonally.

During the closure process, there have been four main changes to water quality. These represent the change from normal operations to flooding and free draining, underground treatment to improved water quality followed by the installation of bulkheads. The last change also includes treatment of the water once the bulkheads have filled. It is considered that prior to mine closure the long standing underground treatment system which involved several stages of pumping and settlement produced an acceptable water quality leaving the mine. As this discharge had occurred for several decades, the receiving waters of the Wingecarribee River had adapted to this change.

When assessing the impacts of the Colliery discharge, consideration is given to the long standing water source provided to the river at the discharge point. The river has adapted to this water source for 90 years, however up until August 2015 the mine discharge was controlled by normal operations of the mine. Since this time, the mine discharge has changed in both volume and quality. It is this period that has been the subject of this scientific investigation.

The first period of free draining involved the discharge of significantly poorer quality water which caused a deterioration in water quality in the Wingecarribee River, particularly in the mixing zone downstream of the discharge point. The underground treatment system returned the water quality to similar levels that occurred during normal operations. This can be more readily seen visually as shown in Plates 7a and 7b.

Plate 7a – Mixing Zone before underground treatment

Plate: 7b: Mixing Zone after underground treatment

Given the prevailing drought conditions the river has not experienced any high volume flushing events which would have removed the build-up of mineralised sediments within the mixing zone. Despite the natural dynamic processes which influence the quality of water within the Wingecarribee River, this build up in sediment has had a measurable ongoing effect on water quality in the mixing zone. This has been exacerbated during low flow conditions by existing low flow influences such as sewerage treatment plant discharges.

The results from ambient monitoring within the Wingecarribee River showed a slight improvement however given the exceptionally dry conditions in 2018/19, the natural flow in the river has been very low. The discharge from the mine has been the dominant water source for the river for most of 2019. Although large flow events also cause poor water quality, they also serve to remove the build-up of sediments as well as nutrients from surrounding farmland and the sewage treatment plant discharge.

The first high flow event in two years occurred in February 2020. It is likely however to take several high flow flushing events to remove and dissipate the remaining accumulated sediments within the mixing zone. Once this occurs and assuming the underground treatment system continues to mirror the historic water quality discharged from the mine, the impacts of water quality in the river will stabilise at historic levels.

4. Aquatic Ecology

4.1 Introduction

The ecological health of the Wingecarribee River is a component in the assessment methodology of the ANZECC 2000 guidelines. In order to understand the human impact on aquatic ecosystems, monitoring is progressively moving towards an approach using ecological measures compared to the traditional chemical indicators (Ravengai *et al.* 2005). Aquatic macroinvertebrates can be used as biological indicators because chemical characteristics including metal concentrations and acidity are driving their spatial distributions (Alvial *et al.* 2012). Macroinvertebrates are organisms visible to the naked eye that do not possess a backbone, including insects and larvae, worms and shrimp (Barbour *et al.* 1992).

Macroinvertebrates are positive indicators of stream health because they are frequent, widespread and sedentary in nature (Basset, Pinna & Renzi, 2017). Different species are sensitive to a variable range of pollutants, water quality and habitat conditions which helps pinpoint threats within the waterway (Barbour *et al.* 1992). They have relatively short lifespans, from a few months to years, which allows efficient detection of changes to water quality (Basset, Pinna & Renzi, 2017). Macroinvertebrates exist at the base of the food web, allowing a greater understanding of bio-accumulation and risks associated with higher trophic levels (Sullivan *et al*. 2014)

Three individual aquatic ecology studies have been conducted to examine the impact of Berrima Colliery Mine discharge on the Wingecarribee River over a 7 year period. The first study was carried out by Marine Pollution Research Pty Ltd from 2012 to 2014 (MPR), followed by a study by Wright, Paciuszkiewicz and Belmer in 2017 (Wright) and finally a third study by Niche Environment and Heritage over 2018 and 2019 (Niche). These studies shared a common aim to evaluate how aquatic macroinvertebrate populations respond to mine discharge over a distance gradient along the Wingecarribee River, in order to assess the overall health of the ecosystem.

4.2 Methods

The studies sampled at variable locations, ranging from 3500m upstream of the discharge point, to 9500m downstream on the Wingecarribee River. Although these sample sites are not parallel across all studies, they can be compared on a gradient to observe changes along the mixing zone of the river. Figure 4.1 shows the locations of the sites sampled in the three studies.

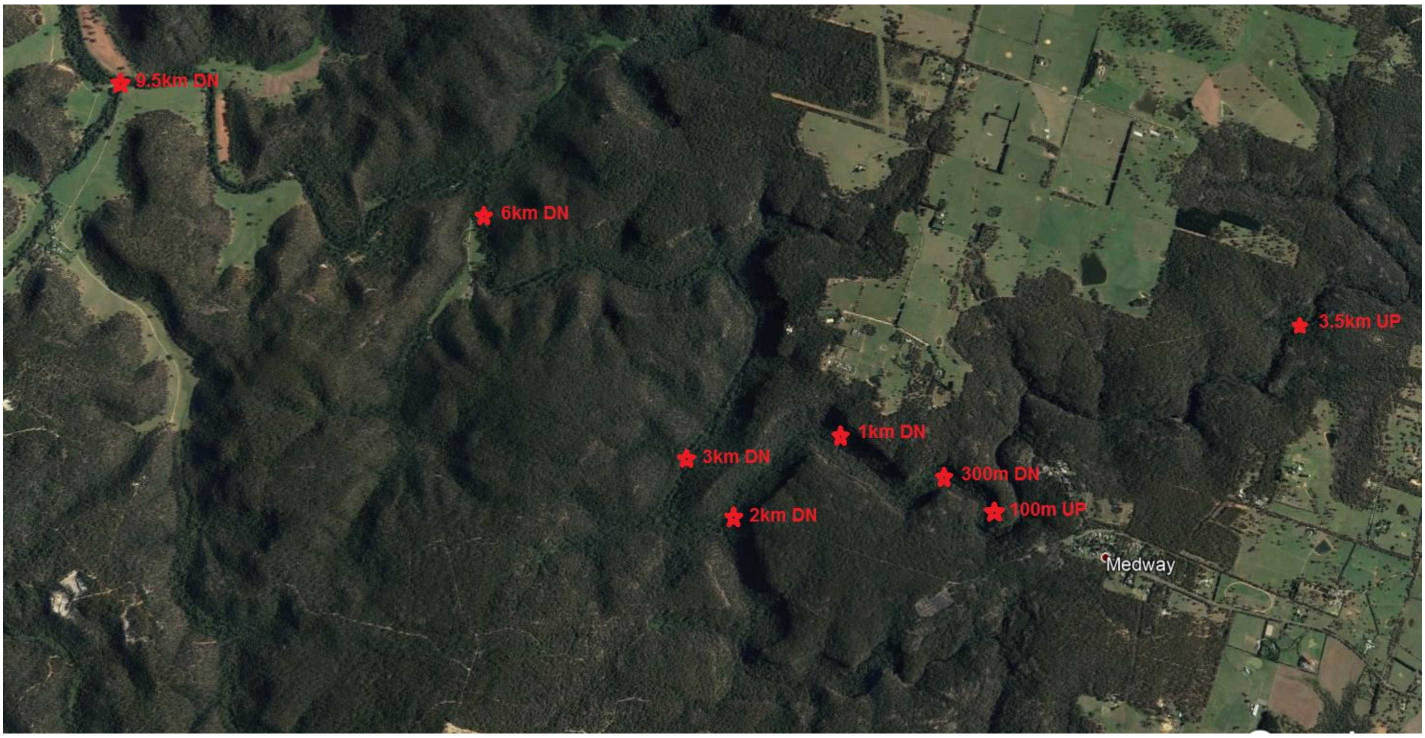


Figure 4.1 Location of sample sites

Each study used comparable macroinvertebrate sampling techniques known as riffle sampling (MPR), kick sampling (Wright) and dip net sampling (Niche). Such techniques involve holding a 30cm wide net on the riverbed into the flow of the water and disturbing the upstream substrate with the feet. Wright and Niche timed each sample for 30 seconds and one minute respectively, whereas MPR disturbed the substrate for a length of 10 metres per sample. Samples were taken in riffle habitats, defined as an area of broken water with rapid current that has some cobble or boulder substratum (MPR, 2014). The number of replicates taken per study is variable, with seven, ten and five samples taken at each site by MPR, Wright and Niche respectively. Samples at all locations were always undertaken during the same or succeeding day. Samples are stored in containers and preserved with 70% ethanol whilst taken to the laboratory for taxonomic analysis to the family level.

All studies were undertaken during different years which enables the application of a metanalysis to observe the effects of the mine discharge over time. Table 4.1 below shows the dates of sampling for each study.

Table 4.1 Sampling dates of studies conducted by MPR, Wright and Niche

	Sample 1	**Sample 2**	**Sample 3**
MPR	November 2012	June 2013	May 2014
Wright	February 2017		
Niche	March 2018	June 2018	September 2018
Niche	April 2019	September 2019	

The Wingecarribee River flow has been monitored approximately 3500m upstream of the discharge at Macarthur's Crossing on a daily basis. As of June 2019, the River flow monitoring was discontinued due to unforeseen complications and an average of 5 ML/Day will be assumed for the second half of 2019. The volume of water released from the adit discharge point is also monitored each day.

In order to measure the response of macroinvertebrates within the mine discharge mixing zone in the Wingecarribee River, comparisons have been drawn among three biotic indices. Measuring the macroinvertebrate population using taxonomic richness, abundance and EPT provides a strong indication of the ecological health of the river (Qu *et al.* 2010). Taxonomic richness refers to the number of different individuals observed, often performed at the family level. Abundance is a measure of the total number of macroinvertebrates included in the sample. The EPT index is used to calculate the abundance of pollution sensitive macroinvertebrates from the Orders Ephemeroptera, Plecoptera and Trichoptera (Wright & Ryan 2016).

4.3 Results

The river flow during the sampling months is recorded in Table 4.2 below. The majority of months had similar averages ranging from 7.4 ML/Day to 15.26 ML/Day. One outstanding month was June 2013 which had a monthly average of 418 ML/Day.

Table 4.2 Wingecarribee River flow during sample months

Study	Period	Average (ML/Day)	Min	Max
MPR	November 2012	15.26	3.18	143
	June 2013	418	24	2390
	May 2014	12.8	4.9	32
Wright	February 2017	13.3	1.85	80.4
Niche	March 2018	8.16	1.9	31.5
	June 2018	14.4	6.35	34.9
	September 2018	7.4	2.3	13.9
Niche	April 2019	7.4	2.8	17.7
	September 2019	3.0	3.0	3.0

The average, minimum and maximum V Notch discharge volumes (mine discharge) for the sampling months is recorded below in Table 4.3. Higher volumes of water were discharged from the mine in September 2018 in order to drain all water from the underground workings to enable the installation of the bulkheads. Low volumes of discharge were recorded during 2019 due to the bulkheads preventing water flow into the river.

Table 4.3 V Notch Discharge Flow

Study	Period	Average (ML/Day)	Min	Max
MPR	November 2012	2.78	0.77	3.51
	June 2013	2.78	0.32	4.05
	May 2014	3.28	1.45	4.63

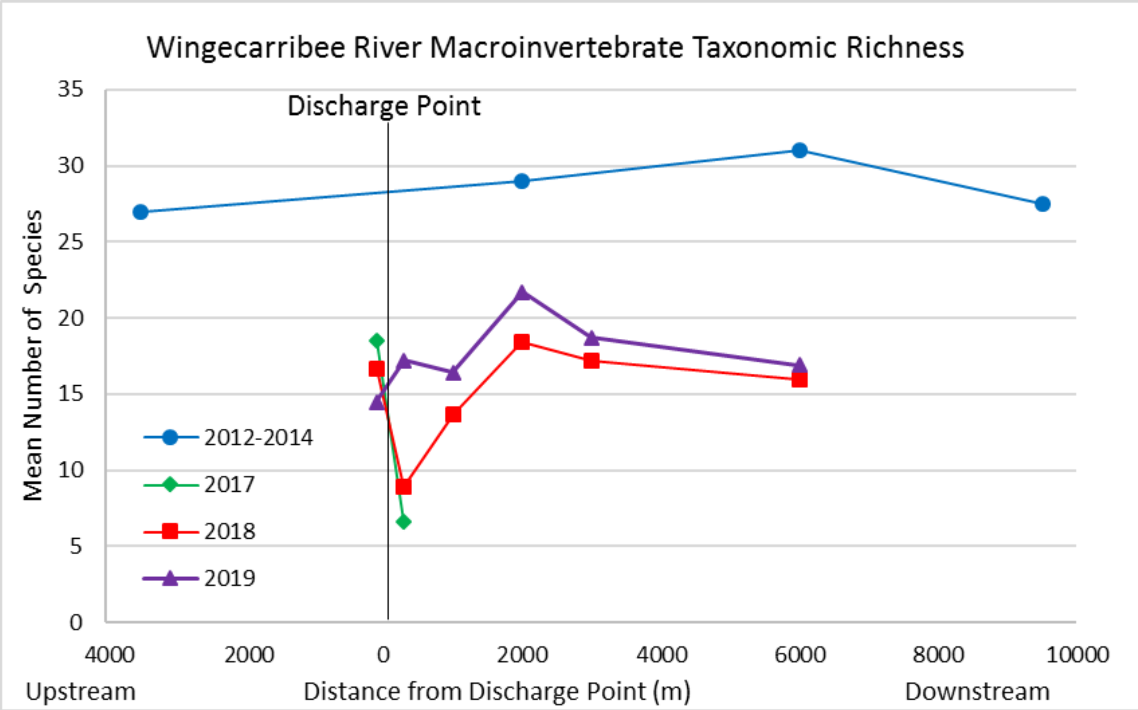
Wright	February 2017	2.47	2.26	2.75
Niche	March 2018	2.29	1.97	3.38
	June 2018	2.05	1.49	2.33
	September 2018	4.25	1.64	5.14
Niche	April 2019	1.0	0.04	1.79
	September 2019	0.13	0.13	0.14

4.3.1 Taxonomic Richness

Results show that the diversity of macroinvertebrate family assemblages has declined since 2012-2014 across the entire study area of the Wingecarribee River sampled. In 2012-2014, taxonomic richness ranged from 27 to 31 families with an average of 28.6, whereas data from 2017 to 2019 shows an average number of families was 15.8 with a minimum of 6.6 and a maximum of 21.7. Nevertheless, the past three years have shown a gradual increase in taxonomic richness, with an increase of 2.5 families per year over the study area.

Although taxonomic richness declines in 2017 and 2018 samples at 300m downstream of the discharge point, there was an average of three additional families found downstream which are not located at 100m upstream in 2019 (Graph 4.1). At the sampling point 1000m down, the data from 2019 shows that the macroinvertebrate diversity has increased slightly to 16.4 families. Graph 4.1 shows that a higher number of families always exist at 2000m downstream than samples 100m upstream of the discharge point in the same year. Although the most recent results from samples taken in 2019 are substantially lower than 2012-2014 taxonomic richness, there has been an increase in the number of macroinvertebrate families at all sites downstream of the discharge point since 2018.

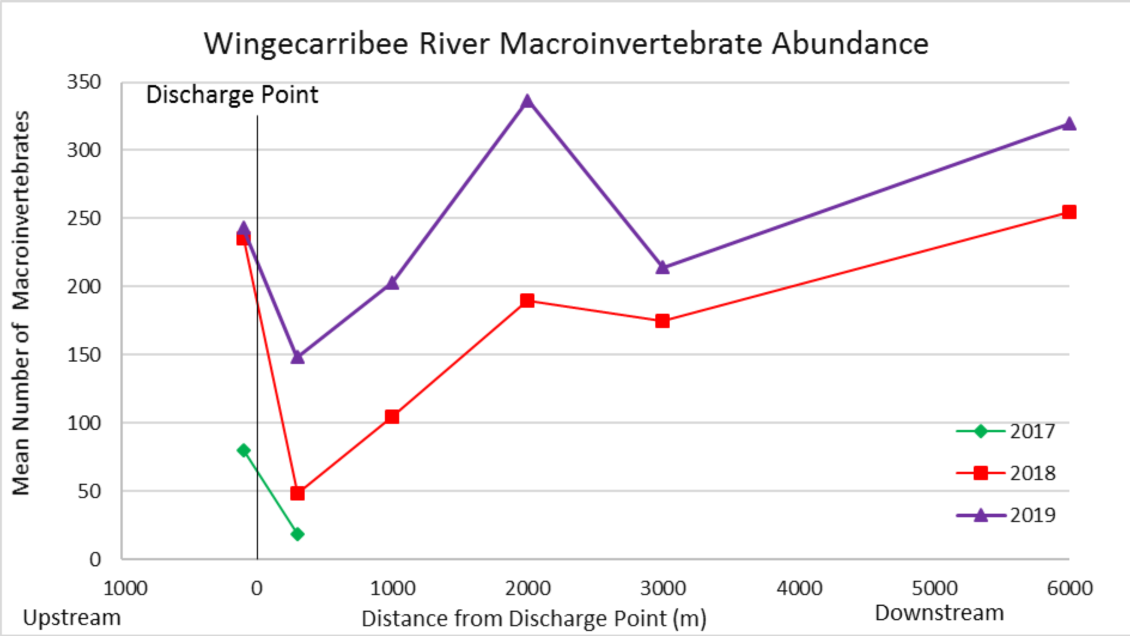
The most common type of macroinvertebrate varied between studies. In the study by MPR, insect taxa were the most common with 51 families, followed by 9 crustaceans and 8 molluscs. Meanwhile in 2017, the Aquatic worms *Oligochaeta* were sampled with the greatest frequency and the mayfly family *Baetidae* were second. Other families collected included a leech, freshwater mite, springtail, flatworm, hydroid and roundworm.



Graph 4.1 Macroinvertebrate Taxonomic Richness Upstream and Downstream of the Adit Discharge Point on the Wingecarribee River

4.3.2 Abundance

Graph 4.2 shows that progressively over the past three years, there has been a notable increase in macroinvertebrate abundance. Years 2018 and 2019 have followed the same general trend, showing two sites with consistently greater abundances being 2000m and 6000m downstream. As expected, the three sampling years have shown that the abundance was much lower immediately downstream of the discharge (300m) than at the site 100m upstream. Graph 4.2 shows that the abundance downstream increases with an increased distance from the discharge point.



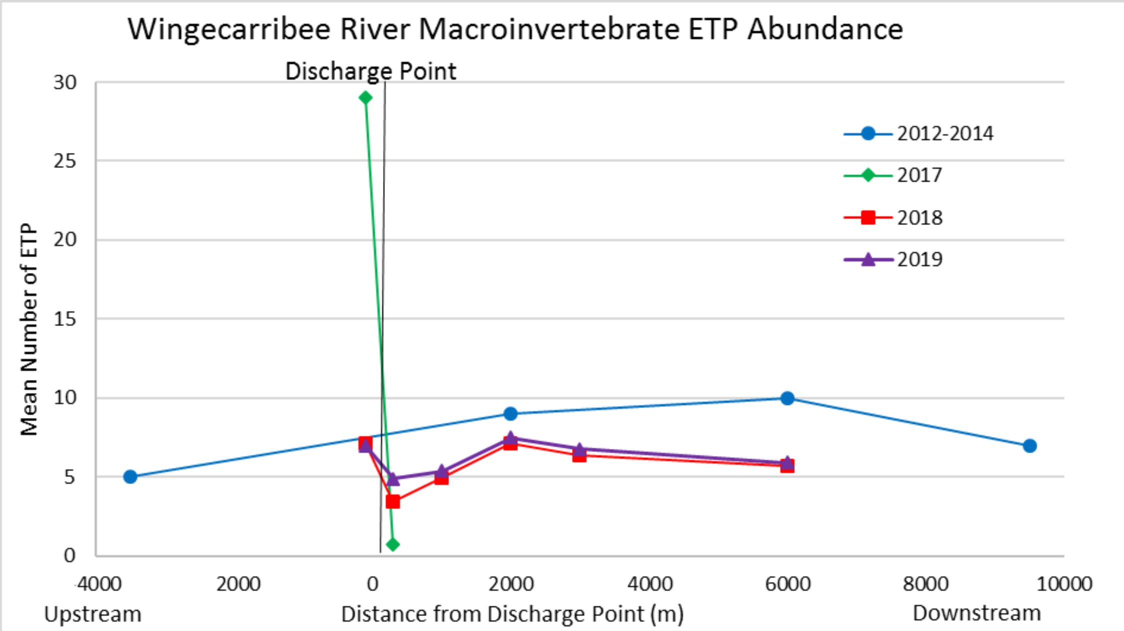
Graph 4.2 Macroinvertebrate Abundance Upstream and Downstream of the Adit Discharge Point on the Wingecarribee River

4.3.3 ETP Abundance

A substantially greater number of pollution sensitive EPT taxa were sampled at the 100m upstream site in 2017, with 29 macroinvertebrates from the orders *Ephemeroptera, Plecoptera* and *Trichoptera* identified. The study in 2017 showed the greatest range in abundance, from 29 at 100m upstream to 1 individual at 300m downstream. Data from 2012-2014, 2018 and 2019 were more comparable, with EPT abundance ranging from 3.4 to 10 across all samples and site locations. Overall the 2012-2014 study observed a higher number of EPT taxa with a mean EPT abundance of 7.75 compared to means of 5.8 and 6.2 EPT in 2018 and 2019 respectively.

Graph 4.3 shows that in 2012-2014, the number of EPT were always higher at downstream sites. Data from 2018 and 2019 show a decline at the 300m downstream site, followed by a steady increase with abundances remaining similar to the site 100m upstream. Ultimately, Graph 4.3 shows that the five sites located downstream of the adit are becoming more similar to the site 100m upstream.

The 2012-2014 study found a total of 11 EPT taxa in the Wingecarribee River. An average of 8 of these families were found upstream, compared to an average of 7 located downstream. Similarly, 12 families from the EPT orders were identified in 2017; 8 in which were from the *Trichoptera* order, *Ephemeroptera* had 3 families present and the remaining family belonged to the order *Plecoptera*. All except for two of the *Trichoptera* families were present in 2018.



Graph 4.3 Macroinvertebrate ETP Abundance Upstream and Downstream of the Adit Discharge Point on the Wingecarribee River

4.4 Discussion

4.4.1 Variation Observed on a Temporal Scale

The results show that temporal variability is present between studies. In 2012-2014, MPR sampled a substantially greater number of macroinvertebrate families than sampled in the most recent three years. The abundance of macroinvertebrates both upstream and downstream of the discharge point was deemed greatest in 2019 showing a gradual rise since 2017. The number of sensitive EPT individuals showed a dramatic decline below the discharge in Wrights' 2017 study, which was not reciprocated in 2012-2014, 2018 or 2019. There are several explanations to explain such differences, including the differences in sampling techniques and changes in river quality, which are further discussed below.

The method adopted by MPR in 2012-2014 involves sampling 10 metres for each replicate, compared to a stationary timed sample used in all other surveys. This technique may result in a greater number of taxa being collected because an increased number of microhabitats including multiple boulders and reeds are sampled. Abundance was lower in 2017 than 2018 and 2019, which could be due to the extended length of sampling in 2017 that allows macroinvertebrates to escape the net.

An alternative explanation is that more families were detected by MPR in 2012-2014 due to higher habitat quality. These samples were taken when the mine was still in operation, discharging water with lower mineral content. Coal extraction operations stopped in October 2013, underground pumping stopped, and the workings flooded with groundwater. While the mine was flooding, the discharge to the river was minimal. The mine commenced free draining at the end of March 2016 and the discharge volume gradually rose to an average of 2.4ML/day and 2.5 ML/day during 2017 and 2018 respectively.

Wright undertook his study 39 months after the Berrima Colliery had ceased mining, when groundwater was free-draining and the water quality was at its all-time lowest. The timing of the 2017 sampling can explain why total and EPT abundance was low. Underground treatment of water commenced in 2018, improving metal concentrations and overall river health. The 2018 results show increased taxonomic richness and abundance which supports the success of the water treatment. Underground water treatment was continued in 2019, showing further improvement in discharge water quality which was combined with low discharge volumes averaging 0.75 ML/day over the 12 month period. The low discharge flow and improved water quality in 2019 is reflected by the improved macroinvertebrate composition during this time.

A valid argument suggested by Loayza-Muro *et al.* (2010) is that taxonomic richness and abundance will not always be consistently high in the same samples due to competition and community composition. As chemical concentrations are reduced, more sensitive species will become non-existent at a site due to competition, hence reducing species richness and abundance. In turn, the resistant taxa will boost their abundance to replace sensitive species because the competition for resources is now limited. Only when concentrations become higher than the resistance for all species, will the richness and abundance both decline (Loayza-Muro *et al.* 2010).

4.4.2 Impacts of Metals and Acidity on River Macroinvertebrates

A range of elements discharged from the mine can have variable deleterious effects on aquatic macroinvertebrates to cause reductions in population size and diversity. Slightly acidic pH values, elevated Iron, Zinc and Nickel are general characteristics of the Wingecarribee River over the past three years.

Concentrations of Zinc have been known to reduce energy absorption in macroinvertebrates, which has been linked to a reduction in reproductive output (Ravengai *et al.* 2005). Iron precipitates in the water can cause the destabilisation of benthic substrate and destroy ecosystem habitat (Rodrigues & Bueno, 2016).

Low concentrations of metals including Zinc and Iron within waterways can cause water acidification (Ravengai *et al.* 2005). Acidity weakens shells and exoskeletons of macroinvertebrates (Stumpf, Darby and Gwilliam, 2009). Acidification can cause the addition of Sulfuric Acid and Iron Sulphate into the waterway which consumes oxygen and limits respiratory efficiency and causes deformities in larvae (Rodrigues & Bueno, 2016).

These studies however, usually refer to much higher pH acidity and metal concentrations than that occurring within the mixing zone. During 2019 results have shown increases in pH to slightly alkaline levels. As shown in Chapter 3, the concentration of minerals below the mixing zone are now comparable to the levels in 2013 when the mine was operational. This mineral load has been a feature of the Wingecarribee River for nearly 90 years. By meeting the historic mineral load, it could be assumed that the impacts of the mineral composition of the discharge will be no greater. As the concentration of mineral elements generally meet ANZECC default trigger values for 95% ecosystem protection, it should not be a limiting factor to river health.

4.4.3 Impacts on Macroinvertebrates Downstream of the Discharge Point

The total abundance and EPT abundance showed significant declines at 300m downstream of the discharge over the past three survey years. These results show that the groundwater released from the mine in recent years has impacted on the macroinvertebrates within the mixing zone. On a positive note, the taxonomic richness increased at 300m downstream in 2019. This indicates a strong improvement in discharge water quality in the past 12 months. No decline in abundance or richness was observed at a distance of 2000m below the discharge in 2012-2014. The 2012-2014, 2018 and 2019 study show that below 2000m the macroinvertebrate diversity and abundance is the same or greater than the upstream levels.

These results confirm that the river is negatively impacted close to the site of the discharge, however the distance of impact is short and quickly improves downstream. MPR suggest that the distance of mixing zone required to return to healthy levels is approximately 1500m. The data collected downstream in 2012-2014, 2018 and 2019 are higher than upstream sites on multiple occasions, indicating a complete recovery. These observations conclude that no long-term impacts on macroinvertebrate populations are evident.

The return of the river to the equivalent of background ecological function and health meets an overriding objective of the ANZECC 2000 guideline. As previously anticipated, the poorer mixing zone ecology in 2018 compared to 2013 improved over 2019, as the discharge quality remained similar to historic levels.

4.4.4 Differences in Species Diversity and Abundance

The 2012-2014 study concluded that insect larvae were the most common macroinvertebrates and in opposition, worms were the most frequent in 2017. Samples were taken in different seasons, which could result in the presence of different species. The concentration of different pollutants at different time periods can also be linked to differences in species composition and climatic events such as heavy rainfall and increased river flow.

Samples by MPR were taken in spring and winter, whereas Wright undertook his study in summer 2017. Many species-specific explanations can be assumed, such as reproductive seasons, periods of torpor as experienced in molluscs, and times of higher food availability. High diversity is known to occur in periods of low water flow and increased temperatures (Waterwatch, 2001), although results show that flow was relatively consistent during most of the sampling months. Hill, Sayer & Wood (2016) claim that the best season to evaluate macroinvertebrate diversity is during Autumn.

All organisms have altered tolerances to different contaminants. The higher toxicants present in 2017, could limit the abundance of some species, but increase the population sizes of others due to reduced competition (Loayza-Muro *et al.* 2010). A representative species of this is *Chironomidae*, the non-biting midge who may have become dominant in locations of high metal concentrations (Smolders *et al.* 2003). Chironomids are known to benefit from a dynamic environment because they can adapt to change and recolonise when other species diminish (Ravengai *et al*. 2005; Qu *et al.* 2010).

In correspondence with Wrights' study, Qu *et al*. (2010) claims that *Oligochaetes* known as worms are a contamination tolerant taxon that are often inhabitants of degraded waterways. *Oligochaetes* were also claimed to be metal tolerant by Loayza-Muro *et al*. (2010), which was also the case in 2017 when the Wingecarribee River had its highest metal contamination levels recorded.

Previous studies have also agreed with findings by MPR in 2012-2014, in which *Diptera* was the most common species in healthy aquatic ecosystems. Qu *et al.* (2010) found that *Diptera* are highly sensitive to Cadmium and Lead. Some groups of *Diptera* were also deemed sensitive to metals and acidity in another study (Loayza-Muro *et al.* 2010).

4.5 Conclusion

The combined results of the studies presented above support the contention that the mine discharge into the Wingecarribee River does influence macroinvertebrate diversity and abundance below the mine adit discharge within the mixing zone. In terms of aquatic ecology, the mixing zone is approximately 2000 m downstream of the discharge point. The studies have also shown that a complete recovery is observed further downstream. A key observation from the 2019 study was that the macroinvertebrate taxonomic richness no longer showed an impact downstream of the discharge, with numbers consistently higher than the upstream site. Macroinvertebrate populations were observed at their lowest existence in 2017, however water treatment commenced in 2018, and bulkheads were installed in 2019 which have seen an increase in population health that is expected to continue.

5. Ecotoxicology Assessment

5.1 Introduction

Ecotoxicology refers to the study of the effects of chemical interactions on organisms (Assessment of Ecotoxicity, 2014). Such studies are common in freshwater ecosystems due to the discharge of waste into natural waterways (Assessment of Ecotoxicity, 2014). The goal of ecotoxicology is to understand and predict the impacts of pollution to avoid any damaging costs to ecosystems, and to restore previously polluted environments (Altenburger, 2011). Common pollutants to waterways analysed in ecotoxicology studies include Heavy Metals, PCBs, Pesticides, Mould and Chlorine (Chapman, 2002).

Ecotoxicology studies will examine the impact on a species as well as the compounding risks to ecological entities (Segner, 2011). This knowledge is important because exposure to toxic chemicals can have detrimental effects on species at an individual and community level. Chemicals which are absorbed by organisms in high doses can cause death directly, or indirectly cause population decline via changes in behaviour, reproduction, development and mutation (Relyea and Hoverman, 2006). The cascading effects are clear, with lower trophic level declines reducing food sources and biomagnification of chemicals influencing predatory species.

Aquatic ecosystems have a high biodiversity, so indicator organisms are used to assess the toxicity of various hazards present in waterways (Assessment of Ecotoxicity, 2014). From this perspective, scientists can examine the transfer pathways of hazards from indicator organisms and how they are integrated into the ecosystem (Segner, 2011). Ecotoxicity is often measured via length of exposure, and endpoints used are often related to survival, growth, development, and reproduction (Peake and Tremblay, 2016). Studies will then develop triggers to predict when waterways can be classified as an 'Environment that May Be Affected' (EMBA) (Relyea and Hoverman, 2006).

Ecotoxicological studies were conducted in the Wingecarribee River in 2012, 2017/2018 and 2019 to examine the influence of the Berrima Colliery discharge on ecosystem health. This study aims to:

- ❒ Identify potential chemical hazards at toxic levels within the Wingecarribee River during three time periods, and
- ❒ Compare changes in river toxicity on a temporal scale.

5.2 Methods

The ecotoxicological studies were undertaken during the same time periods as the Aquatic Ecology study, that is, 2012, 2017/2018 and 2019 but were undertaken at different locations. Comparisons will be made on a gradient along the mixing zone of the river.

Four 1 litre samples from each monitoring site were sent to laboratories at Ecotox Services Australia (ESA) in 2012 and the OEH Environmental Forensics (EF) Team in 2017/2018 and 2019 for assessment of toxicological quality. Sampling, sample handling and delivery followed laboratory recommended protocols.

Differing indicator species were used, however all three studies used *C. dubia*, and thus this is a key species used for comparison in this study. Species have variable tolerance thresholds and therefore it must be noted that acute toxicity testing durations vary between species. The information for each species and sampling period is provided below in Table 5.1.

Table 5.1 Sample Species Duration of Acute Toxicity Testing

Sampling Periods	**2012**	**Dec 2017**	**Apr 2018**	**Sept 2019**
Sampling Locations:	400m Up, Discharge, 100m dn, 200m dn	100m Up, 100m dn, 2000m dn, 2500m dn		100m Up, 100m dn
Ceriodaphnia dubia	48h	7d	24h, 48h, 6d	48h
Parayta australiensis	96h	24h, 48h, 72h	96h	-
Chironomous tepperia	48h	-	-	-
Melanotaenia duboulayi	-	24h, 48h	24h, 48h	48h
Hydra vulgaris	-	24h, 48h, 72h, 96h	24h, 48h, 72h, 96h	-
Raphidocelis subcapitata	-	72h	72h	72h

Samples collected from the Wingecarribee River were diluted at different factors using filtered and thiosulphate-treated Sydney mains water with the addition of 5% mineral water, conductivity adjusted to 500 ± 20 µS/cm with filtered seawater. Four different dilution factors were used among species and sampling periods (Table 5.2).

Table 5.2 Four Treatment Dilution Factors Used

Dilution Factor 1	**Dilution Factor 2**	**Dilution Factor 3**	**Dilution Factor 4**
Control	Control	Control	Control
1.6	4	1	100
3.1	7	6.25	-
6.3	12	12.5	-
12.5	20	50	-
25	35	100	-
50	60	-	-
100	100	-	-

In-house cultures of each indicator species were added to Wingecarribee River water samples diluted to different factors, to test the toxicity of the river water. In 2012, the three study species were each subjected to acute toxicity testing of immobilization, compared to a wider range of chronic and acute endpoints used in 2017/2018 and 2019 listed below:

- 7-d cladoceran *C. dubia* lethality and reproduction impairment (chronic);
- 48-h cladoceran *C. dubia* immobilisation (acute) (2019 only);
- 72-h alga *R. subcapitata* growth inhibition (chronic);
- 48-h larval rainbowfish *M. duboulayi* imbalance (acute);
- 96-h shrimp *P. australiensis* lethality (acute) (2017/2018 only); and
- 96-h 'pink Hydra' *H. vulgaris* lethality (acute) (2017/2018 only).

Water chemistry was also tested to make predictions regarding which chemicals are likely contributing to water toxicity.

5.3 Results

A summary of the toxicity test results between the three studies is provided in Tables 5.3 to 5.5. It should be noted that direct comparison of the test results is difficult given these were done by different laboratories using different test methodologies. Although the test locations are similar, it is not possible to accurately determine the precise locations, so the distances below the discharge points are indicative only.

Table 5.3 Summary of 2012 Toxicity Test Results

Test species (end point)	Upstream 400m	Discharge Point	Downstream 100m	Downstream 200m
C. dubia (immobilisation)	Mildly toxic at greater than 25% concentration	Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
P. australiensis (immobilisation)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
C. tepperia (immobilisation)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
M. duboulayi (imbalance)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
H. vulgaris	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
R. subcapitata (growth inhibition)	Significantly lower cell yield	Significantly lower cell yield	Significantly lower cell yield	No difference

Table 5.4 Summary of 2017/2018 Toxicity Test Results

Test species (end point)	Upstream 100m	Downstream 100m	Downstream 2000m	Downstream 2500m
C. dubia (immobilisation)	-	Significantly lower survival and reproduction	No difference	No difference
M. duboulayi (imbalance)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
P. australiensis (lethality)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic

H. vulgaris (lethality)	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic	Not Acutely Toxic
R. subcapitata (growth inhibition)	-	Significantly lower cell yield	No difference	No difference

Table 5.4 Summary of 2019 Toxicity Test Results

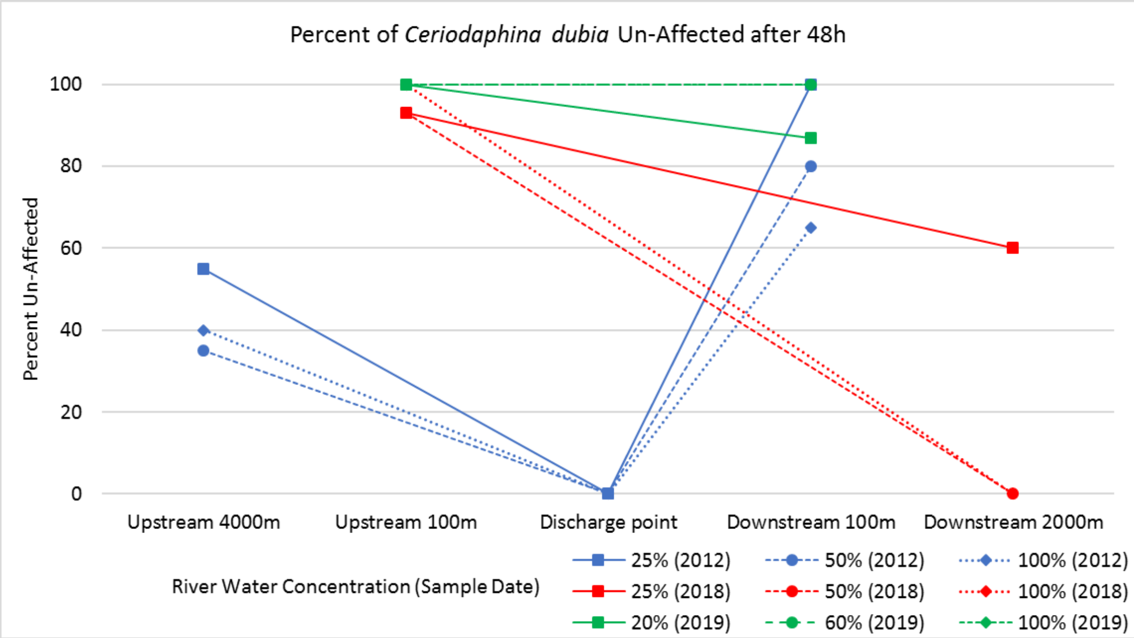
Test species (end point)	Upstream 100m	Downstream 100m
C. dubia (immobilisation/reproduction impairment)	No Significant Difference	No Significant Difference
C. dubia (immobilisation)	Not Acutely Toxic	Not Acutely Toxic
M. duboulayi (imbalance)	Not Acutely Toxic	Not Acutely Toxic
R. subcapitata (growth inhibition)	Not Chronically Toxic	Not Chronically Toxic

The Graphs 5.1 to 5.6 below show a comparison of the main results observed for each indicator species at sites along the mixing zone, taken years apart, in separate trials. Low dilution factors are not included in graphs because they are not tested on all occasions. Samples with a single point (Graph 5.4) indicate trials in which only 100% river water was compared against a control at only one site.

As expected, 100% concentrated river water caused a greater percentage of the water flea *C. dubia* to show effects from river water toxicants. In 2012, samples collected from the discharge point affected 100% of individuals. Graph 5.1 shows that in 2012 water at 4000m upstream had higher effects at 35 to 55% unaffected than 100m downstream of the discharge point at 65 to 100% unaffected. Contrasting results were recorded in 2019, in which 100% *C. dubia* were unaffected at 60% and 100% dilution levels, whereas 87% were unaffected in the 20% dilution at 100m downstream.

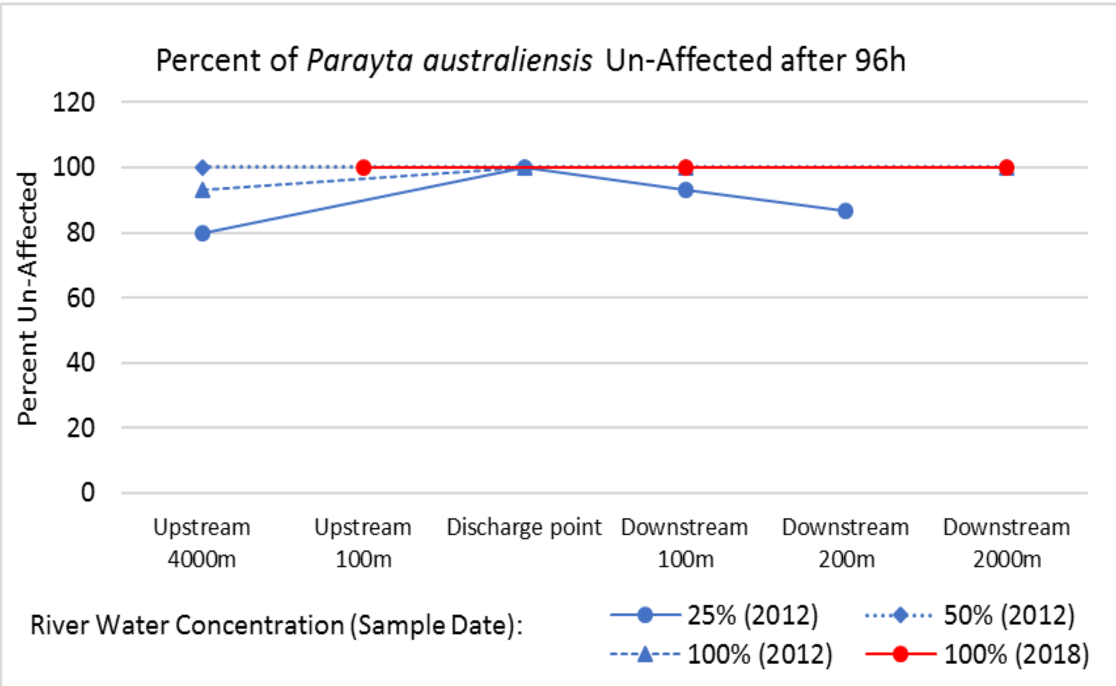
Data from 2018 shows that water from 2000m downstream has significant effects with 0 to 60% survival and reproduction when compared to survival of 65 to 100% 100m upstream (Graph 5.1). An 11 times dilution was required to remove the toxicity to levels not causing an effect on *C. dubia* from 2000m downstream (see Table 5.5).

Over the past three trial years, *C. dubia* has shown an increase in percentage unaffected following 48h at all three river water dilutions presented in Graph 5.1. The most recent results from 2019 indicate a reduction in toxicity of the Wingecarribee River, with 100% of water flea unaffected in 60% and 100% river water. Following 48 hours, the water flea showed slight immobilisation (<13%) at both sampling locations during the control and 7% dilution, and also downstream at 12% and 20% dilutions (Table 5.5).



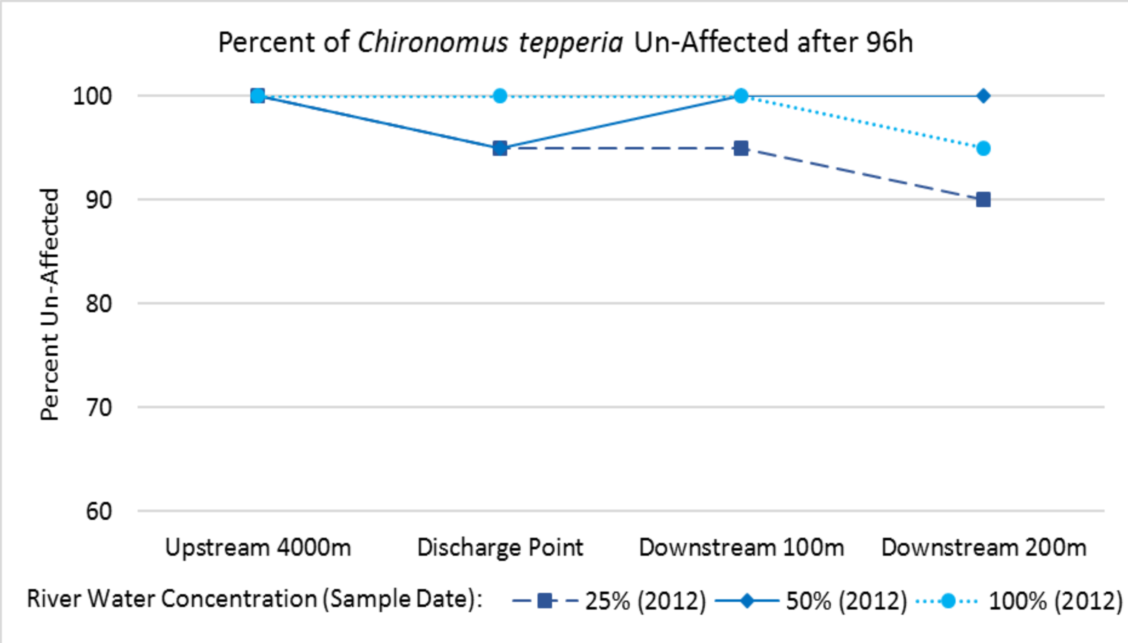
Graph 5.1 Percent *Ceriodaphnia dubia* unaffected after 48h

Graph 5.2 shows that only minor effects were experienced by the glass shrimp *P. australiensis* down to 80% unaffected at lower dilution levels of 25%. These effects in 2012 were not significant. Similarly in 2018, no acute toxic effects were observed in 100% concentrated waters at all sample locations. Samples taken in 2012 and 2018 were not significantly different at sites upstream or downstream of the discharge point. Toxicity tests were not undertaken on *Parayta australiensis* in 2019.



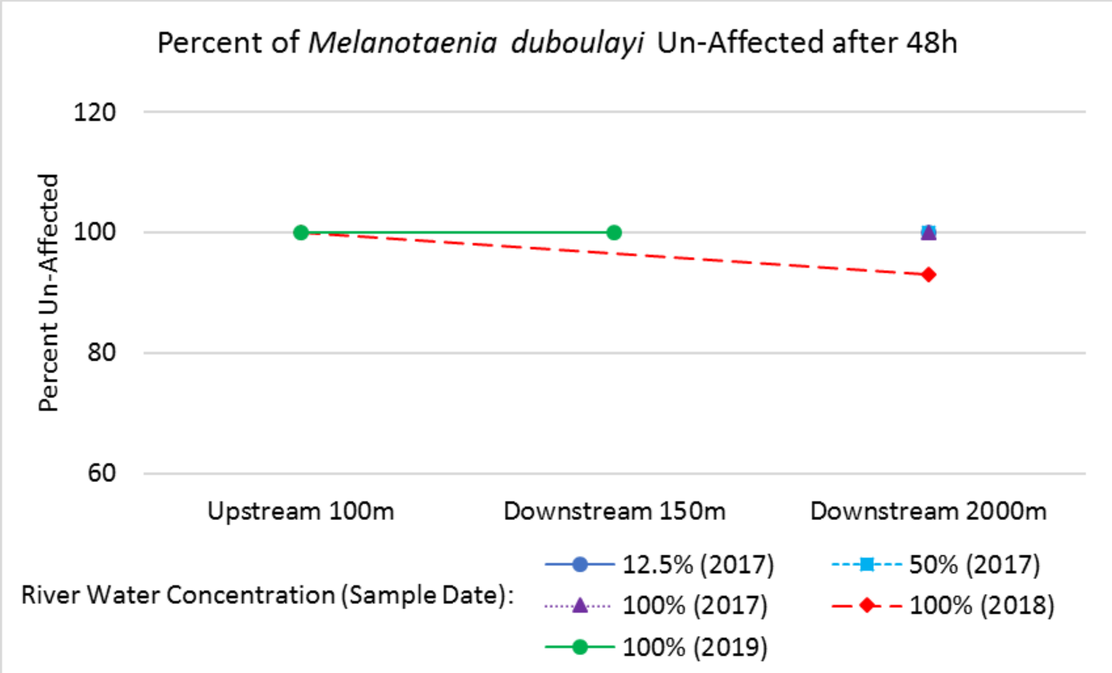
Graph 5.2 Percent *Parayta australiensis* unaffected after 96h

The non-biting midge (chironomid) larvae was used as an indicator in 2012 only. Percentages of unaffected individuals remained above or at 90% at all dilutions and sampling sites. Results in Graph 5.3 indicate that there was little acute toxicity apparent for this species following 96 hours of exposure.



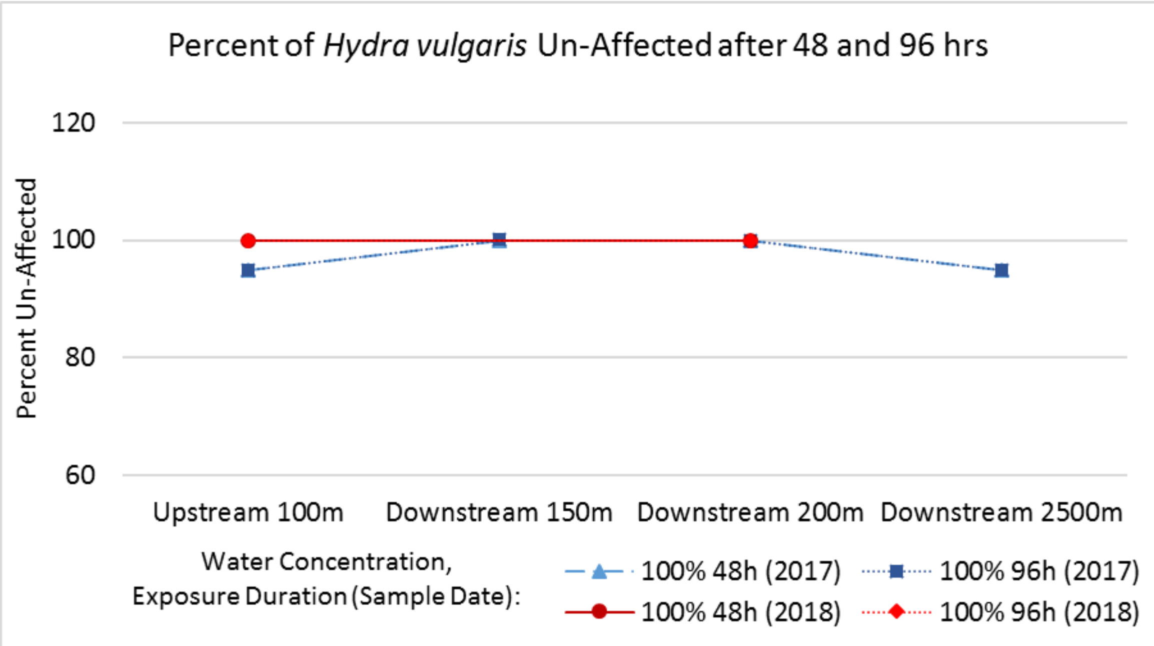
Graph 5.3 Percent *Chironomous tepperia* unaffected after 96h

Graph 5.4 shows the 2017/2018 and 2019 results of the larval rainbowfish *M. duboulayi* upstream and downstream of the discharge point. In 2017, all individuals were unaffected at 2000m downstream under three dilution factors; 12.5%, 50% and 100%. The percent of unaffected *M. duboulayi* dropped to 93% in 2018 at 2000m downstream, although this result was not deemed to have an acute toxic effect on the species. In 2019, samples were taken from 100m upstream and 100m downstream. At both sites, the percent of larval rainbowfish unaffected in full strength river water was 100%.



Graph 5.4 Percent *Melanotaenia duboulayi* unaffected after 48h

Pink hydra *H. vulgaris* was unaffected by river water at 100% concentration at all sites following 48 and 96 hours of exposure as seen in Graph 5.5. In 2017 5% of polyps were affected 100m upstream and 2500m downstream following 48 and 96 hours, however this was not a significant result.

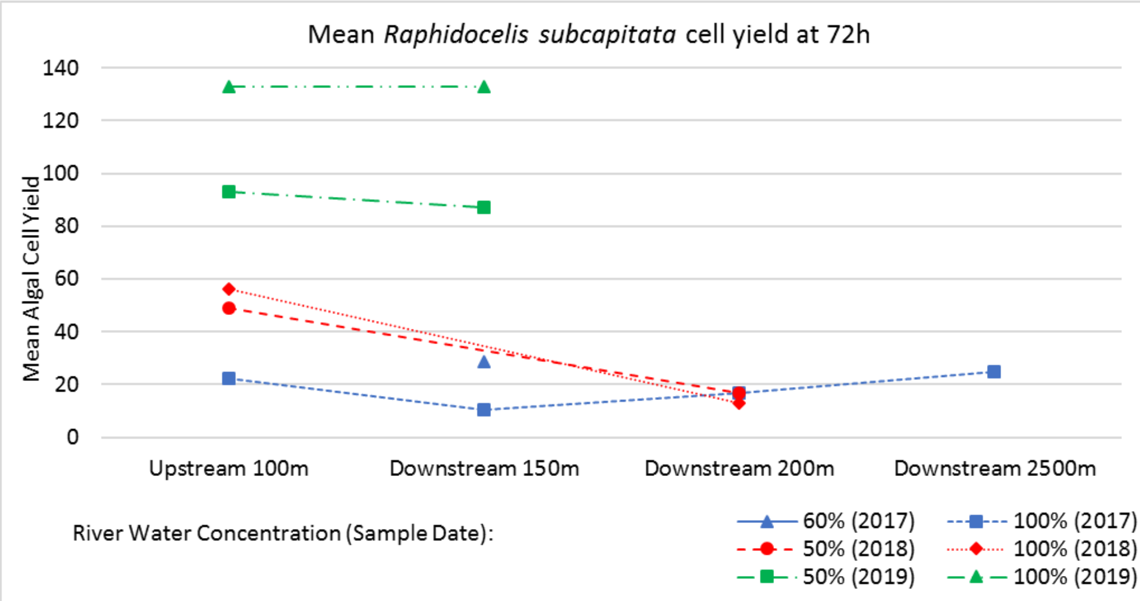


Graph 5.5 Percent *Hydra vulgaris* unaffected after 48h and 92 hrs

Growth of the green microalga *R. subcapitata* was measured in 2017/2018 and 2019 at 50% and 100% river water following 72 hours, as shown in Graph 5.6. Growth 100m upstream was 34% lower in 2017 than 2018 in undiluted river samples. Results from 2017 show that growth 100m upstream and 2500m downstream were at similar levels, with mean algal cell yields of 22.3% and 24.7% respectively. A 60% dilution of river water 150m downstream of the discharge resulted in an 18% increase in cell yield during 2017. Samples from 2018 recorded 43% and 32% inhibition in algal growth in 100% and 60% river water samples respectively.

When compared to the control diluent in 2018 (Table 5.5), sites 100m upstream, 200m and 2500m downstream exhibited an increase in algal growth. Undiluted water from 150m downstream were the only samples showing a decrease in algal cell yield relative to the control diluent.

Algal cell yields were significantly higher in 2019 at both sampling locations, under all dilution factors. The cell yield both upstream and downstream in 2019 doubled that in 2018 in 100% river water (Graph 5.6).



Graph 5.6 Mean *Raphidocelis subcapitata* cell yield at 72h

5.4 Discussion

The most recent results have shown an improvement in the Wingecarribee river water toxicity, with increased percentages of unaffected *C. dubia* and *M. duboulayi*, and higher cell yields of *R. subcapitata* (See Table 5.5 for full results). No signs of toxicity were observed for the three indicator species tested during 2019.

Hazardous influences of the Wingecarribee River water were not observed as close as 100m downstream in *C. dubia.* Water downstream of the discharge often displays similar ecotoxicity results as water upstream, suggesting that influences from the discharge do not extend into the mixing zone. In some cases, as for *C. dubia* and *R. subcapitata* (in 2012) the toxicity effects are higher at upstream sites, highlighting that external factors are also contributing to river health. It is also interesting to note that a higher percentage of the midge *C. tepperia* were impacted at sites furthest from the discharge point in 2012.

A chemical analysis prepared by OEH Environmental Forensics in 2019 also found an improvement in river water quality since previous sampling events in December 2017 and April 2018. Levels of major cations and anions, conductivity, total alkalinity, dissolved oxygen, nutrients and all major metals (excluding aluminium) showed no significant differences upstream and downstream of the discharge point. Aluminium was found to be present in 'an insoluble form or associated with particulates', and all trace metals concentrations were low, often below the detection limits. In previous sampling events (2017/2018) the dissolved metals Cobalt, Nickel and Zinc exceeded the ANZG (2019) Default Guideline Value (DGV) downstream of the discharge point. There were no dissolved metal concentrations exceeding the corresponding criteria in September 2019. Concentrations of the metals Calcium, Manganese, Magnesium and Strontium showed no significant difference between sites upstream and downstream of the discharge point. In addition, the metals Cobalt, Nickel, Manganese and Zinc were lower than concentrations during 2017/2018 at both upstream and downstream sites.

Two of the indicator species had greater responses to river toxicity than the other four species. *Ceriodaphnia dubia* is a species of water flea known to be sensitive to low concentrations of metals (Hyne *et al.* 2005). This species has been an asset to this study because it has shown disparity in response to pollutants at the different sites, with results corresponding to the metal concentrations evident in the chemical analysis. In 2017, the growth of the green microalga *R. subcapitata* was greatly reduced at 200m downstream, although growth was higher in water from all other sites than in the dilution control. A range of factors influence algae growth including light, carbon dioxide and nutrients, however a study by Baken *et al.* (2014) suggests that the presence of metals can limit nutrient availability. The 2019 *R. subcapitata* cell count doubled from 2018 samples and tripled from samples taken in 2017. This improved result can be expected with lower metal concentrations within the river water.

The 2012 ecotoxicological studies were undertaken when the mine was operating and represented the benchmark level against which the subsequent studies can be compared. The 2017-2018 studies showed an increased in toxicity levels within the mixing zone however the 2019 studies showed a reduction in toxicity levels. This indicates that the water quality within the mixing zone has improved and is approaching historic levels. This conclusion is supported by the water quality data discussed in Chapter 3 and the aquatic ecology assessments discussed in Chapter 4.

Table 5.5

Ecotox analysis for *Ceriodaphnia cf dubia*

Aug-12					Dec-17				
	U/S		D/S			U/S		U/S	
48hrs	% Un-Affected		% Un-Affected		7days	% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Conc %	Av.	S.D	Av.	S.D
1.6					1.6			100	0
3.1					3.1			90	10
6.3	100	0	100	0	6.3			100	0
12.5	100	0	100	0	12.5			80	13
25	55	10	100	0	25	100	0	0	0
50	35	10	80	23	50			0	0
100	40	23	65	25	100	90	10	0	0

Apr-18					Apr-18				
	U/S		D/S			U/S		D/S	
24hrs	% Un-Affected		% Un-Affected		48hrs	% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Conc%	Av.	S.D	Av.	S.D
4	100	0	100	0	Control	10	6	93	7
7	100	0	100	0	7	13	13	93	7
12	100	0	100	0	12	0	0	93	7
20	100	0	80	0	20	0	0	60	20
35	100	0	20	20	35	0	0	53	29
60	93	7	7	7	60	0	0	0	0
100	100	0	7	7	100	0	0	0	0

Apr-18					Sept-19				
	U/S		D/S			U/S		D/S	
6days	% Un-Affected		% Un-Affected		48h	% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Conc%	Av.	S.D	Av.	S.D
1.6	100	0	100	0	Control	90	6	90	6
3.1	100	0	100	0	7	87	13	93	7
6.3	100	0	100	0	12	100	0	93	7
12.5	100	0	100	0	20	100	0	87	7
25	100	0	100	0	35	100	0	100	0
50	100	0	100	0	60	100	0	100	0
100	100	0	0	0	100	100	0	100	0

Ecotox analysis for *Paratya australiensis*

Nov-12									
Location		U/S		Discharge		D/S		D/S	
Results	96hrs	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	6.3	100	0	100	0	100	0	100	0
	12.5	100	0	100	0	93.3	11.6	100	0
	25	80	34.6	100	0	93.3	11.6	86.7	23.1
	50	100	0	100	0	100	0	100	0
	100	93.3	11.6	100	0	100	0	100	0

Dec-17									
Location		U/S		D/S		D/S 2km		D/S 2.5km	
Results	24, 48, 72h	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	Control	100	0	100	0	100	0	100	0
	100	100	0	100	0	100	0	100	0

Apr-18									
Location		U/S		D/S		D/S 2km		D/S 2.5km	
Results	96hrs	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	Control	100	0	100	0	100	0	100	0
	100	100	0	100	0	100	0	100	0

Ecotox analysis for *Chironomus tepperia*

Dec-12									
Location		U/S		Discharge		D/S		D/S	
Results	48hrs	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	6.3	95	10	100	0	100	0	95	10
	12.5	100	0	100	0	100	0	100	0
	25	100	0	95	10	95	10	90	11.6
	50	100	0	95	10	100	0	100	0
	100	100	0	100	0	100	0	95	10

Ecotox analysis for *Melanotaenia duboulayi*

Dec-17								
	U/S		D/S		D/S 2km		D/S 2.5km	
24hrs	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
1			100	0				
6.25			100	0				
12.5			100	0				
50			100	0				
100	100	0	100	0	100	0	100	0

Dec-17								
	U/S		D/S		D/S 2km		D/S 2.5km	
48hrs	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
1			100	0				
6.25			100	0				
12.5			100	0				
50			100	0				
100	100	0	100	0	100	0	100	0

Apr-18					Apr-18					Sept-19				
	U/S		D/S			U/S		D/S			U/S		D/S	
24hrs	% Un-Affected		% Un-Affected		48hrs	% Un-Affected		% Un-Affected		48h	% Un-Affected		% Un-Affected	
Conc %	Av.	S.D	Av.	S.D	Conc %	Av.	S.D	Av.	S.D	Conc %	Av.	S.D	Av.	S.D
Control	100	0	100	0	Control	100	0	100	0	Control	100	100	100	100
100	100	0	100	0	100	100	0	93	7	100	100	100	100	100

Ecotox analysis for *Hydra vulgaris*

Dec-17									
Location		U/S		D/S		D/S 2km		D/S 2.5km	
Results	24, 48, 72h	% Un-Affected		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	Control	100	0	100	0	100	0	100	0
	100	95	5	100	0	100	0	95	5

Dec-17									
Location		U/S		D/S		D/S 2km		D/S 2.5km	
Results	48hrs	96hrs		% Un-Affected		% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	Control	100	0	100	0	100	0	100	0
	100	95	5	100	0	100	0	95	5

Apr-18						Apr-18					
Location		U/S		D/S		Location		U/S		D/S	
Results	24, 48, 72h	% Un-Affected		% Un-Affected		Results	96hrs	% Un-Affected		% Un-Affected	
	Conc %	Av.	S.D	Av.	S.D		Conc %	Av.	S.D	Av.	S.D
	Control	100	0	100	0		Control	100	0	100	0
	100	100	0	100	0		100	100	0	100	0

Ecotox analysis for *Raphidocelis subcapitata*

Dec-17									
Location		U/S		D/S		D/S 2km		D/S 2.5km	
Results	72hrs	Algal Cell Yield		Algal Cell Yield		Algal Cell Yield		Algal Cell Yield	
	Conc %	Av.	S.D	Av.	S.D	Av.	S.D	Av.	S.D
	Control	13.4	0.5	13.4	0.5	13.4	0.5	13.4	0.5
	60			28.5	2.3				
	100	22.3	2.7	10.4	0.6	16.6	0.8	24.7	3.1

Apr-18					
Location		U/S		D/S	
Results	72hrs	Algal Cell Yield		Algal Cell Yield	
	Conc %	Av.	S.D	Av.	S.D
	1.6			24.1	3.9
	3.1			23.5	5.1
	6.3	51.3	3.9	28.3	5.3
	12.5	50.8	6.8	20.2	4.3
	25	36.8	6.3	23.8	3.9
	50	48.8	8.4	16.7	0.9
	100	56.3	4	13	1.1

Sept-19					
Location		U/S		D/S	
Results	72hrs	Algal Cell Yield		Algal Cell Yield	
	Conc %	Av.	S.D	Av.	S.D
	Control	0	9	0	9
	1.3			42	9
	3.1			149	4
	6.3	88	20	107	27
	13	36	31	100	30
	25	71	15	71	15
	50	93	27	87	16
	100	63	13	56	21
	100 (unfiltered)	133	20	133	14

Comparison of metal concentrations in the Wingecarribee River samples taken in December 2017, April 2018 and September 2019 (Directly from Environmental Forensics Wingecarribee River Assessment Report

Dissolved Metals (mg/L)	**Water Quality DGV[1]**	**September 2019**		**April 2018**		**December 2017**	
		Upstream	**Downstream**	**Upstream**	**Downstream**	**Upstream**	**Downstream**
Calcium	-	13	13	13	26	12	28
Magnesium	-	5.3	5.9	7.1	24	6.5	23
Manganese	1.9	<0.02	<0.02	0.003	1.6	0.002	3.0
Strontium	-	0.05	0.06	0.08	0.12	0.078	0.13
Sulphur	-	10	12	7.9	37	6.8	40
Cobalt	0.0014	<0.01	<0.01	0.0001	0.017	<0.0001	0.035
Nickel	0.011	<0.02	<0.02	0.0023	0.063	0.0009	0.099
Zinc	0.008	<0.03	<0.03	0.005	0.060	<0.001	0.058

[1] Default guideline value for the protection of 95% of species for metals (ANZG 2019). Concentrations that exceed their respective guideline are identified in **bold**.

6. Sediment Analysis - Fate Assessment

6.1 Introduction

The quality of sediment is important for the overall health of an aquatic ecosystem. Many aquatic macroinvertebrates and benthic organisms will obtain large amounts of their diet from the substrate, in which the levels of deposited contaminants consumed can have cascading effects on ecosystems (Chapman, 1992). This Chapter investigates how the concentration of metals and other pollutants present in the sediment can influence macroinvertebrate health and ecotoxicity, as discussed in Chapters 4 and 5.

Sediment quality must be considered when drawing conclusions about the health of an aquatic ecosystem. Aquatic substrate is often an environmental sink for contaminants which undergo variable biological mechanisms including sorption, biodegradation and deposition which cause large amounts of particles present in the water column to end up in the benthic environment (Dickson *et al.* 1984). The river flow rate is directly related to the levels of pollutants present in the sediment (Chapman, 1992). High flow rates are associated with greater concentrations of total suspended solids, hence extending the length of the mixing zone and maintaining metals in solution.

Chemical reactions continuously influence the transition of metal distribution from the sediment to the water column, and back again (Chapman, 1989). Thus, it is important to analyse sediment quality in conjunction with the water quality to grasp the complete impact of the mine adit discharge on the health of the Wingecarribee River. Chapter 3 analyses the concentration of total and dissolved metals present in the river water; however these measurements only include the contaminants contained in the water column itself. In order to examine the concentration of deposited material, the sediment must be sampled to give a more complete picture of the river contaminants.

The analysis draws comparisons between sediment data collected over a six year period, in 2013 2018 and 2019 to view changes in the health of the river's benthic habitat on a temporal scale. This study aims to provide a comprehensive assessment of the contaminants present in all elements of the waterway, as well as tracking the movement of metals through deposition and river flow.

6.2 Methods

Several surface sediment subsamples are taken from multiple locations at each site to capture a clear representation of the location. Sediment is collected from the top 15cm of the substrate using a hand trowel and placed into 250ml glass jars supplied by Australian Laboratory Services. The samples were transported to the laboratory on the day of collection. Chain of Custody records are kept and include the time, date and location of sample, name of the person collecting the sample and records of the analysis to be performed. Water quality samples were taken at the same time and location as sediment samples on all occasions.

6.2.1 Ambient Sediment Quality Results

During 2013 when the mine was operating, sediment samples were taken on a monthly basis from the four ambient monitoring sites:

- ❒ Wingecarribee River upstream of the mine adit discharge at Old Hume Highway Crossing at Berrima, referred to below as Upstream
- ❒ Macarthur's Crossing, also upstream of the mine but within the Hawkesbury Sandstone
- ❒ Wingecarribee River approximately 6km downstream of the mine adit discharge at Biloela Camp Site. Sampling commenced in August 2013.
- ❒ Wingecarribee River downstream of mine adit discharge at Black Bob's confluence, referred to below as Downstream.

Samples were taken from the same sites in November 2018 and 2019 to observe any changes in sediment quality over the past 6 years. Graphs 6.1 - 6.4 below show the results for Iron, Manganese, Nickel and Zinc taken as an average for 2013 and in November 2018 and 2019.

6.2.2 Localised Sediment Quality Results

Sediment samples have also been taken in concurrence with the Performance Monitoring Aquatic Ecology of the Wingecarribee River and additional samples were taken in November 2018 and 2019. These results give a more localised representation of the influence of the mine discharge on the river over shorter distances. Samples have been taken to test for the concentration of Iron, Manganese, Nickel, Zinc and Cobalt at the following sites:

- ❒ 100m upstream from the Adit Discharge (WR 100m Up)
- ❒ Approximately 300m downstream of the Adit Discharge (WR ~300m Dn)
- ❒ 1km downstream of the Adit Discharge (WR 1km Dn)
- ❒ 2km downstream of the Adit Discharge (WR 2km Dn)
- ❒ 3km downstream of the Adit Discharge (WR 3km Dn)
- ❒ Biloela approximately 6km downstream (Biloela ~ 6km Dn)

6.2.3 River Load

In order to determine the fate of minerals discharged from the mine, water quality and flow data was used to estimate mineral load, changes in concentration of minerals in sediments and to determine the effect of river flow.

The total mineral loads predicted to discharge from the mine adit are presented as a calculation of the average monthly mine discharge volume (taken from the V Notch Weir site) multiplied by the mineral concentration each month. This can be used to calculate the load actually leaving the mine and enables tracking of the minerals between sediment and water at sites downstream of the discharge.

By multiplying a monthly average of the Wingecarribee River flow by the water concentration of metals including Iron, Manganese, Nickel and Zinc, the load of metals expected to be travelling downstream as well as being deposited in the sediments was calculated. The River flow volume which was measured at Macarthur's Crossing was discontinued in June 2019, therefore an average of 5 ML/Day was assumed for the second half of the year. This allowed for a comparison of water quality changes to sediment variations over time and distance upstream and downstream of the discharge point. These graphs are split into annual results for 2018 and 2019 to improve ease of interpretation.

Tables 6.1 to 6.4 at the end of the results section show total quantity of minerals removed from the discharge (retained in the mine) during 2018 when the underground water treatment system was running.

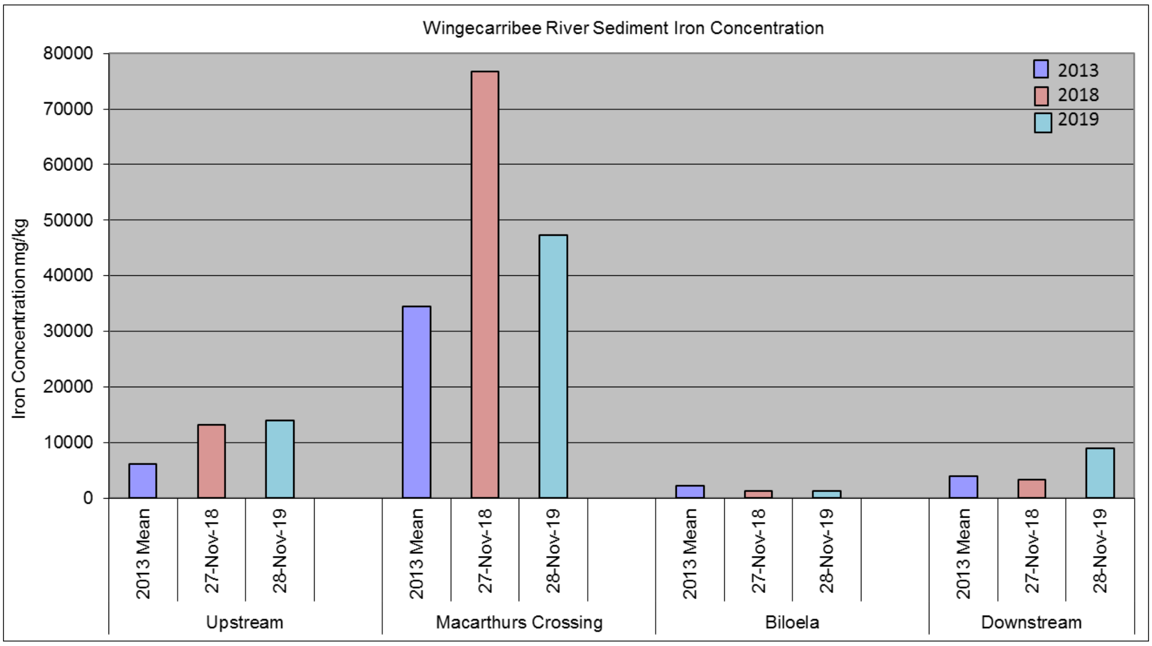
6.3 Results

The results are presented with the ambient sites first as this includes the original data set when the mine was operational. An average value noted as 2013 is used so that the more recent results obtained during the mine closure process can be more closely examined. It should be noted however that sediment results have a greater variability than water quality results. This is largely a factor of access to the river bed at the time of sampling. Although each sample is a composite made up of small amounts of sediment at each location, as the river flow changes, the actual sample points may differ slightly. Over time, the data normalises and has reached the point that clearer trends have emerged.

6.3.1 Ambient Sediment Quality Results

Iron

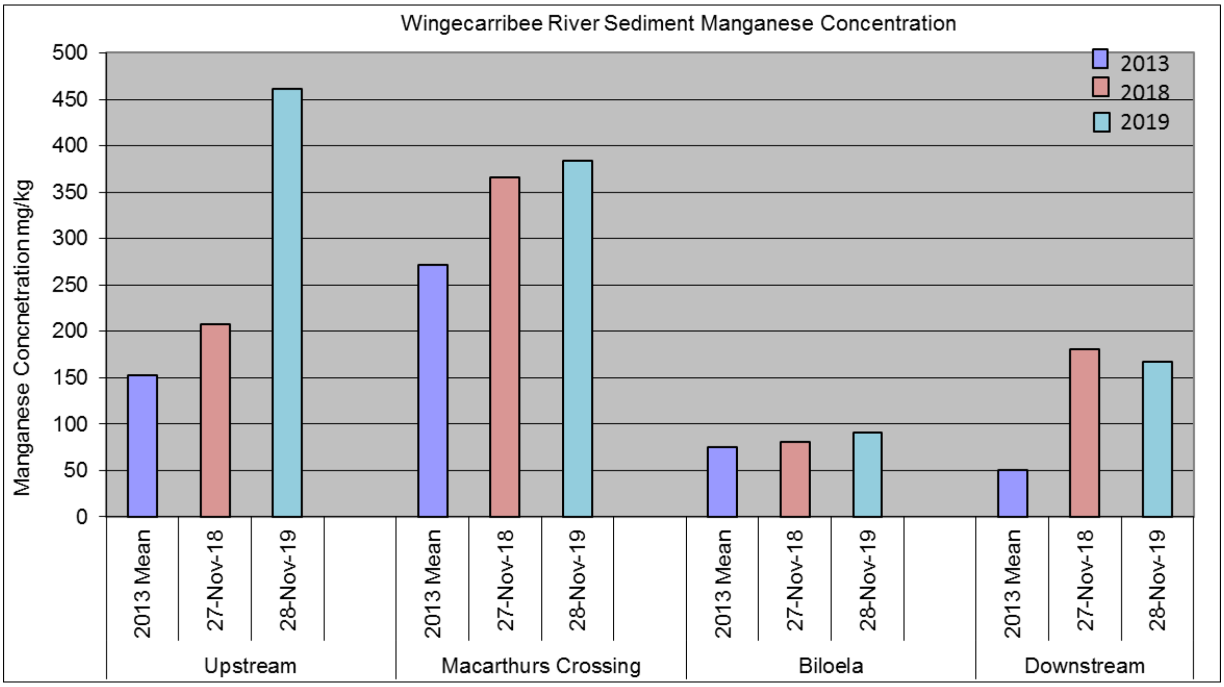
Graph 6.1 shows that the average Iron concentration at the Upstream site is 11088 mg/kg, while the average Iron was 52867 mg/kg at Macarthur's Crossing. Average Iron levels at Biloela and Downstream were much lower, at 5199 mg/kg and 5420 mg/kg respectively over the three years. The notably high levels at Macarthur's Crossing are influenced by the Hawkesbury Sandstone geology located in this area. Iron was higher at Macarthur's Crossing in 2018 than 2013, however no difference between the two time periods was observed at the other three sampling sites. Iron sediment levels fell slightly during 2019 but did not reach the lower levels recorded in 2013 (benchmark level).



Graph 6.1 Ambient Sediment Iron Concentration

Manganese

Similar trends in sediment concentrations are observed for Manganese in Graph 6.2. The presence of the Hawkesbury Sandstone at Macarthur's Crossing has caused an increased Manganese concentration of 340 mg/km compared to 82 mg/kg at Biloela. Manganese concentrations have increased in time, with 2013 concentrations recorded as the lowest and 2019 concentrations higher than 2018. This trend is more prominent at the two upstream sites.

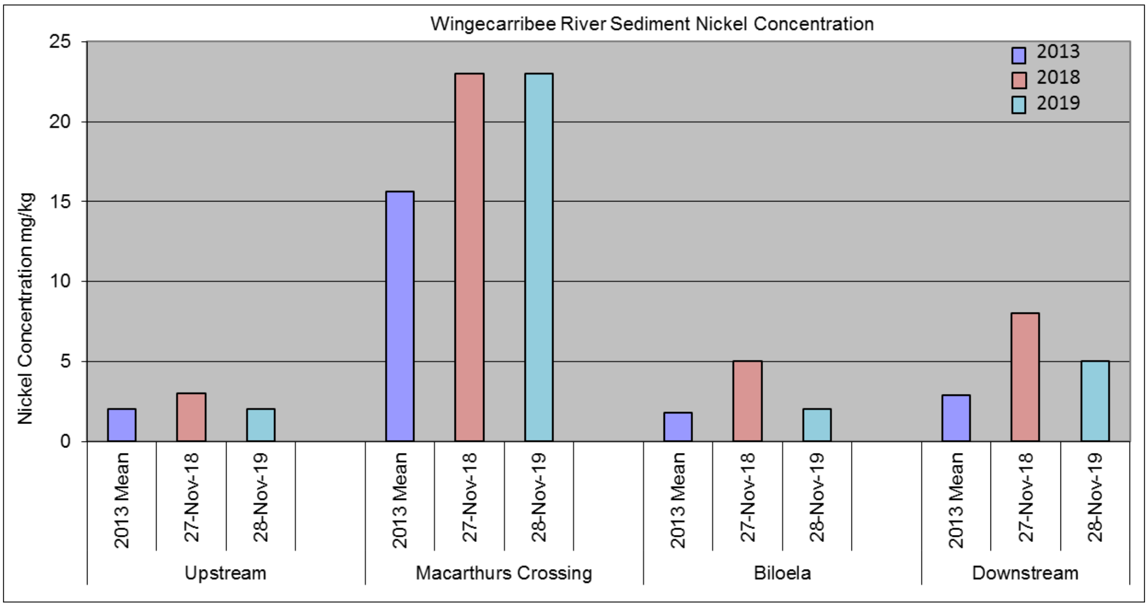


Graph 6.2 Ambient Sediment Manganese Concentration

Nickel

Again, the Macarthur's Crossing site had the highest sediment concentrations of Nickel due to its geology, with an average of 20.5 mg/kg. All other sites had average levels lower than 5.5 mg/kg.

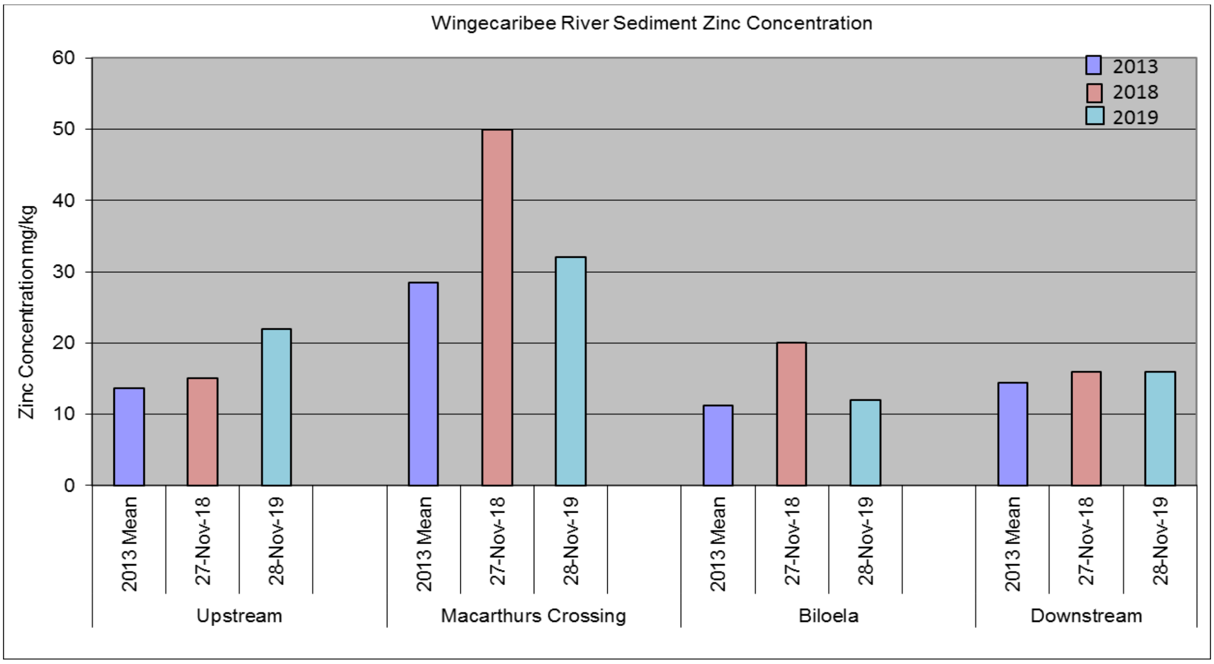
Levels of Nickel were slightly higher below the discharge point in 2018 compared to 2013. Concentrations dropped slightly during 2019 at all sites excluding WR ~300m dn where levels did not change (Graph 6.3).



Graph 6.3 Ambient Sediment Nickel Concentration

Zinc

The concentration of Zinc at Macarthur's Crossing was 36.8 mg/kg which is twice as high as the average concentration of Zinc at the other three sampling sites. From Graph 6.4 it can also be seen that the levels of Zinc at Macarthur's Crossing in 2018, reaching 50 mg/kg, were higher than in 2013, but dropped again in 2019. The concentration of Zinc below the discharge point at Biloela was slightly higher in 2018 compared with 2013 and 2019 but were still well below the upstream site at Macarthur's Crossing.

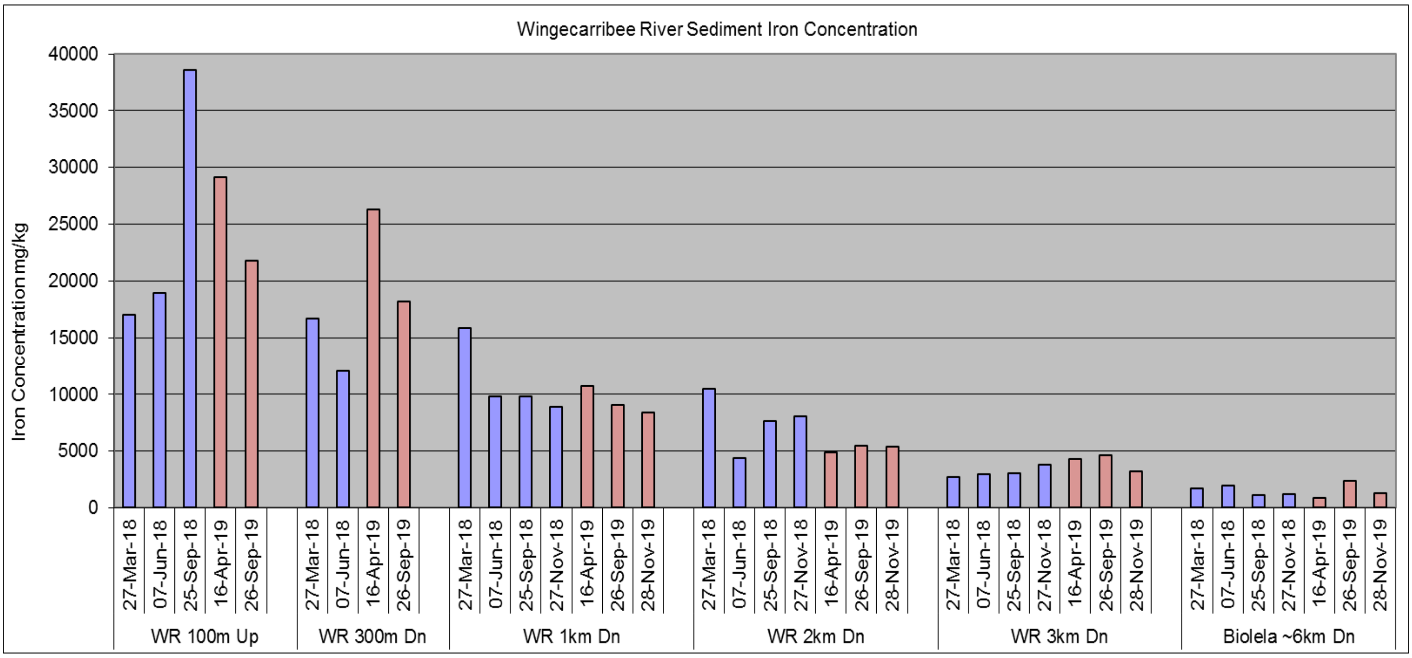


Graph 6.4 Ambient Sediment Zinc Concentration

6.3.2 Localised Sediment Quality Results

Iron

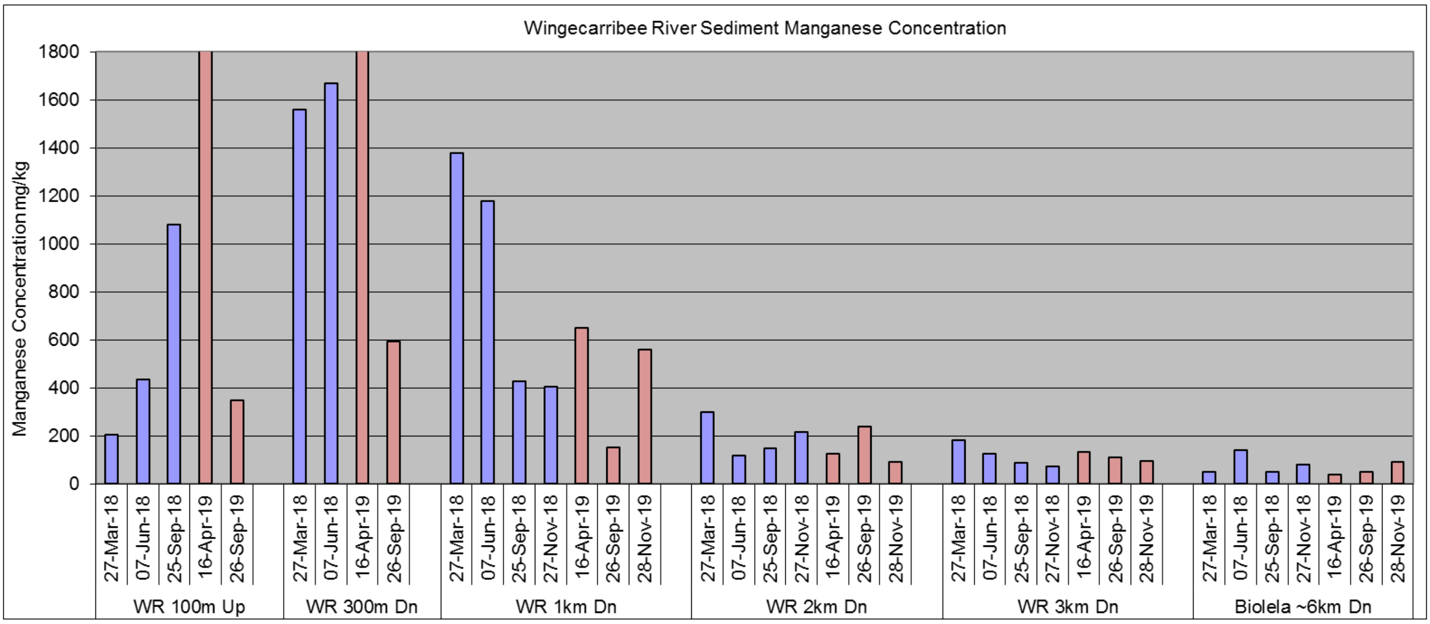
Graph 6.5 shows that the level of Iron contained in the river sediment gradually declines going downstream. The average Iron levels over the past two years start at 25,800 mg/kg at WR 100m up and drops to 1,517 mg/kg at Biloela. The Iron levels have remained relatively stable from 2018 to 2019, with only a small increase from an annual average of 9370 mg/kg to 9745 mg/kg. Since Iron is highest at the site above the adit discharge point, it shows that Iron is contained in the sediment from alternative sources other than the discharge. There is visible evidence of Iron in the surface sediments just below the discharge point which gradually reduces with distance downstream. This gradual progression is shown below in Graph 6.5.



Graph 6.5 Localised Sediment Iron Concentration

Manganese

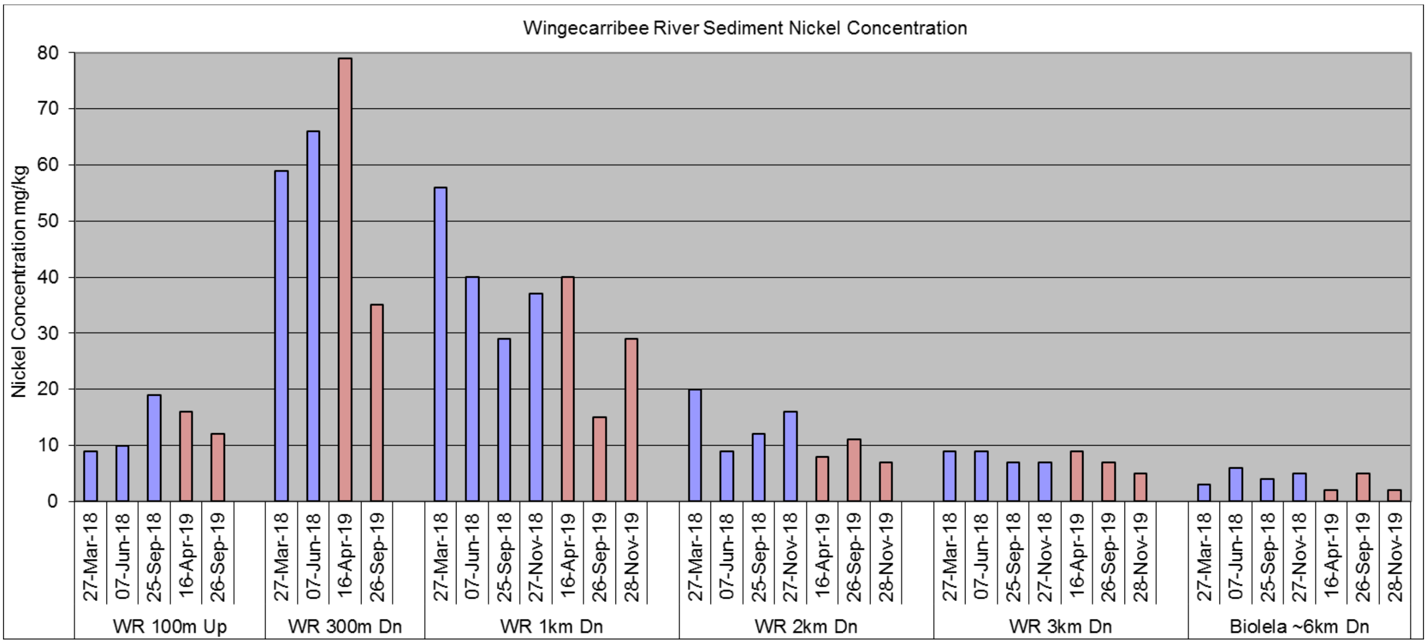
Manganese concentrations are highest at sampling sites WR 100m up and WR ~300m dn, with average concentrations of 846 mg/kg and 1,626 mg/kg respectively. Levels decline progressively moving away from the discharge point, however levels are higher at WR 100m up than at WR 1km dn, WR 2km dn, WR 3km dn and Biloela. There is visible evidence of Manganese deposition within the mixing zone and the results of the sediment analysis correspond well with the water quality results from the same locations.



Graph 6.6 Localised Sediment Manganese Concentration

Nickel

Graph 6.7 shows that sediment concentrations of Nickel follow a similar trend to Manganese levels. Nickel was highest over 2018 and 2019 at WR ~300m dn with an average of 60 mg/kg followed by WR 1km dn with an average of 35 mg/kg. The four remaining sampling sites had averages below 15 mg/kg. The annual average sediment Nickel concentration dropped slightly from 2018 to 2019, with averages over all sites of 21 mg/kg and 17 mg/kg respectively. These results also correspond to water quality results presented in Chapter 3.

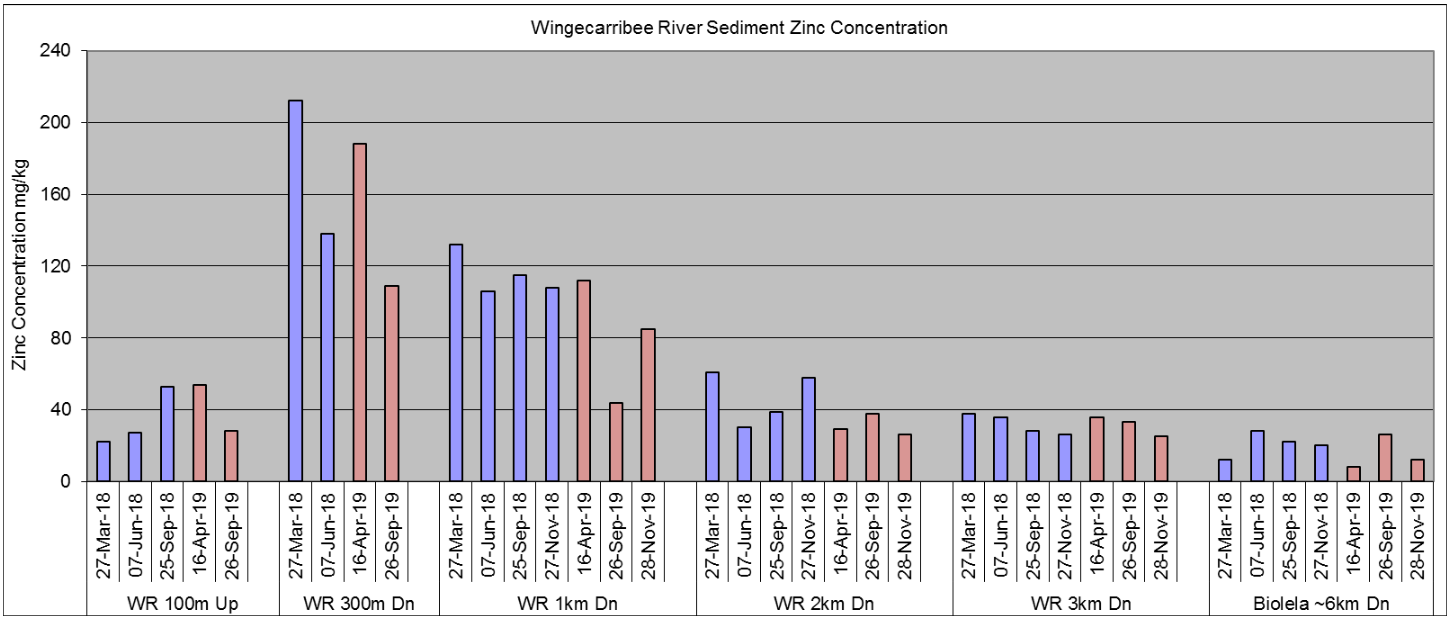


Graph 6.7 Localised Sediment Nickel Concentration

Zinc

Graph 6.8 shows the Zinc concentrations at the Performance Monitoring sites during 2018 and 2019. The average Zinc deposition at WR ~300m dn was 161 mg/kg, while the average at WR

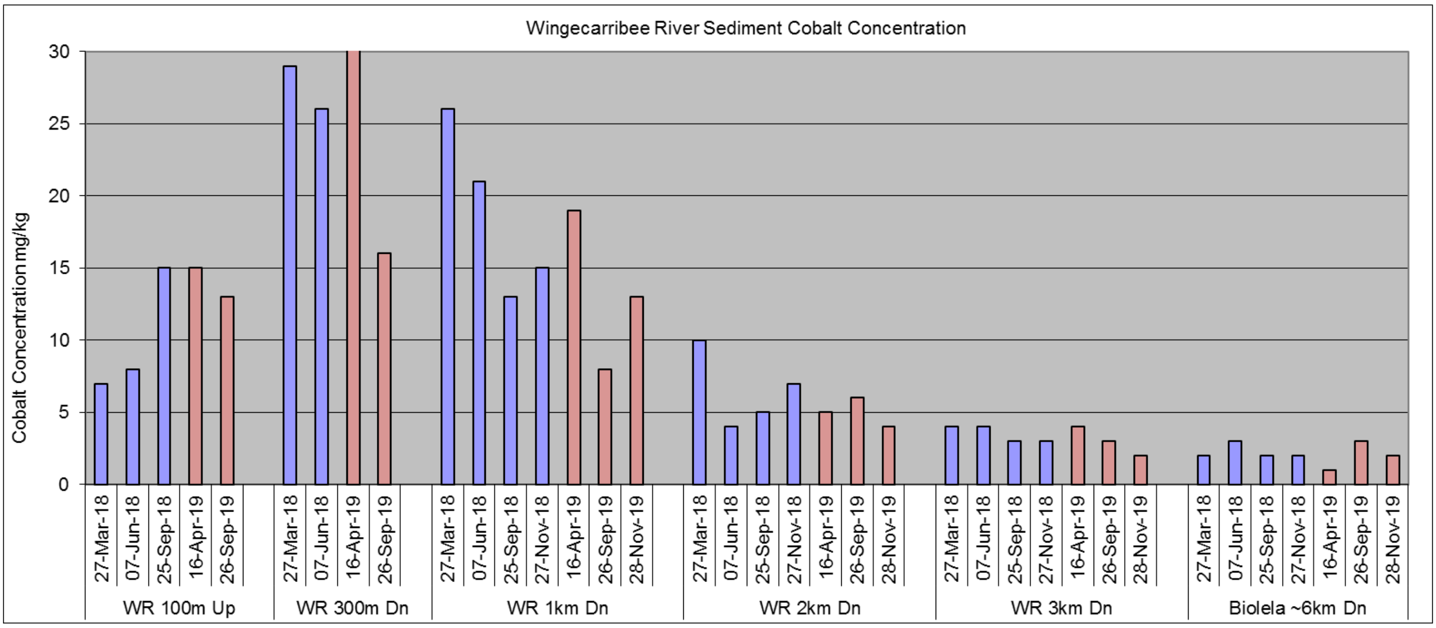
1km dn was 100 mg/kg. The averages for the other four sites fell below 50 mg/kg. The variance in Zinc concentrations were higher than would have been expected from the corresponding water quality results which indicate that the Zinc has formed a stable sediment and is not bioavailable.



Graph 6.8 Localised Sediment Zinc Concentration

Cobalt

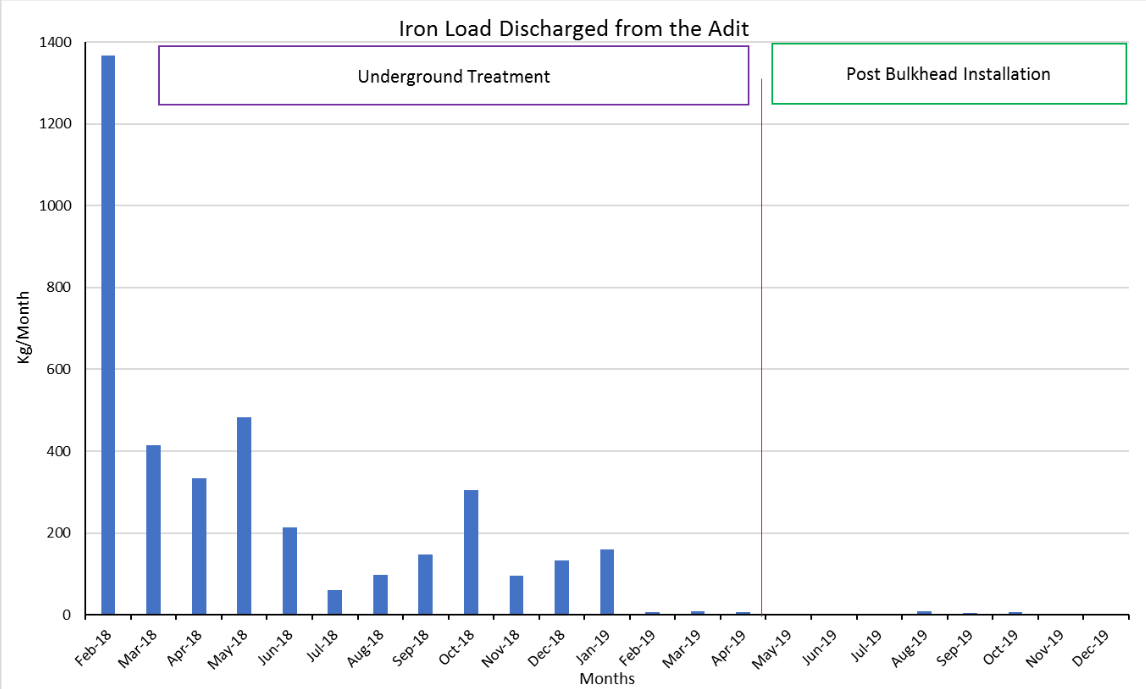
The same trends were observed for Cobalt as other metals, with averages at WR ~300m dn and WR 1km dn of 29.5 mg/kg and 16 mg/kg respectively, with Cobalt concentrations at these sites three and two-fold higher than the other sampling locations. There was no change in the annual average sediment Cobalt concentrations during 2018 and 2019 (Graph 6.9).



Graph 6.9 Localised Sediment Cobalt Concentration

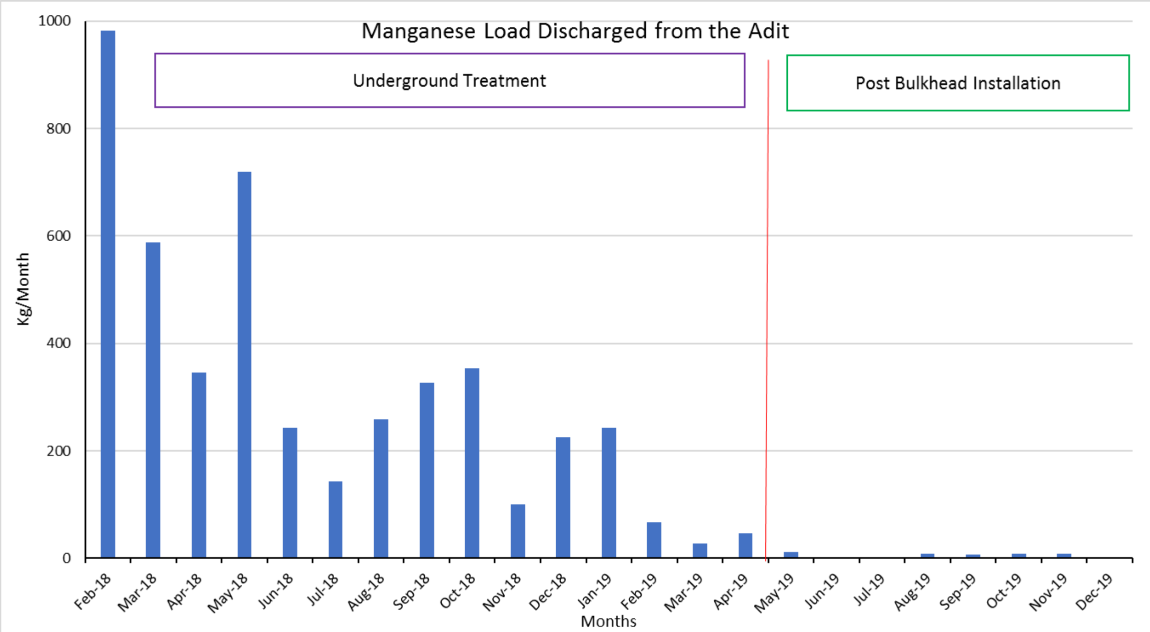
6.3.3 River Load

The Iron loads discharged from the mine adit have declined progressively over the past two years (Graph 6.10). The highest load was in February 2018 at 1367 kg/month. From March 2018 through until January 2019, the average of the Iron discharge load was 222 kg/month with a range from 60 kg/month to 482 kg/month. Levels dropped substantially from February 2019 with Iron concentrations remaining below 8.79 kg/month for the remainder of the year. The recommencement of underground treatment of water pumped from behind the bulkheads is expected to increase discharge load, largely a result of the volume of water being discharged.



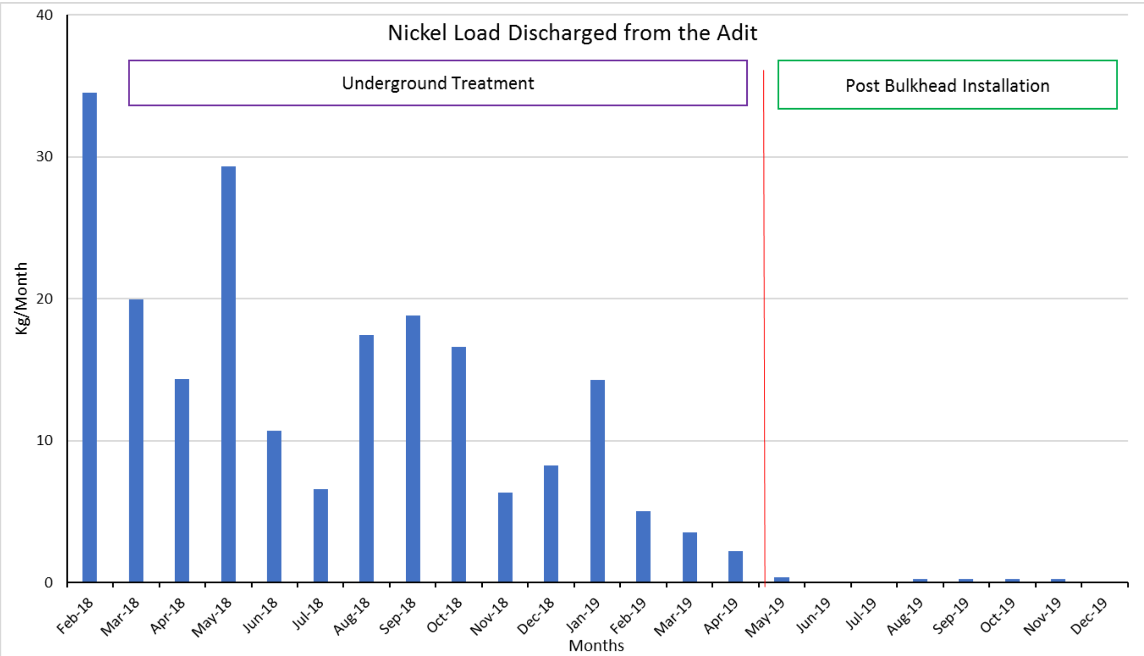
Graph 6.10 Iron Load Discharged from the Adit

Graph 6.11 shows the monthly Manganese loads discharged from the Adit during 2018 and 2019. The load was highest in February 2018 at 982 kg/month. The Manganese load fluctuated between 100 kg/month and 719 kg/month during 2018 with a progressive decrease over time. The Manganese load decreased further with the installation of the bulkheads in May 2019 limiting the water discharged from the Colliery. Concentrations from May to December 2019 were an average of 6.77 kg/month.



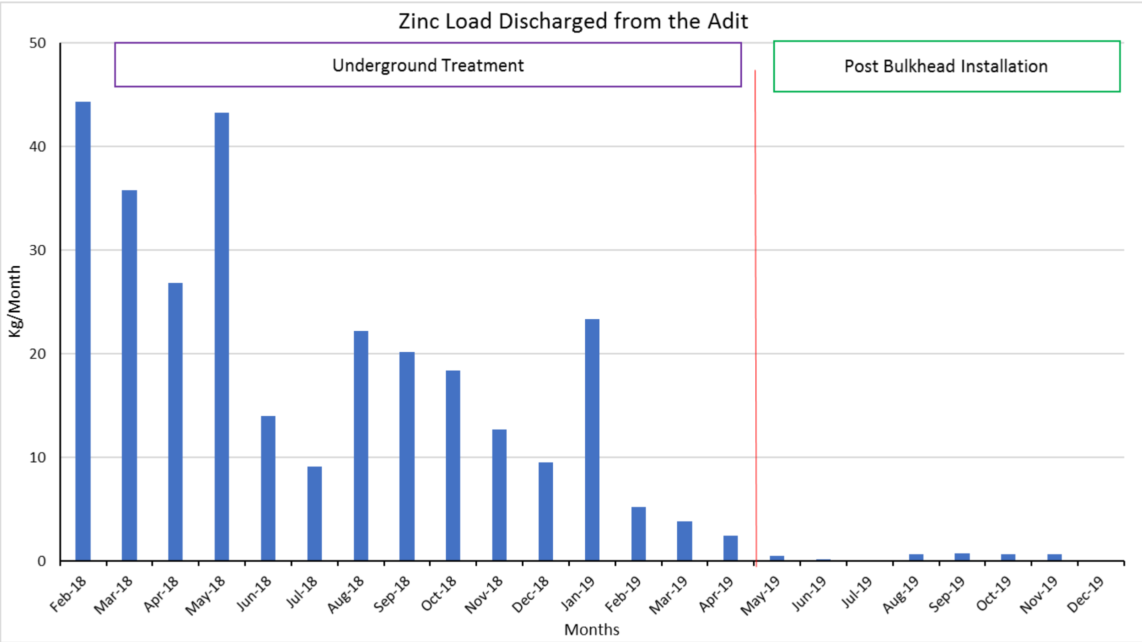
Graph 6.11 Manganese Load Discharged from the Adit

The highest Nickel load was calculated in February 2018 at 34.5 kg/month, followed by May 2018 with a concentration of 29.3 kg/month. The remainder of the monthly loads in 2018 remained below 20 kg/month. As seen for the loads of Iron and Manganese above, there is a significant decrease in Nickel loads from May 2019 when the bulkheads were installed. Graph 6.12 below shows that the Nickel loads range from 0.06 kg/month to 2.23 kg/month during the second half of 2019.



Graph 6.12 Nickel Load Discharged from the Adit

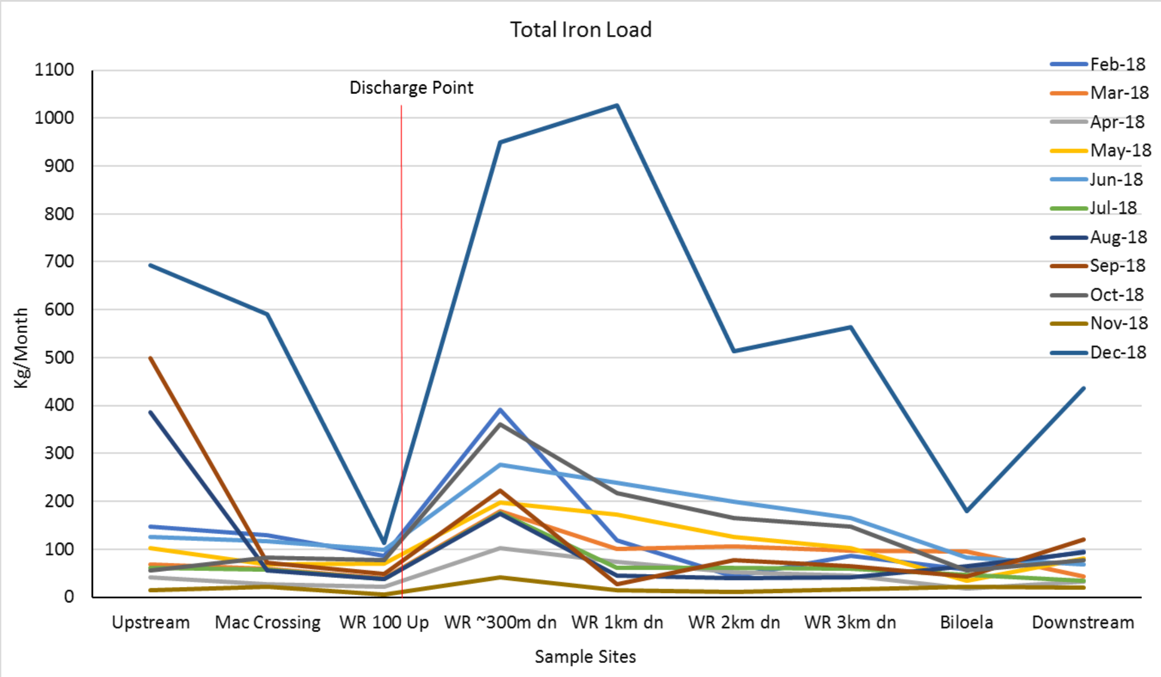
The same trend can be seen in the Zinc load discharged from the adit in Graph 6.13 below. The highest concentration in February 2018 is 44.4 kg/month, with an average of 23.3 kg/month during 2018. Zinc load levels range from 2.5 kg/month to 23.3 kg/month in the first quarter of 2019. The load concentrations drop significantly in May 2019 and remain below 0.7 kg/month for the remainder of the year, with an average of 0.5 kg/month during this 8 month period.



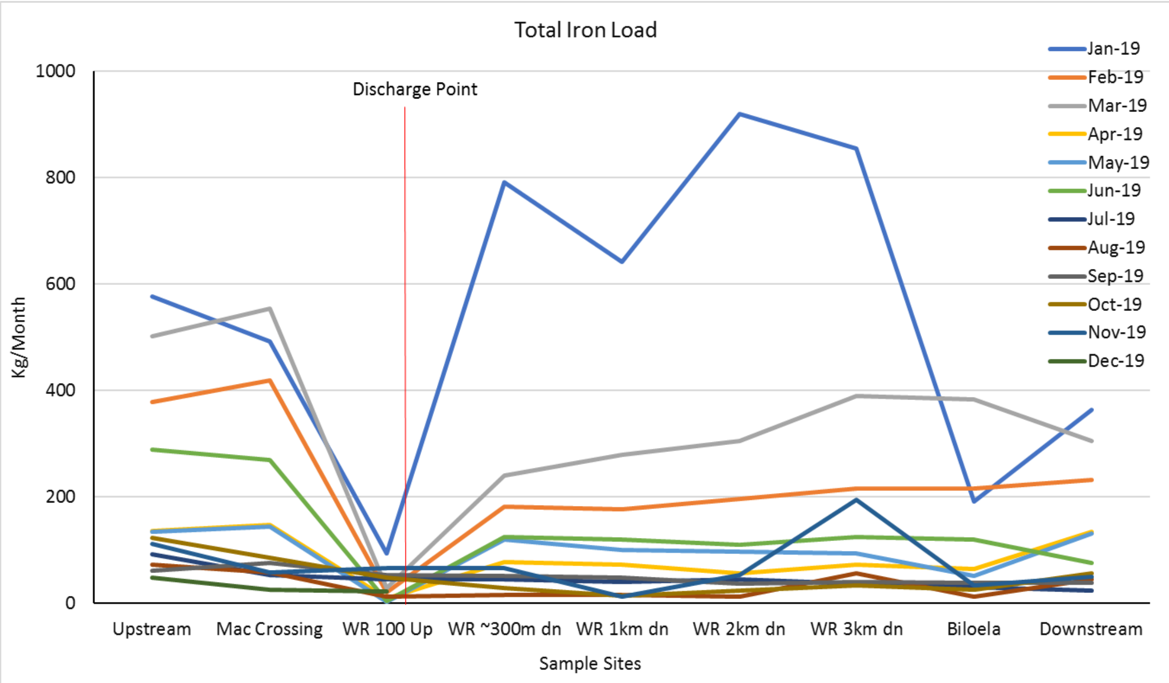
Graph 6.13 Zinc Load Discharged from the Adit

During 2018 the Iron concentrations remain relatively low, below 300 kg/month for most of the year. In Graph 6.14 below, December 2018 shows drastically higher Iron loads than all other months, with values up to four times higher at some sites. This is a result of much higher river flow which increased sediment load along the entire length of the Wingecarribee River within the study area. A high concentration of 442 kg/month was observed Upstream during September 2018. The months of December, May, June and October have greatest loads and they also follow the same trend, showing increased Iron levels at WR ~300m dn, before declining back to levels equivalent to those Upstream. This trend is less visible for the remaining months, which show lower levels of Iron at all sampling sites. The principle factor governing sediment load within the river is flow.

Iron loads remained relatively constant over the past 12 months. During 2018 the annual average Iron concentration was 140 kg/month, whereas the average Iron load in 2019 was 149 kg/month. The highest Iron loads were recorded during the first three months of 2019, which corresponded to greater volumes of river flow (Graph 6.15). From April to December, the Iron load averaged at 70 kg/month and remained below 200 kg/month.



Graph 6.14 Total Iron Load in the Wingecarribee River During 2018

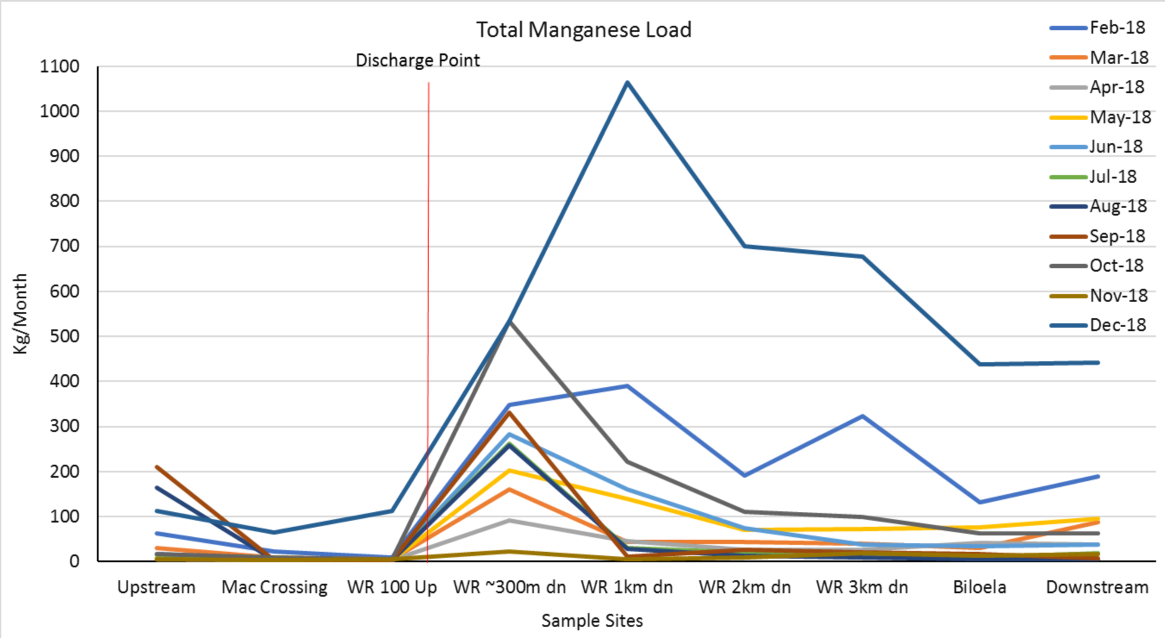


Graph 6.15 Total Iron Load in the Wingecarribee River During 2019

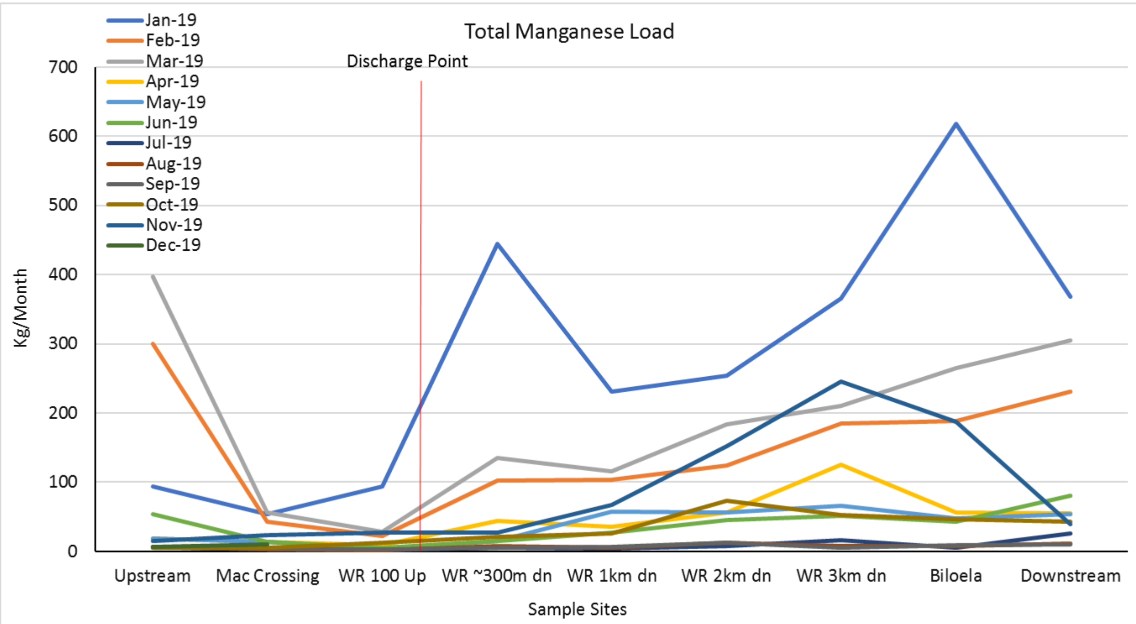
The total Manganese load in December was up to three times higher than in other months, with levels increasing to 1065 kg/month at WR 1km dn due to very high river flow. Other months also followed this trend, with an increased monthly load at sites immediately downstream of the discharge followed by a decrease back to levels similar to upstream at Biloela. Graph 6.16 below shows that all other months have low Manganese loads, averaging 118 kg/month over all sites.

A decrease in the average total Manganese load is visible from 2018 (Graph 6.16) to 2019 (Graph 6.17) with annual averages of 107 kg/month and 77 kg/month respectively. During

January, February and March in 2019 the total Manganese load progressively increases downstream of the discharge point. This trend is most visible in these months as they have an increased load up to 444 kg/month in January. This trend can indicate that the load is now less stable, as it has been transported further downstream. The peak immediately downstream of the discharge as seen in 2018 is less prominent in 2019. The Manganese load peaks at the upstream site in February and March, reaching levels of 300 and 400 kg/month. The following graph shows that from March onwards in 2019, months have low Manganese loads, averaging 48 kg/month over all sites.



Graph 6.16 Total Manganese Load in the Wingecarribee River During 2018

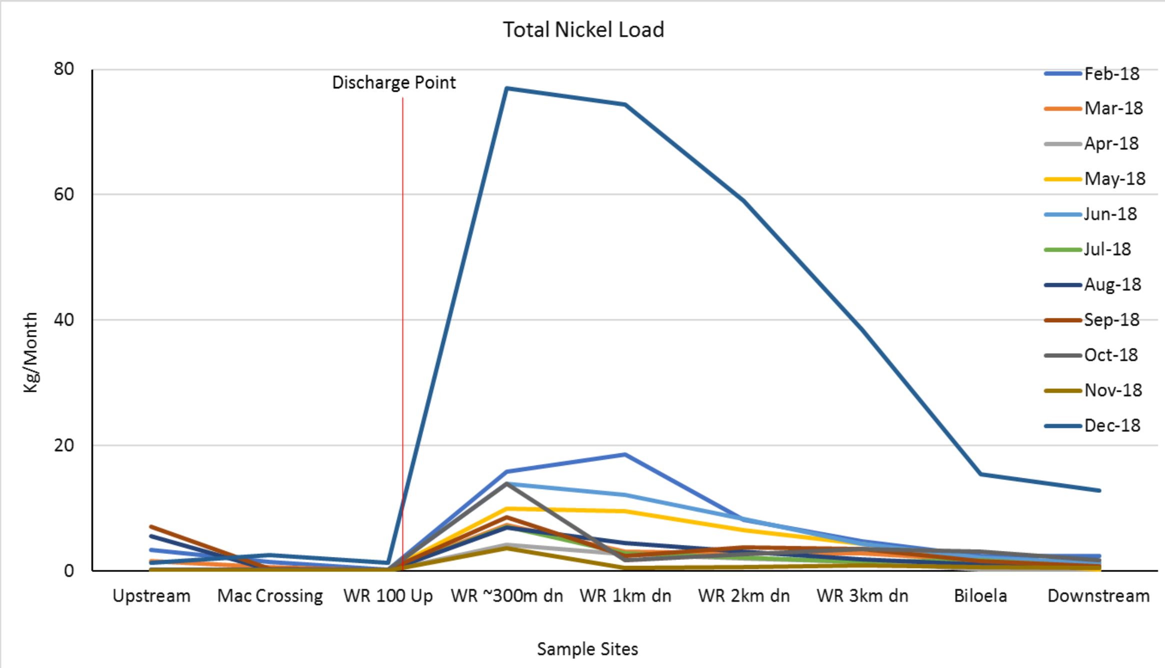


Graph 6.17 Total Manganese Load in the Wingecarribee River During 2019

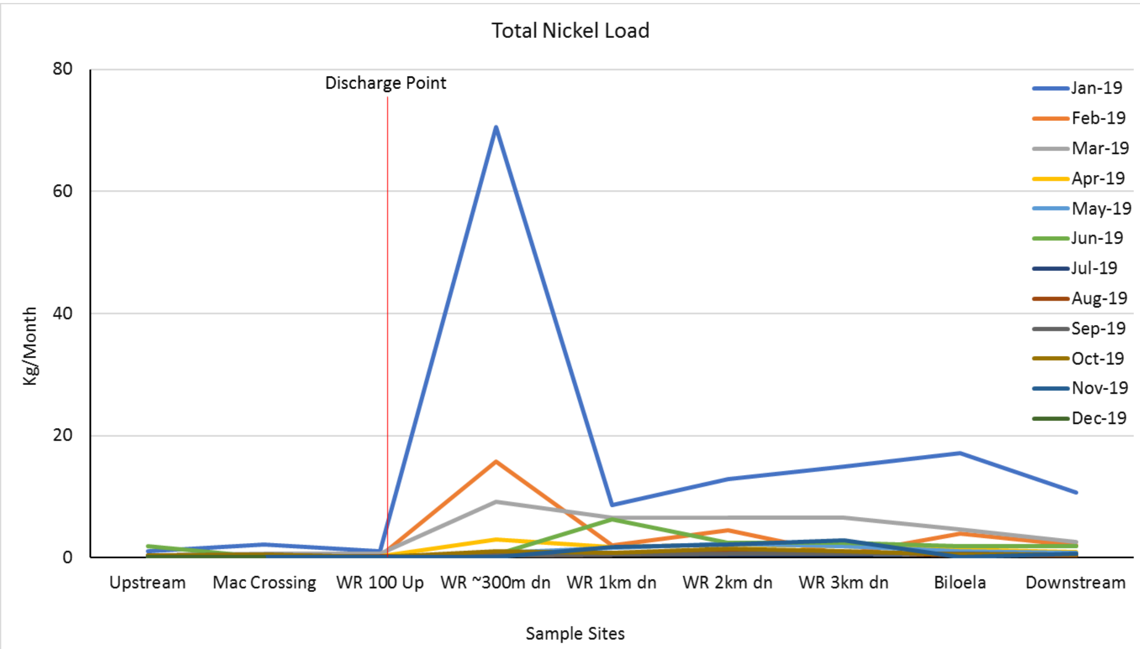
Monthly loads for Nickel are shown below in Graph 6.18. As observed for Iron and Manganese, December concentrations were significantly higher than all other months due to high river flow.

The same trend is also observed for Nickel, as greatest concentrations are recorded at WR ~300m dn, with a decline further downstream. February, June and May display similar trends to December loads, although at levels below 20 kg/month. All other months remain constantly low, with averages Nickel loads of 5.3 kg/month.

Nickel concentrations from January 2019 were the highest due to increased river flow. Nickel levels remained notably higher immediately downstream of the discharge point, although levels dropped sharply at WR 1km dn, following a similar, but more defined trend to the Nickel loads calculated from 2018. Loads of Nickel have declined over the past 12 months, with an annual average of 5.5 kg/month in 2018 to 2.6 kg/month in 2019 across all sites.



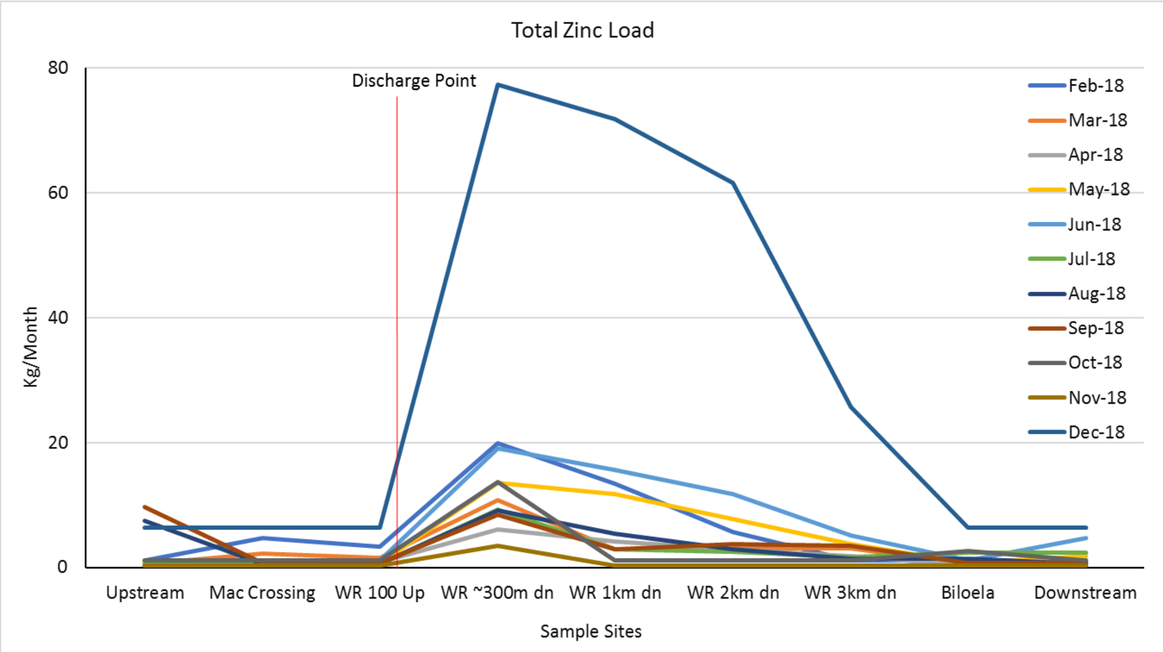
Graph 6.18 Total Nickel Load in the Wingecarribee River During 2018



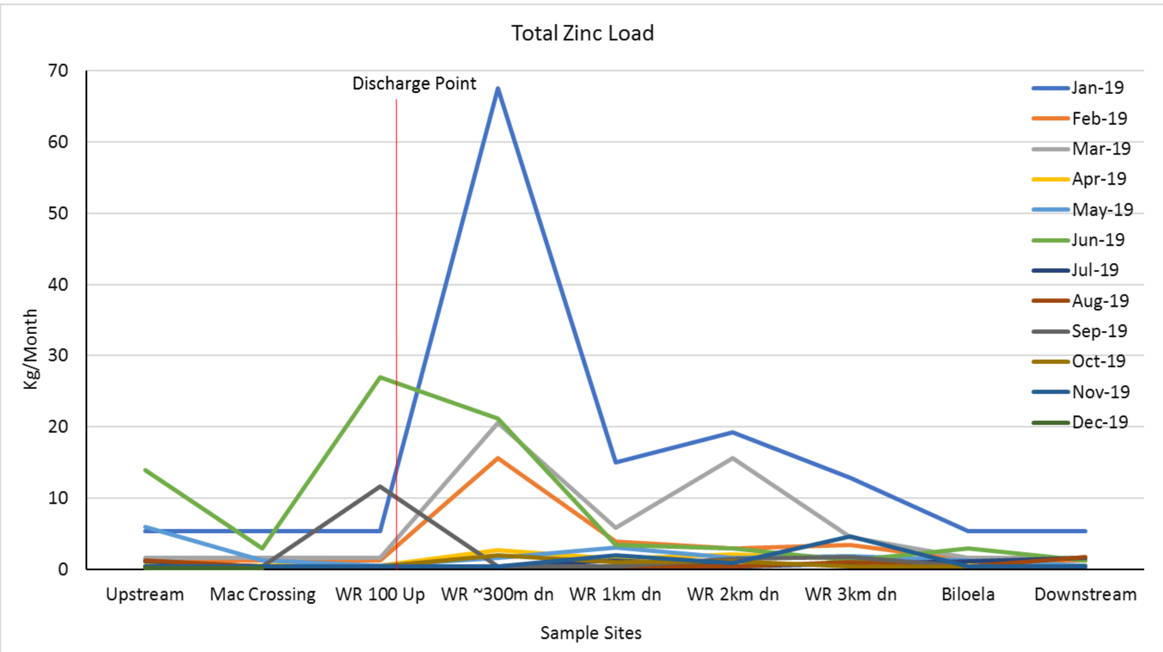
Graph 6.19 Total Nickel Load in the Wingecarribee River During 2019

The river load calculated for Zinc presented similar results to Nickel. During 2018 the Zinc loads ranged from 0.28 kg/month to 77.39 kg/month (Graph 6.20). The Zinc load is highest at the WR~300m dn site and declines further downstream. As seen previously, concentrations of Zinc were highest in December.

The Zinc load in 2019 follows the same trend, as seen in Graph 6.21. The annual average across all sites in 2018 was 5.85 kg/month, which dropped to 3.72 kg/month in 2019. The highest Zinc load was calculated at the WR~300m dn site in January at 67.6 kg/month. At the same site, the concentrations in March and June was 20.5 kg/month. From July to December 2019, the Zinc load concentration did not exceed 0.8 kg/month across all sites.



Graph 6.20 Total Zinc Load in the Wingecarribee River During 2018



Graph 6.21 Total Zinc Load in the Wingecarribee River During 2019

Table 6.1 Iron (Total)

Date	Vol water ML for period	Initial sediment load, 400 D12	Sediment Retention before 400 C8	Remaining load at 400 C8	Sediment retained prior to Discharge	Discharge load	Total load retained in mine (Kg)
15/02/2018 - 21/02/2018	19.23	159.22	154.61	4.62	-297.30	301.91	
22/02/2018 - 14/03/2018	48.15	449.72	447.31	2.41	-313.46	315.86	
15/03/2018 - 25/04/2018	73.49	700.36	696.69	3.67	-491.65	495.32	
26/04/2018 - 2/05/2018	13.30	214.13	213.47	0.67	-52.27	52.93	
3/05/2018 - 13/05/2018	34.98	538.69	536.94	1.75	-103.89	105.64	
14/05/2018 - 30/05/2018	57.76	854.85	851.96	2.89	-102.24	105.12	
31/05/2018 - 27/06/2018	57.99	1072.82	1069.92	2.90	-189.63	192.53	
28/06/2018 - 25/07/2018	49.70	964.18	959.71	4.47	-138.66	143.14	
26/07/2018 - 27/08/2018	123.55	2347.45	2341.27	6.18	-113.67	119.84	
28/08/2018 - 24/09/2018	123.02	1869.90	1863.75	6.15	-141.47	147.62	
25/09/2018 - 29/10/2018	75.99	1565.39	1561.59	3.80	-301.68	305.48	
30/10/2018 - 26/11/2018	52.26	600.99	598.38	2.61	-93.55	96.16	
Total to date (Kg)	710.19	11337.71	11295.60	42.11	-2339.45	2381.56	8956.15

Table 6.2 Manganese (Total)

Date	Vol water ML for period	Initial sediment load, 400 D12	Sediment Retention before 400 C8	Remaining load at 400 C8	Sediment retained prior to Discharge	Discharge load	Total load retained in mine (Kg)
15/02/2018 - 21/02/2018	19.23	97.11	-1.35	98.46	-83.65	182.11	
22/02/2018 - 14/03/2018	48.15	246.53	63.56	182.97	-187.30	370.27	
15/03/2018 - 25/04/2018	73.49	238.84	13.96	224.88	-340.26	565.14	
26/04/2018 - 2/05/2018	13.30	110.12	41.76	68.36	-10.64	79.00	
3/05/2018 - 13/05/2018	34.98	99.48	-70.17	169.65	-15.39	185.04	
14/05/2018 - 30/05/2018	57.76	367.35	114.36	252.99	-5.78	258.76	
31/05/2018 - 27/06/2018	57.99	423.33	248.78	174.55	-118.88	293.43	
28/06/2018 - 25/07/2018	49.70	381.70	278.82	102.88	-98.90	201.78	
26/07/2018 - 27/08/2018	123.55	1006.93	743.77	263.16	4.94	258.22	
28/08/2018 - 24/09/2018	123.02	885.74	605.26	280.49	-45.52	326.00	
25/09/2018 - 29/10/2018	75.99	715.83	542.57	173.26	-180.86	354.11	
30/10/2018 - 26/11/2018	52.26	434.80	433.91	0.89	-98.93	99.82	
Total to date (Kg)	729.42	5007.77	3015.24	1992.53	-1181.16	3173.69	1834.08

Table 6.3 Nickel (Total)

Date	Vol water ML for period	Initial sediment load, 400 D12	Sediment Retention before 400 C8	Remaining load at 400 C8	Sediment retained prior to Discharge	Discharge load	Total load retained in mine (Kg)
15/02/2018 - 21/02/2018	19.23	4.37	-0.21	4.58	-3.60	8.17	
22/02/2018 - 14/03/2018	48.15	12.04	3.90	8.14	-8.04	16.18	
15/03/2018 - 25/04/2018	73.49	13.52	2.94	10.58	-9.70	20.28	
26/04/2018 - 2/05/2018	13.30	3.56	1.50	2.06	-1.16	3.22	
3/05/2018 - 13/05/2018	34.98	3.59	-1.90	5.49	-1.05	6.54	
14/05/2018 - 30/05/2018	57.76	13.34	3.64	9.70	-0.75	10.45	
31/05/2018 - 27/06/2018	57.99	15.38	7.15	8.23	-3.60	11.83	
28/06/2018 - 25/07/2018	49.70	12.92	5.37	7.55	-1.39	8.95	
26/07/2018 - 27/08/2018	123.55	33.61	10.87	22.73	5.31	17.42	
28/08/2018 - 24/09/2018	123.02	29.28	7.26	22.02	3.20	18.82	
25/09/2018 - 29/10/2018	75.99	23.10	9.12	13.98	-2.66	16.64	
30/10/2018 - 26/11/2018	52.26	12.70	12.33	0.37	-5.96	6.32	
Total to date (Kg)	729.42	177.40	61.96	115.44	-29.39	144.83	32.57

Table 6.4 Zinc (Total)

Date	Vol water ML for period	Initial sediment load, 400 D12	Sediment Retention before 400 C8	Remaining load at 400 C8	Sediment retained prior to Discharge	Discharge load	Total load retained in mine (Kg)
15/02/2018 - 21/02/2018	19.23	13.46	-0.17	13.63	-1.63	15.27	
22/02/2018 - 14/03/2018	48.15	37.17	15.46	21.72	-14.83	36.55	
15/03/2018 - 25/04/2018	73.49	41.23	18.59	22.63	-12.13	34.76	
26/04/2018 - 2/05/2018	13.30	4.60	2.50	2.10	-2.65	4.75	
3/05/2018 - 13/05/2018	34.98	4.40	-13.65	18.05	9.34	8.71	
14/05/2018 - 30/05/2018	57.76	15.65	6.87	8.78	-5.14	13.92	
31/05/2018 - 27/06/2018	57.99	18.02	10.08	7.94	-8.06	16.01	
28/06/2018 - 25/07/2018	49.70	17.84	10.74	7.11	-4.13	11.23	
26/07/2018 - 27/08/2018	123.55	46.21	24.22	21.99	-0.25	22.24	
28/08/2018 - 24/09/2018	123.02	37.03	15.62	21.41	1.23	20.18	
25/09/2018 - 29/10/2018	75.99	33.82	20.59	13.22	-5.17	18.39	
30/10/2018 - 26/11/2018	52.26	17.98	17.04	0.94	-11.76	12.70	
Total to date (Kg)	729.42	287.42	127.89	159.53	-55.17	214.69	72.72

6.4 Discussion

6.4.1 Ambient Sediment Quality

Generally, there are higher concentrations of Iron, Manganese, Nickel and Zinc in the river sediments upstream of the discharge point compared with the downstream sites. It can also be noted that the higher levels upstream occur once the river passes into the Hawkesbury Sandstone geological sequence at Macarthur's Crossing. The levels at the Upstream site are generally not as elevated but are still often slightly higher than the majority of samples taken at the two downstream sites.

Trends show that concentrations of all four metals tested have remained relatively constant from 2013 to 2018 and 2019. These three years were all very dry, contributing to low river flow which can lead to greater deposition of metals. The increase in sediment load when the mine commenced free draining can be detected, but the overall impact is minor compared to naturally occurring mineral levels at the upstream Macarthur's Crossing site.

The results show that the minerals discharged from the mine did not have an influence on sediment concentration over a broad area of the Wingecarribee River in 2013 but could be detected downstream of the discharge point in 2018. Metal concentrations are often slightly reduced in 2019 compared to 2018, which could be a result of the effectiveness of the underground treatment system as well as the limited discharge from mid-2019 due to the bulkhead installation. The results also suggest that the higher concentrations occur naturally and are a result of geological factors.

6.4.2 Localised Sediment Quality

The data demonstrates the influence of geology on river sediments but also shows variations outside these factors which can be caused by localised mineral deposition. With generally higher concentrations upstream, it is logical to assume that this contributes to the sediment load below the discharge point, particularly during high flow events. Historic data also suggests that flushing events move mineralised sediment from the Ambient upstream sites though the mixing zone to downstream areas. This can influence the results, given the higher mineralised sediments which occur at Macarthur's Crossing.

Sediment load below the adit discharge at the sites WR ~300m dn and WR 1km dn still reflects the higher discharge of metals which occurred in the mixing zone during the initial closure process, that is, when the mine flooded and first free drained prior to the underground treatment. The high sediment load immediately below the adit discharge may also be having a longer term influence on water quality within the mixing zone, which may have influenced more recent water quality results. The high metal concentration in the sediments is also a function of the very low rainfall prevailing over the past two years. This is likely the result of increased mineral concentration within the discharge water between the commencement of the mine free draining and the implementation of the underground treatment system. The movement of the built-up sediments to further downstream is unlikely to occur without several large flushing event in the river. The first large flow event in two years occurred in February 2020, the results of which may be detected in any future monitoring work.

6.4.3 River Load

The data indicates that river load is highly dependent on river flow. However, it also shows that sediment deposited immediately below the discharge point has not yet moved further downstream. This is likely the result of the prevailing drought conditions and the lack of flushing events. The data correlates with visual evidence of mineral deposition within the immediate mixing zone, but equally corresponds to visible iron staining at Macarthur's Crossing. The difference being that the high metal bearing outcrops of Upper Hawkesbury Sandstone at Macarthur's Crossing is natural whereas the mineral deposits within the mixing zone are not. The visual Iron staining downstream of the discharge point was considerably less during 2019, which is reflected by the sediment load results.

The highest river load occurred in December 2018 and January 2019 after a modest increase in rain but also corresponded to the period of water transfer from the Wingecarribee River by WaterNSW. The river load increased by a factor of up to four times higher than other months. December and January had average river flows of 89 ML/Day and 36 ML/Day respectively, compared to annual flow averages of 18 ML/Day in 2018 and 11 ML/Day in 2019.

Low rainfall and subsequent river flow have been experienced within the Wingecarribee River for the last few years. Although this can be identified as a cause for a build-up in sediments within the mixing zone, the more obvious cause was the increase in discharge concentration of minerals during free draining prior to the installation of the underground water treatment system. The lack of flushing events since this build-up has enabled these sediments to persist over the 2018 to 2019 period. At the time of this report, river flow had increased as a result of heavy rainfall in early February 2020. Sediment data following this event has not yet been obtained.

Given the prevailing drought conditions over 2018 to 2019, the river load at Biloela and the downstream site have been lower than upstream sites. This is generally considered a result of precipitation of the minerals within the mixing zone which have yet to be transported downstream.

6.5 Conclusion

From this study, it can be concluded that:

- The quality of sediments that naturally occur along the Wingecarribee River is largely dependant on geology. The concentration of Iron and Manganese is significantly higher at Macarthur's Crossing that Biloela. However, there is a definable spike in minerals just downstream of the mine discharge.
- The minerals within the mixing zone sediments progressively decrease downstream and have not as yet impacted on sites outside the mixing zone at Biloela and the Downstream Site which is at the Black Bobs Creek confluence.

- There has been a gradual improvement in sediment quality within the mixing zone over the past two years however there are still higher mineral concentrations occurring just below the mine discharge point compared to historic levels or what would be expected to occur due to geology or normal sediment load within the river.
- The mineral load within the river are greater at shorter distances downstream of the discharge point, however concentrations quickly return to levels similar to upstream sites further away from the mixing zone of the mine discharge. This shows that the impact of the mine discharge still remains within the mixing zone under the prevailing low flow conditions.

The December 2018 and January 2019 results indicate the primary cause of high river load is flow. With heavy rainfall and increased flow, deposited minerals will move further downstream and will eventually dissipate within the natural sediments. The discharged minerals are essentially the same as the prevailing sandstone geology and the concentrations found within the mixing zone are still below that found at Macarthur's Crossing. However given that the deposited minerals within the mixing zone are still above the historic levels occurring in this location, there would be a measurable impact on both water quality and aquatic ecology in this location.

This data conforms with the water quality analysis, aquatic ecology and ecotoxicological assessments from previous chapters.

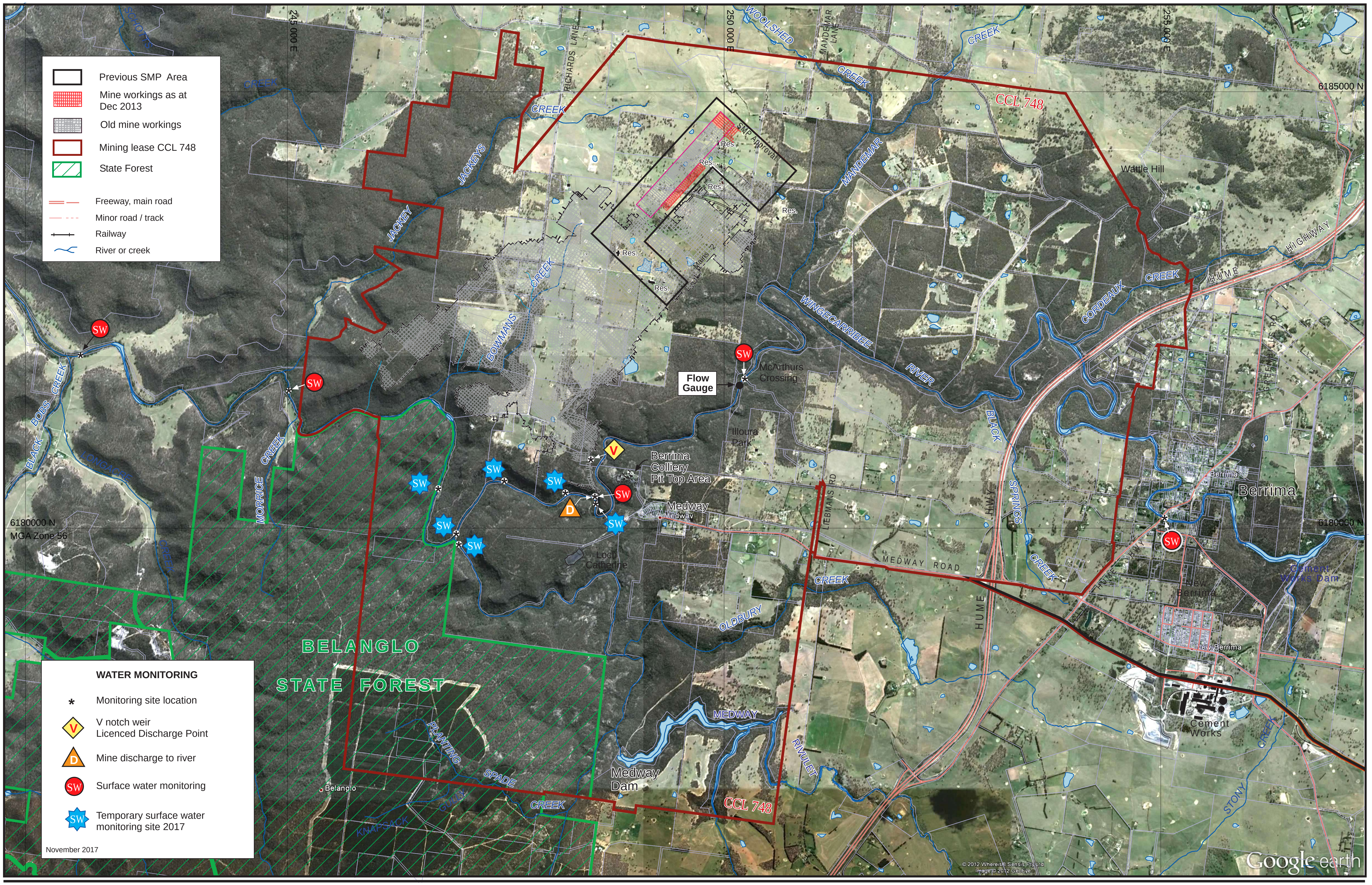
7. Conclusion

This study represents the culmination of the investigations undertaken in 2018 and 2019. It includes a comparison with similar studies undertaken prior to 2013 when the mine was operational. The data indicates the following:

- Water quality discharged from the mine progressively improved during 2018 with the implementation of the underground water treatment system.
- Discharge quality in 2019 prior to the installation of the bulkheads was very similar to the long term average water quality discharged from the mine. This indicates that the underground treatment system was ultimately successful in treating the mine water to equivalent standards as the long term discharge from the mine.
- The quality of water at the Biloela Site meets ANZECC guidelines for 95% ecosystem protection and recreational water.
- The ecology of the river in 2018 and 2019 is comparable to the time when the mine was operational however studies undertaken in 2017 prior to the implementation of underground water treatment system showed a significant reduction in ecological health within the mixing zone.
- The ecotoxicological testing showed that the water within the mixing zone has improved between 2017 and 2019 but is below the levels found in 2013 when the mine was operating.
- Given the prevailing drought conditions over 2018 and 2019, the build-up of minerals within the mixing zone have not yet moved further downstream. Recent high river flow in early 2020 may have commenced the movement of sediments from the mixing zone however it is anticipated that several flushing events will be needed before the mixing zone is comparable to the pre 2013 conditions.
- River load is highly dependent on flow however some sediment movement occurred in late 2018 and early 2019, which was probably more related to water releases from the Wingecarribee Reservoir than natural flow.
- Water quality within the mixing zone has improved over the two year period covered by this report and its consequences on river health have started to show positive signs of improvement. However, it is considered that the main issue is the build up of mineralised sediment within the mixing zone which has not yet dissipated.

Robert Byrnes
Director
International Environmental Consultants Pty Limited

Appendix A - Plans



0 1000 2000 m

N

FIGURE 1
Berrima Colliery
Water Monitoring Sites

Datum: GDA 94 MGA Zone 56

0 250 500 metres

N

FIGURE 2
Berrima Colliery
Water Sampling Sites Detail

Appendix B – References

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