ATTACHMENT 7

Review of revised Dendrobium Mine Extension Project

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Executive summary

The revised Dendrobium Extension Project is likely to cause damage to surface waterways from longwall subsidence that causes water quality and ecological impacts, of a greater scale than is predicted in the EIS documents. I am concerned that subsidence damage to stream channels may not be effectively repairable. Previous coal mining activity in Sydney's Drinking Water Catchments have already caused considerable damage. The Dendrobium Extension Project, if approved, is also likely to also generate an increased volume of wastewater that is to be disposed into Allans Creek, flowing to Port Kembla Estuary. Inadequate information on the impact of the waste discharge (current and predicted future) on Allans Creek, and further downstream to the estuary, was provided in the EIS on this discharge. This is a major omission as sediment in Port Kembla Harbour and Allans Creek are known to be historically contaminated with hazardous concentrations of metals.

I have prepared this report in conformance with Part 31 Division 2 and the Expert Witness Code of Conduct in Schedule 7 of the *Uniform Civil Procedure Rules 2005*, and I am willing to be bound by them.

Scope of this advice

I have been asked to produce an expert report in relation to the Revised Dendrobium Extension Project (Project) that has been exhibited 4 May 2022 to 14 June 2022 to address the following questions:

25. We ask that your report addresses the following issues in regard to any impacts arising as a result of the Project:

a. In your opinion, is the Project likely to have a significant impact on aquatic ecology (including stygofauna)? Please provide reasoning for your answer.
b. The proponent claims that the design of the Project (revised from the earlier refused application) "includes avoidance of key surface features, which would reduce potential impacts to aquatic habitat [and] upland swamp". In your opinion, is this a justifiable and accurate statement?
c. Mining subsidence can have deleterious effects on local water resources. In your opinion, have the risks of subsidence been evaluated appropriately as to their potential to harm local water resources—quantity or quality?
d. In your opinion, is the impact of water use by the mine as envisaged in its extension fully considered in the environmental impact statement, including the discharge of wastewater from the mine (e.g. discharge into Allans Creek), and the potential proposed pumping station at Cordeaux River?
e. The Project proposal indicates that the proponent will continue to conduct aquatic ecology monitoring under 'Mitigation Measures and Monitoring' (see IMC 2020). In your view is the monitoring sufficiently rigorous and robust to meet its aims, track deleterious environmental changes, and inform mitigation activities, if required?
f. Provide any further observations or opinions which you consider to be relevant.

In providing this advice I have reviewed the relevant environmental assessment materials provided on the NSW Planning Portal for the revised Dendrobium Mine Extension Project.

a. In your opinion, is the Project likely to have a significant impact on aquatic ecology?

The EIS Revised Appendix E 'Aquatic Ecology Assessment' (AEA) 30 March 2022 Executive Summary (page iv) makes the following statement:

> Subsidence induced fracturing and flow diversion is expected to occur in first and second order drainage lines directly above the proposed longwalls and in first, second and third order watercourses located up to 400 m from the longwalls. Fracturing would also occur in bedrock underlying swamps resulting in reductions in shallow groundwater levels, levels of soil moisture and changes in extent and composition of swamp vegetation communities. These are expected to impact aquatic ecology as follows:
>
> - Fracturing and flow diversions in first, second and third order drainage lines are expected to result in localised (i.e. within 400 m of proposed longwalls in Area 5) reductions in aquatic habitat and loss of some biota. This could result in the loss of semi-permanent pool habitat and likely also associated biota (primarily aquatic macroinvertebrates and potentially some non-threatened native fish). However, based on experience of previous mining at Dendrobium Mine, such impacts would be localised and relatively minor compared to the extensive aquatic habitat in the broader region. The cumulative impact to the upper Avon River and Cordeaux River catchments due to loss of such habitat should, however, be considered. No significant reductions in catchment yield and no more than minor, localised and short-term impacts to water quality are predicted. Thus, impacts to downstream aquatic ecology due to reduced water availability are not expected nor are any more than localised and minor impacts to aquatic ecology due to the minor changes in water quality.

I agree that fracturing of bedrock (triggered by longwall subsidence) is likely to modify surface water flows and diminish habitat quality for biota. But my own research on longwall subsidence and impacts to surface water quality and ecology (Wright et al. 2015; Morrison et al., 2018; Morrison et al., 2019) has revealed that subsidence-triggered fracturing of stream channels can also cause changes in water quality and inflict substantial adverse impacts to stream ecosystems that are not 'minor' and 'localised'. My research was conducted in the nearby southern coalfield of the Sydney Basin (impacted Redbank Creek near Picton) in comparable sandstone geology to that of Project. In my opinion, the Aquatic Ecology Assessment produced for the Project understates the potential for adverse impacts, caused by longwall subsidence, that can cause long-term impairment to stream flow, water quality and health of stream ecosystems.

The Aquatic Ecology Assessment (page 35 of AEA) also makes the following statement, which has important implications for impacts on aquatic ecosystems of surface waters:

> Potential impacts to water quality as a result of the predicted subsidence effects associated with the Project would be localised and minor (HEC 2022). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, there have been no reports of any measurable effect on water quality in downstream dams in the Southern Coalfield.

This statement is factually incorrect. WaterNSW have made a conflicting statement confirming that metal concentrations in two storages in two 'undermined' catchments have been increasing over several decades (Lake Cordeaux and Lake Cataract). This graph is included in the WaterNSW submission the Independent Expert Panel on Mining in the Catchment (WaterNSW, 2018, page 24).

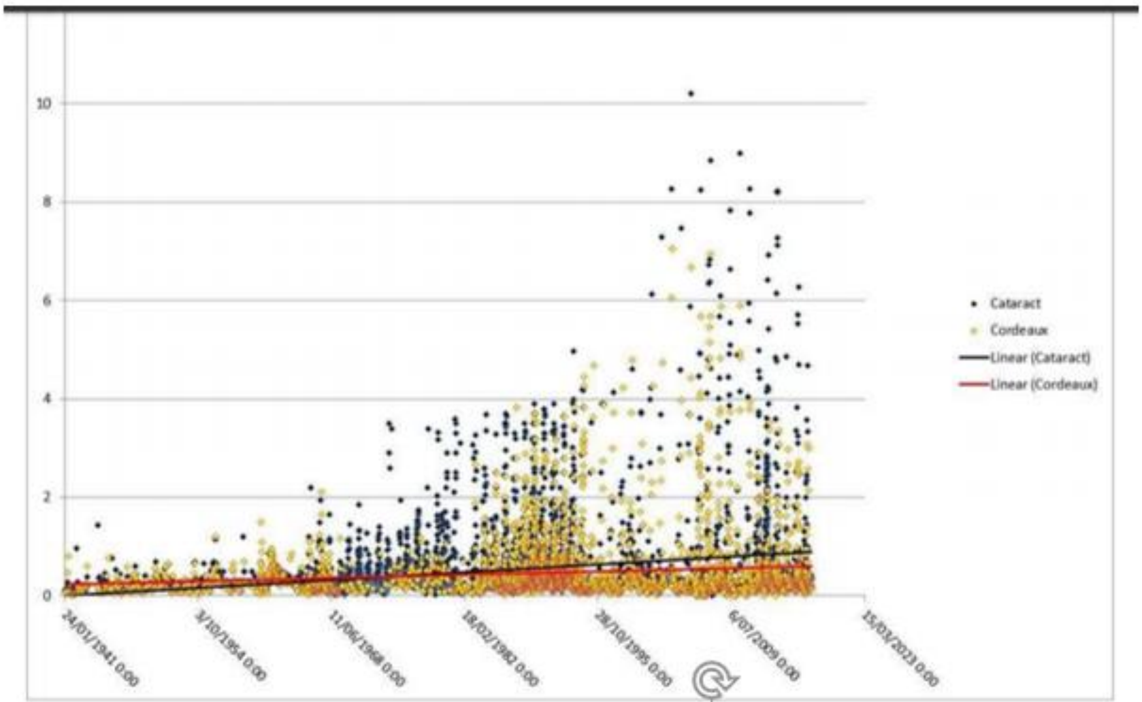


Figure 4-1. Measured iron concentrations in Cataract and Cordeaux Reservoirs

An issue which particularly concerns WaterNSW is that it is anticipated that any additional increases in iron, manganese and possibly aluminum and other species dissolved from undermined catchments will impact on raw water quality delivered to Sydney Water and other customers. WaterNSW applies artificial destratification in most of these storages to manage water quality during summer months. The deep water columns of most reservoirs

My own published research on the topic of longwall coal mining subsidence demonstrates that it can cause substantial and complex changes to stream water quality. This is contrary to the statements in the environmental assessment on the previous page that water quality impacts are likely to the 'isolated, episodic and localised'. I base my opinion on several years of experience and associated peer-reviewed research that I have conducted on water pollution triggered by subsidence and channel fracturing from Tahmoor Colliery on Redbank Creek from 2012 to 2017 (Wright et al. 2015; Morrison et al., 2018; Morrison et al., 2019). This is some of the only peer-reviewed water pollution research done on this topic in Australia. Although based in a different location, it is within the Sydney basin and is likely to be representative of the potential environmental damage to streams and river from the Project as it is a very similar geological and climatic setting, using similar longwall mining technology. It is important to recognise that such independent and peer-reviewed research is currently very difficult to undertake within the Drinking Water Catchment Special Areas, where the Project is located, which has highly restricted access.

I consider it to be inadequate that this assessment has not reported details and data on potential ecological impacts to the aquatic ecology associated with previous similar underground coal mines in the in the southern Sydney basin coal fields. The Tahmoor Colliery and Redbank Creek subsidence is only about 10 to 20 km from the Project. It is my opinion that the proposed long-wall mining activity does risk causing substantial habitat and water quality degradation that is likely to causes much greater harm to aquatic ecosystems than is predicted in the assessment documents.

b. Subsidence - physical, chemical and biological damage to Redbank Creek

I provide the following information as an example of the type of impacts that can be expected to occur as a consequence of the Project. In my opinion such detail about likely subsidence impacts was not fully considered in the revised Project EIS documents.

The subsidence-induced fracturing of Redbank Creek, Picton NSW ranges from small hair-line fractures, to sections of creek channel that can be described as extensive and high-impact. See Picture 1, the section of creek within this subsidence only flowed after heavy rain, with smaller flows disappearing underground through the fractures.

Picture 1: Severe longwall induced subsidence fracturing of Redbank Creek, near Picton. This was upstream of the isolated pool (Picture 1).

Picture 1 shows a section of extreme subsidence fracturing. Whole slabs of sandstone have fractured and been lifted. The Project assessment predicts some occurrence of subsidence and damage to stream channels – damage similar to that observed in Redbank Creek (Picture 1) may potentially result. However, damage from the Project may be hidden from public view as unauthorised public access to the Special Area Water Catchment is prohibited (as it is located within a Special Area with restricted access). Similar fracturing damage to that observed in Redbank Creek, due to long-wall subsidence, has also been observed within Sydney's drinking water catchments. This is detailed in Dr Peter Turner's Open Letter (of which I am a signatory) to the NSW Premier (18 May 2020) [https://ssec.org.au/wp-content/uploads/2020/06/Open_letter_to_Premier_re_mining_in_the_Special_Areas.pdf] and has similar images taken from inspections of waterways within Sydney drinking water catchment special areas.

Downstream of the Redbank Creek 'severe' fracture zone (Picture 1) were a series of isolated pools in low lying sections of the creek channel (Picture 2). I have observed and collected data from pools similar to this over about 1 km of the Redbank Creek channel over the period 2012–2017. These pools all had very poor water quality: high salinity, elevated metals, and typically very low dissolved oxygen levels. Many attributes of water quality were at levels harmful to aquatic biota (ANZECC, 2000) confirmed with severe negative impacts to stream invertebrate communities (Wright et al. 2015). Whilst the revised Project assessment suggests that there may be some water quality impacts, the assessment suggests that the impact is likely to be 'minor and localised'. I disagree that the likely impacts from subsidence would be local and minor. I base this comment on my observations and research on Redbank Creek from 2012 to 2017, where subsidence has caused impacts that I consider to be of regional impact and substantial in severity of pollution. Given that such impacts from the proposed mining activity associated with the revised Project would occur in a protected drinking water catchment, I consider that any potential negative impact to surface water quality to be unacceptable. The water quality impacts that I consider to be likely from the Project could include physical, chemical and ecological impacts, similar to those that my research documented in Redbank Creek (Wright et al., 2015). This is explained further below.

Picture 2: An isolated pool on Redbank Creek, near Picton. This pool was regularly stagnant, with minimal flow due to extensive channel fracturing and loss of flow through bedrock fractures. The mixture of stream water with sections of fracturing rock causes the mobilisation of salts, minerals and metals and combined to create water quality that was hostile to stream biodiversity.

Picture 3: Severe subsidence fracturing of Redbank Creek, near Picton. This was the site of a ground water ‘vent’ where upwelling groundwater flowed into Redbank Creek, through a fresh subsidence fracture. Water quality was extremely poor for the aquatic ecosystem with very low dissolved oxygen, very high salinity, and hazardous concentrations of metals, such as zinc and nickel (Morrison et al. 2018; Morrison et al. 2019).

The pool in Picture 3 was filled by an upwelling of ground water triggered by subsidence fracturing. The upwelling water had very low dissolved oxygen, inadequate for the survival of invertebrates and fish. It also had highly elevated salinity, zinc and nickel that together combined to created highly polluted water that was hazardous to aquatic life (ANZECC, 2000; Morrison et al. 2018; Morrison et al. 2019; Wright et al. 2015).

I consider it to be likely that such subsidence-triggered impacts and damage to stream channels, stream water quality and aquatic ecosystems, similar to Redbank Creek, could occur in the future to water catchment waterways due to the proposed revised Project.

Subsidence fracturing damage to Redbank Creek provided habitat and condition for mosquitos

Picture 4: This pool in Redbank Creek was affected by subsidence and recorded a very high abundance of mosquito larvae and pupae. It also had very few 'normal' stream invertebrates.

See Picture 4. I sampled this isolated pool on Redbank Creek over a period of more than two years and it provided a rich habitat for mosquitos. More sensitive typical stream invertebrates were missing due to the highly impaired water quality. This pool had depleted dissolved oxygen, very high salinity and elevated zinc and nickel (Wright et al. 2015). This physical subsidence damage to the creek channel, the impaired water quality and adverse impacts to the aquatic ecosystem have all occurred over many years in Redbank Creek. The transformation of a healthy stream ecosystem into one that supports a domination by mosquitos is unusual and is a potential ecological impact. It also has potential human health implications, if the mosquito species are disease vectors.

I am uncertain how quickly and effectively repairs/rehabilitation of such damage to stream channels can be achieved. The damage to Redbank Creek was covered by ABC in September 2018 and Sydney Morning Herald in June 2020 (Hannam, 2020). I am yet to observe major subsidence damage to a creek or river channel effectively repaired. The issue of how effective repairs to channel fracturing (such as polyurethane grouting) is also discussed in the Open Letter by Peter Turner et al. (2019; see page 32). I have personally observed repairs to channel fracturing in the Georges River and also Redbank Creek, but I am yet to see any evidence that repairs are effective.

In my opinion the revised Dendrobium Project environmental assessment fails to provide adequate, detailed information on exactly how minor, moderate and severe damage to stream and river channels is to be repaired. The information provided in Attachment 9 'Rehabilitation Strategy and Mine Closure Addendum' (particularly page A9-23 to 24) lacks detail, and also lacks independent verification that such technology is robust and effective. I remain concerned that subsidence damage from the Project to surface waterways may not be repairable.

In my opinion, the risks of subsidence having deleterious effects on water resources were not fully evaluated appropriately in the EIS. The EIS also fails to refer to published scientific studies that have been conducted on underground-coal-mine subsidence impacts to Redbank Creek at Picton (from Tahmoor Colliery longwall subsidence).

The EIS for the revised Project also failed to mention one of the most detailed studies on the topic of longwall subsidence within a Drinking Water Catchment. The research was done for the Honours thesis by Catherine Cunningham (University of Canberra, 2016) *'The effect of subsidence from long wall coal mining on the ecology and water quality of streams'*. The research by Catherine Cunningham was conducted on two streams (Waratah Rivulet and Eastern Tributary) flowing within the Woronora drinking water catchment. See photo of discolouration of Eastern Tributary, in the Woronora Drinking Water Catchment. Her research detected both water quality impairment and ecological modification (macroinvertebrates and algal diatoms) in the two catchment streams that were affected by underground long wall subsidence.

Picture 5. Discolouration (due to subsidence damage) of Eastern Tributary in Woronora Drinking Water Catchment, 2019. Photo by author.

d.	In your opinion, is the impact of water use by the mine as envisaged in its extension fully considered in the environmental impact statement, including the discharge of wastewater from the mine (e.g. discharge into Allans Creek), and the potential proposed pumping station at Cordeaux River?

I am aware that current waste discharges from Dendrobium Colliery, combined with wastes from at least one other mine in South 32's Bulli Seam Operations ('brine'), are released into Allans Creek via LDP5 (under Environment Protection Licence EPL 3241) and are very likely to be causing substantial water quality impairment to the receiving waterways. This is an important issue which is not covered adequately in the revised Project assessment and further information is required. In my opinion, the various assessment documents in the revised Project provided inadequate information on this issue to allow a complete assessment of this issue.

This is a serious issue and I consider the lack of supporting detail on the downstream water quality and ecological impacts of the current and future LDP5 waste discharge to Allans Creek be a major deficiency. I also note that this information is available and should have been included in the EIS as the NSW EPA required a study to be undertaken, as Special Condition E1.1 of EPL 3241, 'Allans Creek Monitoring Program'. See extract from EPL 3241 (page 18). To fully evaluate impacts from the Project such information should be made available.

8 Special Conditions

E1 Allans Creek Monitoring Program

E1.1 The licensee must undertake a water quality monitoring program to determine the effect of the discharge from point 5 on water quality in Allans Creek.

The results of the monitoring must be compared to predicted concentrations and conclusions made about the bioavailability of As, Zn, Ni and Cu in the brine discharge study report (doc ref 2440/1330) titled "Allans Creek licensed discharge water quality and hydrochemical modelling report", EGI, 13 December 2019.

A copy of the monitoring program report must be submitted to the EPA by the due date.

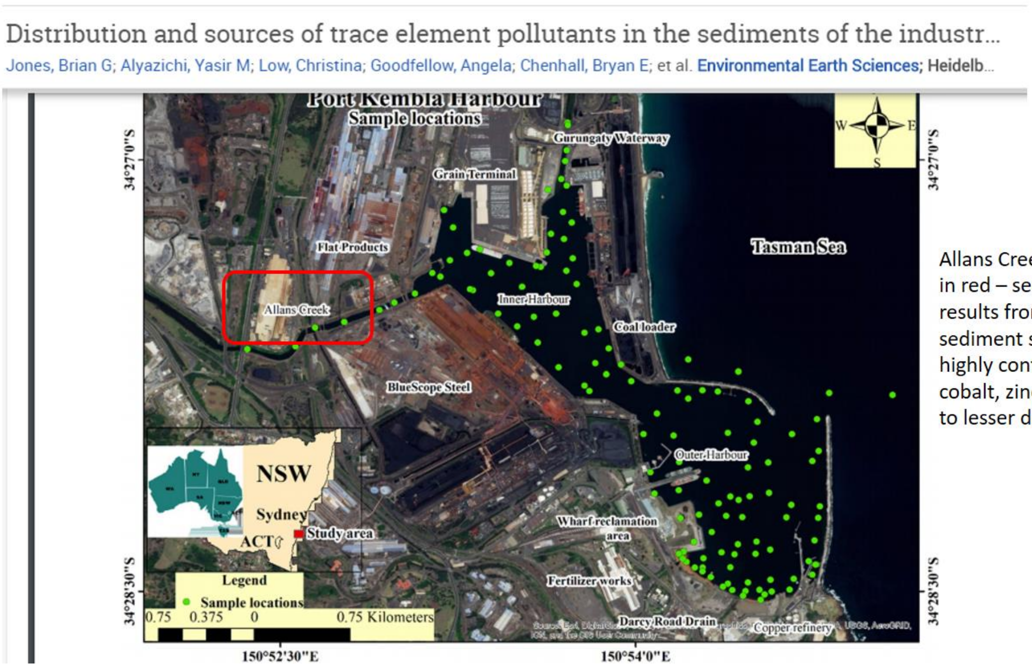
DUE DATE: 6 months following the commencement of operation of the new and expanded water treatment plants required by condition E1.1 of Environment Protection Licence 2504 held by Endeavour Coal Pty Ltd.

Allans Creek forms part of Port Kembla Harbour estuary. Published results indicate that both Port Kembla harbour estuary and Allans Creek has hazardous concentration of several metals that have accumulated in the harbour and creek sediment (Pictures 6,7 and 8; Jones et al. 2019). The data used in the publication by Jones et al. (2019) was published recently but used data collected many years earlier, with the majority of samples collected between 1996-1998. In my opinion, further sediment and water sampling should have been undertaken and reported for this EIS, particularly along Allans Creek, above and below the LDP 5 discharge.

I consider that LDP 5 waste discharges are almost certainly contributing to the pollution of Allans Creek and Port Kembla Harbour estuary. The nature and magnitude of the potential pollution are currently unknown, and inadequate information was provided in the EIS documents to understand this likely environmental impact. In my opinion, further information on the current and future waste discharge from LDP5 is urgently required. With the revised Project proposal indicating that increased flow of wastewater would be released from LDP 5, the approval of the revised Dendrobium extension would very likely increase the magnitude of the pollution in Allans Creek. This is potentially serious environmental impact from the current Dendrobium Colliery operation that is inadequately addressed in the revised Dendrobium assessment. The EIS documents for the revised Project claim that the increased flows of wastewater that are anticipated to be generated by the Project will not exceed the EPL 3241 discharge limits. This is not surprising to me. See extract from page 10 of EPL 3241 below. In my opinion these 100 percent concentrations limits are far too large, well above ANZECC (2000) trigger values for protection of aquatic species and probably allow the Project to add to the historic contamination reported in Allans Creek and Port Kembla Harbour by Jones et al.(2019).

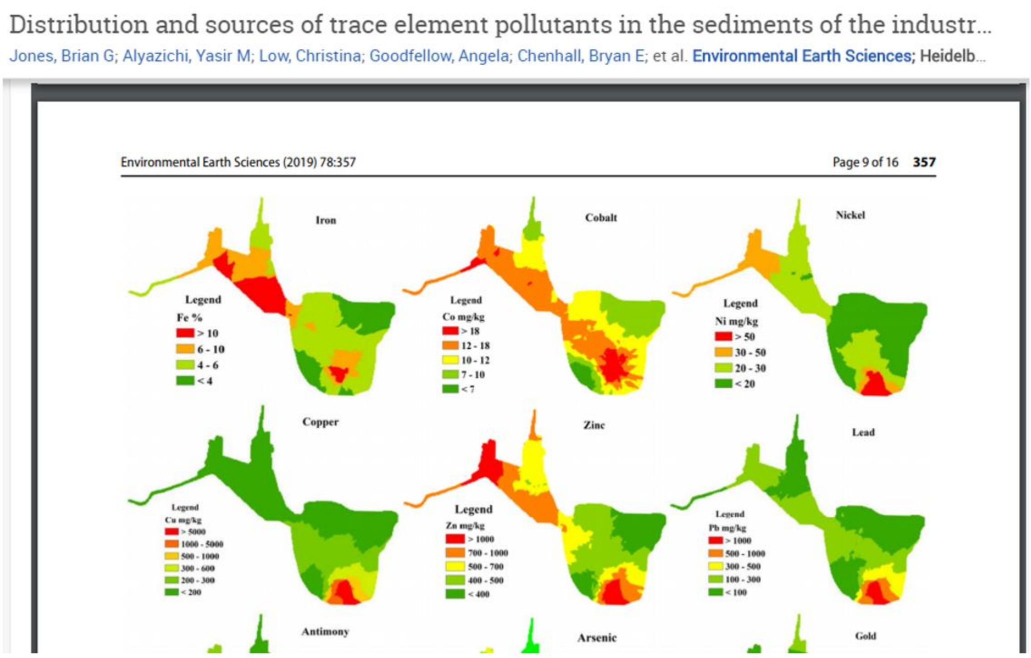
POINT 5

Pollutant	Units of Measure	50 percentile concentration limit	90 percentile concentration limit	3DGM concentration limit	100 percentile concentration limit
Arsenic	milligrams per litre				1.3
Copper	milligrams per litre				0.080
Nickel	milligrams per litre				5
Oil and Grease	milligrams per litre				10
pH	pH				6.5-9.0
Total suspended solids	milligrams per litre				30
Zinc	milligrams per litre				0.4



Allans Creek is circled in red – see the metal results from the sediment study. It has highly contaminated cobalt, zinc and nickel to lesser degree.

Picture 6: Sample locations used by Jones et al. (2019) in their investigation of sediment chemistry in Port Kembla Harbour. Allans Creek is highlighted.



Picture 7: Summary results by Jones et al. (2019) in their investigation of sediment chemistry in Port Kembla Harbour. See picture 12 for location of Allans Creek.

Environmental Earth Sciences (2019) 78:357
https://doi.org/10.1007/s12665-019-8358-1

ORIGINAL ARTICLE

Check for updates

Distribution and sources of trace element pollutants in the sediments of the industrialised Port Kembla Harbour, New South Wales, Australia

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Abstract
A detailed geochemical analysis of sediment samples from the heavily industrialised Port Kembla Harbour, 70 km south of Sydney in New South Wales, Australia, has delineated areas that are heavily contaminated with trace element pollutants. Local creek delta sand accumulations, basin mud deposits, reclamation deposits and exposed bedrock on the present harbour floor are consistent with the twentieth century Port Kembla industrial land and harbour development history, as well as known maritime shipping practices. The closed electrolytic copper refinery, one of the two major pollutant sources, has provided a very clear signature in the harbour opposite the main drain that discharged from these works. Copper pollution (up to 6070 mg/kg) is strongly correlated with high concentrations of gold, selenium, antimony, arsenic, lead and zinc. These pollutants appear to occur as silt- and sand-sized particulate matter, as well as pollutants that are probably chemically bound to clay, pyrite and organic matter. The second main pollutant source is the BlueScope steelworks that has been responsible for high concentrations of iron (and minor associated cobalt), kish, pyrolytic carbon and fly ash. The steelworks, along with other industrial, urban and automobile sources, supply additional quantities of copper, lead and zinc to the aquatic environment. Coal and coke dust also form important pollutants. The pollutants are currently fairly stable under the prevailing alkaline reducing conditions within the sediment. The proposed future reclamation and dredging within the harbour needs to consider the implications of moving highly contaminated sediment, without altering its alkalinity or oxidation potential, to prevent release of contaminants.

Picture 8: Abstract and details of the sediment contamination study by Jones et al. 2019.

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Qualifications and experience

I am an environmental and water scientist with more than 25 years of experience investigating the impact of human activities on waterways of the Sydney basin. I am currently employed as a Senior Lecturer in the School of Science and Health at Western Sydney University. Earlier in my career I was a freshwater scientist, working in various roles at Sydney Water. This included working as a scientific officer in Sydney Water's scientific laboratories at West Ryde. I then worked as catchment officer in Sydney Water's drinking water catchments. After received my PhD, I was awarded a Postdoctoral Research Fellowship in freshwater ecology and water pollution research at Western Sydney University. Before becoming a fulltime lecturer in 2012, I established a consulting business, mainly helping local Government with projects associated with urban water quality and ecology. I am an advocate for sustainable water and catchment management and I strongly support multi-disciplinary projects. I seek to manage industry problems with evidence-based science. I have specialist scientific expertise in freshwater ecology, water chemistry, pollution ecology of waters, freshwater macroinvertebrates as pollution indicators, impact of urban development, sewage effluent, agricultural, and mine waste impacts on streams and rivers. I have expertise in the sampling design of environmental science studies and statistical analysis of environmental data. I have published (as senior or junior co-author) more than 80 peer-reviewed publications. I have provided independent expert testimonies for environmental science matters for the NSW Land & Environment Court. I am an enthusiastic participant in community engagement activities in my field of expertise.

Qualifications

2006. Doctor of Philosophy, University of Western Sydney.

1995. Master of Science (by research), Macquarie University.

1988. Bachelor of Applied Science (Agriculture), Hawkesbury Agricultural College.

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1. Education

2006 Doctor of Philosophy. Western Sydney University.
1995 Master of Science (by Research). Macquarie University.
1988 Bachelor of Applied Science (Agriculture) with Merit. Hawkesbury Agricultural College.

2. Employment History

2017- Senior Lecturer in School of Science. Western Sydney University (current position)

2012-6 Lecturer/Associate Lecturer in School of Science. Western Sydney University.

2010-12 Casual Lecturer: School of Science and Health. Western Sydney University. Graduate School of the Environment. Macquarie University.

2007-9 Post-Doctoral Research Fellow (Aquatic Ecology), Western Sydney University.

2006-7 Principal Environmental Scientist, Ku-ring-gai Council.

2005-6 Senior Scientist (Collaborative Research), Sydney Catchment Authority.

2000-5 Senior Team Leader (Aquatic Ecology), Environmental Policy Analyst, Sydney Water Corporation.

1998-0 Environmental Scientist, Sydney Water Corporation.

1996-98 Full-time PhD student, Australian National University, Visiting Scientist CSIRO Division of Entomology.

1989-96 Scientific Officer, Catchment Protection Officer, Sydney Water Corporation.

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2011. 'Investigation of water quality in the upper Coxs River: focus on the influence of Wallerawang Power Station wastewater discharges'. Prepared for the NSW Land and Environment Course. Blue Mountains Conservation Society Report.

2011. 'Review of options to improve Sydney Water's wastewater system at Winmalee (aquatic ecology)' Independent review for Sydney Water Corporation's Wet Weather SewerFix Program'.

2011. 'Assessment of Aquatic Macroinvertebrates and Aquatic Ecosystem Health in Ku-ring-gai Council waterways'. Report prepared for Ku-ring-gai Council.

2011. 'Review of Duralie Extension Project Environmental Assessment: focus on water quality and aquatic ecology / biodiversity'. Report prepared for NSW Land and Environment Court (March 2011)

2011. 'Review of Bankstown City Council's Water Quality Monitoring Program 1997-2009'. Report prepared for Bankstown Council.

2011. 'Review of Hornsby Shire Council's Aquatic Ecosystem Program (2002-2007) Macroinvertebrates and Algal Diatoms'. Report prepared for Hornsby Council.

2010. 'Assessment of Aquatic Macroinvertebrates and aquatic ecosystem health in Penrith City Council waterways'. Report prepared for Penrith Council.

2010. Submission to the NSW Planning Minister's Planning Assessment Commission into the extension of the Bulli Seam Operation.

2009. Co-authored 'Stream studies featuring the Wolgan River & Carne Creek 2009'. Prepared by UWS Native and Pest Animal Unit for Wolgan Valley Emirates Estates. University of Western Sydney.

2009. 'Review of the EPBC Act: Case Study Pollution of the Grose River, Blue Mountains World Heritage area'. Submission to the Independent Review of the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act) (2009). Available at (https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.587.9973&rep=rep1&type=pdf)

Environmental
Defenders Office

25 May 2022

Dr Ian Wright
Senior Lecturer,
School of Science and Health
Western Sydney University

By email: I.Wright@westernsydney.edu.au

CONFIDENTIAL AND PRIVILEGED

Dear Dr Wright,

Brief to Expert – Dendrobium Mine Extension Project SSI – 33143123

1. We act for Protect Our Water Catchment (**POWC**) in relation to the proposed Dendrobium Mine Extension Project (SSI - 33143123) (**Project**) by Illawarra Coal Holdings Pty Ltd (**Applicant**), a subsidiary of South32 Limited.

2. The Project is an extension of the Applicant's existing underground coal mine located around 8 km west of Wollongong in the Southern Coalfield of New South Wales (**NSW**). The Applicant is seeking development consent to extract up to 5.2 million tonnes per annum (Mtpa) of ROM coal, through underground mining operations within Area 5 (location of the Project) until approximately 2035, in extending the life of Dendrobium Mine until 2041. The Project is a redesign of the Applicant's previous Significant State Development (**SSD**) application (Dendrobium Extension Project, SSD 8194).

3. Our client intends to make a submission on the Project which is currently being publicly exhibited to ensure the decision-maker has independent expert advice on the Project.

4. We seek to engage you on behalf of our client to review the environmental impact statement (**EIS**) for the Project and prepare an independent expert report in relation to your area of expertise, aquatic ecology and mine subsidence, in accordance with the *Uniform Civil Procedure Rules 2005* (UCPR) and the Expert Witness Code of Conduct.

Background

5. On 5 February 2021, the Applicant's SSD application (Dendrobium Extension Project, SSD 8194) for the Project was refused by the Independent Planning Commission (**IPC**). The

Applicant appealed the IPC's decision, which is currently the subject of a judicial review proceedings in the Land and Environment Court of New South Wales.

6. On or around December 2021, the Applicant submitted a scoping report for the re-designed SSD Project in support of the application for the Project to be assessed as 'State significant infrastructure' (**SSI**).

7. On 2 December 2021, the Project was declared SSI by the Minister for Planning and Public Spaces.

8. On 23 December 2021, the Department of Planning, Industry and Environment (now the Department of Planning and Environment) issued the Planning Secretary's environmental assessment requirements (SEARs) for the Project.

9. On 4 May 2022, the Project application, EIS and accompanying documents were placed on public exhibition.

Purpose of your expert report

10. We note as a preliminary matter that our primary purpose in briefing you to prepare your report is to provide independent expert advice in your area of expertise. We do not ask you to be an advocate for our client/s. You are requested to prepare an independent report that is clear and well-written.

11. In this respect, we draw your attention to Part 31 Division 2 of the *Uniform Civil Procedure Rules 2005* (NSW) (**UCPR**) and the Expert Witness Code of Conduct (**Code of Conduct**) which govern the use of expert evidence in NSW Courts (**attached**). The SSI public exhibition process is not a Court proceeding; however, we are of the view that the same Code of Conduct should be adhered to in this instance.

12. In particular, clause 2 of the Code of Conduct states that:

> *"An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness."*

13. Your expert report must contain an acknowledgment that you have read the Expert Witness Code of Conduct and that you agree to be bound by it.

14. Your expert report will be used as evidence in chief of your professional opinion. Information of which you believe the decision maker should be aware must be contained in your expert report.

15. In providing your opinion to the decision maker you must set out all the assumptions upon which the opinion is based. This may include, for example, facts observed as a result of fieldwork or 'assumed' facts based on a body of scientific opinion. If the latter, you should provide references which demonstrate the existence of that body of opinion.

16. Your expert report must also set out the process of reasoning which you have undertaken in order to arrive at your conclusions. It is insufficient for an expert report to simply state your opinion or conclusion reached without an explanation as to how this was arrived at. The purpose of providing such assumptions and reasoning is to enable the decision maker and experts engaged by other parties to make an assessment as to the soundness of your opinion.

Overview of work requested

17. We request that you undertake the following work:
    a. review the documents listed below;
    b. prepare a written expert report that addresses the issues identified below ('Issues to address in your expert report'); and
    c. ensure that the work is prepared in accordance with independent expert advice as indicated above.

Documents

18. We enclose the Code of Conduct and Part 31 Division 2 of the UCPR.

19. If you have previously reviewed relevant EIS documents for the previous SSD application (Dendrobium Extension Project, SSD 8194) you may wish to review your previous expert advice.

20. Full Project documentation is available at the following website:
a) NSW Government Planning Portal: https://www.planningportal.nsw.gov.au/major-projects/projects/dendrobium-mine-extension-project-0

21. The following documents relating to the Project are provided for your particular consideration:

Environmental Impact Statement

Executive Summary,
https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061031.074%20GMT

Section 1 – Introduction,
https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061031.900%20GMT

Section 7 – Environmental Assessment,
https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061037.452%20GMT, pp. 7-5 to 7-13, 7-37 to 7-64

Appendix A – Subsidence Assessment,
https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061043.537%20GMT

Appendix E – Aquatic Ecology Assessment,
https://majorprojects.planningportal.nsw.gov.au/prweb/PRRestService/mp/01/getContent?AttachRef=SSI-33143123%2120220427T061047.301%20GMT

22. IMC (2020). Illawarra Metallurgical Coal. Dendrobium Area 3B Watercourse Impact Monitoring, Management and Contingency Plan. https://www.south32.net/docs/default-source/illawarra-coal/dendrobium/subsidence-management-plans---longwalls-14-19/attachment-s-dendrobium-area-3-environmental-performance.pdf?sfvrsn=18df35db_4

23. Other documents relating to the SSD application that may be of relevance include:

a) Dendrobium Extension Project SSD 8194 – Project Area (see attached).
b) Catherine Cunningham, Honours Thesis – the effect of subsidence from long wall coal mining on the ecology and water quality of streams (see attached).

24. You are not limited to the above documents, if there is other material relevant to your expert report, you may wish to refer to this material.

Issues to address in your expert report

25. We ask that your report addresses the following issues in regard to any impacts arising as a result of the Project:

a. In your opinion, is the Project likely to have a significant impact on aquatic ecology (including stygofauna)? Please provide reasoning for your answer.
b. The proponent claims that the design of the Project (revised from the earlier refused application) "includes avoidance of key surface features, which would reduce potential impacts to aquatic habitat [and] upland swamp". In your opinion, is this a justifiable and accurate statement?
c. Mining subsidence can have deleterious effects on local water resources. In your opinion, have the risks of subsidence been evaluated appropriately as to their potential to harm local water resources—quantity or quality?
d. In your opinion, is the impact of water use by the mine as envisaged in its extension fully considered in the environmental impact statement, including the discharge of wastewater from the mine (e.g. discharge into Allans Creek), and the potential proposed pumping station at Cordeaux River?
e. The Project proposal indicates that the proponent will continue to conduct aquatic ecology monitoring under 'Mitigation Measures and Monitoring' (see IMC 2020). In your view is the monitoring sufficiently rigorous and robust to meet its aims, track deleterious environmental changes, and inform mitigation activities, if required?
f. Provide any further observations or opinions which you consider to be relevant.

26. We request that you provide us with a draft of your report for review before finalising it. We emphasise that the purpose of this is not to influence the conclusions or recommendations you make but to ensure that the language and expression of the report is clear and complies with the formal legal requirements of an expert report.

Key dates

27. The Project application, EIS and accompanying documents are on public exhibition from Wednesday 4 May 2022 until 14 June 2022.

28. We kindly request a draft of your expert advice by no later than **Monday 6 June 2022**.

29. Please provide your final expert advice by no later than **Thursday 9 June 2022.**

Duty of confidentiality

30. Please treat your work as strictly confidential, unless authorised otherwise by us. Please mark all documents prepared for the purposes of this brief as "Privileged & Confidential".

Fees and Terms

31. Thank-you for agreeing to provide your advice in this matter on a pro bono (volunteer) basis. EDO relies on experts such as you to assist in matters with very little financial compensation.

32. Please note the following terms:

    a. your work will only be used by EDO to relation to this matter;
    b. Either EDO or our client may choose to make your expert advice publicly available. Any public release of your report may result in disclosure of any works in your report over which you may claim copyright;
    c. EDO will take all reasonable steps to prevent your work being used for purposes other than that mentioned above, but we accept no responsibility for the actions of third parties;
    d. regardless of the above points, EDO may choose not to use your work; and
    e. you will not be covered by the EDO's insurance while undertaking the above tasks.

33. If you would like to discuss this brief further, please contact Jayme Cooper via email jayme.cooper@edo.org.au (cc: matthew.floro@edo.org.au and edward.butler@edo.org.au).

We are grateful for your assistance in this matter.

Yours sincerely,
Environmental Defenders Office

Jayme Cooper
Solicitor

Reference number: s 3326

NSW GOVERNMENT | NSW legislation

Uniform Civil Procedure Rules 2005

Current version for 1 December 2021 to date (accessed 25 May 2022 at 13:36)

Part 31 > Division 2

Division 2 Provisions applicable to expert evidence generally

Note—

The provisions of this Division replace those of former Divisions 2 and 3, as in force immediately before 8 December 2006. The numbering of the individual provisions of this Division varies considerably from that of the provisions of the former Divisions. The following Table identifies the new rules corresponding to former rules 31.17–31.35.

Table

Former rule	New rule
Rule 31.17	Rule 31.18
Rule 31.18	Rule 31.28
Rule 31.18A	Rule 31.29
Rule 31.19	Rule 31.30
Rule 31.20	Rule 31.31
Rule 31.21	Rule 31.32
Rule 31.22	Rule 31.33
Rule 31.23	Rule 31.27
Rule 31.24	Rule 31.34
Rule 31.25	Rules 31.24 and 31.26
Rule 31.26	Rule 31.35
Rule 31.27	Rule 31.36
Rule 31.28	Rule 31.18
Rule 31.29	Rule 31.46
Rule 31.30	Rule 31.23
Rule 31.31	Rule 31.49
Rule 31.32	Rule 31.51
Rule 31.33	Rule 31.52
Rule 31.34	Rule 31.53
Rule 31.35	Rule 31.54

Subdivision 1 Preliminary

31.17 Main purposes of Division (cf Queensland *Uniform Civil Procedure Rules 1999*, rule 423; United Kingdom *Civil Procedure Rules 1998*, rule 35.1)

The main purposes of this Division are as follows—

(a) to ensure that the court has control over the giving of expert evidence,

(b) to restrict expert evidence in proceedings to that which is reasonably required to resolve the proceedings,

(c) to avoid unnecessary costs associated with parties to proceedings retaining different experts,

(d) if it is practicable to do so without compromising the interests of justice, to enable expert evidence to be given on an issue in proceedings by a single expert engaged by the parties or appointed by the court,

(e) if it is necessary to do so to ensure a fair trial of proceedings, to allow for more than one expert (but no more than are necessary) to give evidence on an issue in the proceedings,

(f) to declare the duty of an expert witness in relation to the court and the parties to proceedings.

31.18 Definitions (cf SCR Part 36, rules 13A and 13C; DCR Part 28, rule 8; LCR Part 23, rule 1D)

In this Division—

court-appointed expert means an expert appointed pursuant to rule 31.46.

expert, in relation to any issue, means a person who has such knowledge or experience of, or in connection with, that issue, or issues of the character of that issue, that his or her opinion on that issue would be admissible in evidence.

expert witness means an expert engaged or appointed for the purpose of—

(a) providing an expert's report for use as evidence in proceedings or proposed proceedings, or

(b) giving opinion evidence in proceedings or proposed proceedings.

expert's report means a written statement by an expert (whether or not an expert witness in the proceedings concerned) that sets out the expert's opinion and the facts, and assumptions of fact, on which the opinion is based.

hospital report means a written statement concerning a patient, made by or on behalf of a hospital, that the party serving the statement intends to adduce in evidence in chief at the trial.

parties' single expert means an expert engaged pursuant to rule 31.37.

Subdivision 2 Expert witnesses generally

31.19 Parties to seek directions before calling expert witnesses

(1) Any party—

(a) intending to adduce expert evidence at trial, or

(b) to whom it becomes apparent that he or she, or any other party, may adduce expert evidence at trial,

must promptly seek directions from the court in that regard.

(2) Directions under this rule may be sought at any directions hearing or case management conference or, if no such hearing or conference has been fixed or is imminent, by notice of motion or pursuant to liberty to restore.

(3) Unless the court otherwise orders, expert evidence may not be adduced at trial—

(a) unless directions have been sought in accordance with this rule, and

(b) if any such directions have been given by the court, otherwise than in accordance with those directions.

(4) This rule does not apply to proceedings with respect to a professional negligence claim.

31.20 Court may give directions regarding expert witnesses

(1) Without limiting its other powers to give directions, the court may at any time give such directions as it considers appropriate in relation to the use of expert evidence in proceedings.

(2) Directions under this rule may include any of the following—

(a) a direction as to the time for service of experts' reports,

(b) a direction that expert evidence may not be adduced on a specified issue,

(c) a direction that expert evidence may not be adduced on a specified issue except by leave of the court,

(d) a direction that expert evidence may be adduced on specified issues only,

(e) a direction limiting the number of expert witnesses who may be called to give evidence on a specified issue,

(f) a direction providing for the engagement and instruction of a parties' single expert in relation to a specified issue,

(g) a direction providing for the appointment and instruction of a court-appointed expert in relation to a specified issue,

(h) a direction requiring experts in relation to the same issue to confer, either before or after preparing experts' reports in relation to a specified issue,

(i) any other direction that may assist an expert in the exercise of the expert's functions,

(j) a direction that an expert who has prepared more than one expert's report in relation to any proceedings is to prepare a single report that reflects his or her evidence in chief.

31.21 Expert evidence in chief to be given by way of experts' reports

Unless the court otherwise orders, an expert witness's evidence in chief must be given by the tender of one or more expert's reports.

31.22 Expert witness to provide details of contingency fees or deferred payment schemes

(1) A person who is engaged as an expert witness in relation to any proceedings must include information as to any arrangements under which—

(a) the charging of fees or costs by the expert witness is contingent on the outcome of the proceedings, or

(b) the payment of any fees or costs to the expert witness is to be deferred,

in, or in an annexure to, any report that he or she prepares for the purposes of the proceedings.

(2) If a report referred to in subrule (1) indicates the existence of any such arrangements, the court may direct disclosure of the terms of the engagement (including as to fees and costs).

31.23 Code of conduct (cf SCR Part 39, rule 2; DCR Part 28A, rule 2; LCR Part 38B, rule 2)

(1) An expert witness must comply with the code of conduct set out in Schedule 7.

(2) As soon as practicable after an expert witness is engaged or appointed—

(a) in the case of an expert witness engaged by one or more parties, the engaging parties, or one of them as they may agree, or

(b) in the case of an expert witness appointed by the court, such of the affected parties as the court may direct,

must provide the expert witness with a copy of the code of conduct.

(3) Unless the court otherwise orders, an expert's report may not be admitted in evidence unless the report contains an acknowledgment by the expert witness by whom it was prepared that he or she has read the code of conduct and agrees to be bound by it.

(4) Unless the court otherwise orders, oral evidence may not be received from an expert witness unless the court is satisfied that the expert witness has acknowledged, whether in an expert's report prepared in relation to the proceedings or otherwise in relation to the proceedings, that he or she has read the code of conduct and agrees to be bound by it.

31.24 Conference between expert witnesses (cf SCR Part 36, rule 13CA; DCR Part 28, rule 9D; LCR Part 23, rule 1E)

(1) The court may direct expert witnesses—

(a) to confer, either generally or in relation to specified matters, and

(b) to endeavour to reach agreement on any matters in issue, and

(c) to prepare a joint report, specifying matters agreed and matters not agreed and reasons for any disagreement, and

(d) to base any joint report on specified facts or assumptions of fact,

and may do so at any time, whether before or after the expert witnesses have furnished their experts' reports.

(2) The court may direct that a conference be held—

(a) with or without the attendance of the parties affected or their legal representatives, or

(b) with or without the attendance of the parties affected or their legal representatives, at the option of the parties, or

(c) with or without the attendance of a facilitator (that is, a person who is independent of the parties and who may or may not be an expert in relation to the matters in issue).

(3) An expert witness so directed may apply to the court for further directions to assist the expert witness in the performance of his or her functions in any respect.

(4) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(5) An expert witness who makes such an application must send a copy of the request to the other expert witnesses and to the parties affected.

(6) Unless the parties affected agree, the content of the conference between the expert witnesses must not be referred to at any hearing.

31.25 Instructions to expert witnesses where conference ordered before report furnished

If a direction to confer is given under rule 31.24(1)(a) before the expert witnesses have furnished their reports, the court may give directions as to—

(a) the issues to be dealt with in a joint report by the expert witnesses, and

(b) the facts, and assumptions of fact, on which the report is to be based,

including a direction that the parties affected must endeavour to agree on the instructions to be provided to the expert witnesses.

31.26 Joint report arising from conference between expert witnesses (cf SCR Part 36, rule 13CA; DCR Part 28, rule 9D; LCR Part 23, rule 1E)

(1) This rule applies if expert witnesses prepare a joint report as referred to in rule 31.24(1)(c).

(2) The joint report must specify matters agreed and matters not agreed and the reasons for any disagreement.

(3) The joint report may be tendered at the trial as evidence of any matters agreed.

(4) In relation to any matters not agreed, the joint report may be used or tendered at the trial only in accordance with the rules of evidence and the practices of the court.

(5) Except by leave of the court, a party affected may not adduce evidence from any other expert witness on the issues dealt with in the joint report.

Subdivision 3 Experts' reports and expert evidence

31.27 Experts' reports (cf SCR Part 36, rule 13C; DCR Part 28, rule 9C; LCR Part 23, rule 1D)

(1) An expert's report must (in the body of the report or in an annexure to it) include the following—

(a) the expert's qualifications as an expert on the issue the subject of the report,

(b) the facts, and assumptions of fact, on which the opinions in the report are based (a letter of instructions may be annexed),

(c) the expert's reasons for each opinion expressed,

(d) if applicable, that a particular issue falls outside the expert's field of expertise,

(e) any literature or other materials utilised in support of the opinions,

(f) any examinations, tests or other investigations on which the expert has relied, including details of the qualifications of the person who carried them out,

(g) in the case of a report that is lengthy or complex, a brief summary of the report (to be located at the beginning of the report).

(2) If an expert witness who prepares an expert's report believes that it may be incomplete or inaccurate without some qualification, the qualification must be stated in the report.

(3) If an expert witness considers that his or her opinion is not a concluded opinion because of insufficient research or insufficient data or for any other reason, this must be stated when the opinion is expressed.

(4) If an expert witness changes his or her opinion on a material matter after providing an expert's report to the party engaging him or her (or that party's legal representative), the expert witness must forthwith provide the engaging party (or that party's legal representative) with a supplementary report to that effect containing such of the information referred to in subrule (1) as is appropriate.

31.28 Disclosure of experts' reports and hospital reports (cf SCR Part 36, rule 13A; DCR Part 28, rule 8; LCR Part 23, rule 3)

(1) Each party must serve experts' reports and hospital reports on each other active party—

(a) in accordance with any order of the court, or

(b) if no such order is in force, in accordance with any relevant practice note, or

(c) if no such order or practice note is in force, not later than 28 days before the date of the hearing at which the report is to be used.

(2) An application to the court for an order under subrule (1) (other than an order solely for abridgment or extension of time) may be made without serving notice of motion.

(3) Except by leave of the court, or by consent of the parties—

(a) an expert's report or hospital report is not admissible unless it has been served in accordance with this rule, and

(b) without limiting paragraph (a), an expert's report or hospital report, when tendered under section 63, 64 or 69 of the *Evidence Act 1995*, is not admissible unless it has been served in accordance with this rule, and

(c) the oral expert evidence in chief of any expert is not admissible unless an expert's report or hospital report served in accordance with this rule contains the substance of the matters sought to be adduced in evidence.

(4) Leave is not to be given as referred to in subrule (3) unless the court is satisfied—

(a) that there are exceptional circumstances that warrant the granting of leave, or

(b) that the report concerned merely updates an earlier version of a report that has been served in accordance with subrule (1).

31.29 Admissibility of expert's report (cf SCR Part 36, rule 13B)

(1) If an expert's report is served in accordance with rule 31.28 or in accordance with an order of the court, the report is admissible—

(a) as evidence of the expert's opinion, and

(b) if the expert's direct oral evidence of a fact on which the opinion was based would be admissible, as evidence of that fact,

without further evidence, oral or otherwise.

(2) Unless the court otherwise orders, a party may require the attendance for cross-examination of the expert by whom the report was prepared by notice served on the party by whom the report was served.

(3) Unless the court otherwise orders, such a requirement may not be made later than—

(a) in the case of proceedings for which the court has fixed a date for trial, 35 days before the date so fixed, or

(b) in any other case, 7 days before the date on which the court fixes a date for trial.

(4) The parties may not by consent abridge the time fixed by or under subrule (3).

(5) If the expert's attendance for cross-examination is required under subrule (2), the report may not be tendered under section 63, 64 or 69 of the *Evidence Act 1995* or otherwise used unless the expert attends or is dead or the court grants leave to use it.

(6) The party using the report may re-examine the expert if the expert attends for cross-examination pursuant to a requirement under subrule (2).

(7) This rule does not apply to proceedings in the District Court or the Local Court or to proceedings on a trial with a jury.

31.30 Admissibility of expert's report in District Court and Local Court (cf DCR Part 28, rule 9; LCR Part 23, rule 2)

(1) This rule applies to proceedings in the District Court or the Local Court.

(2) If an expert's report is served in accordance with rule 31.28 or in accordance with an order of the court, the report is admissible—

(a) as evidence of the expert's opinion, and

(b) if the expert's direct oral evidence of a fact on which the opinion was based would be admissible, as evidence of that fact,

without further evidence, oral or otherwise.

(3) Unless the court orders otherwise—

(a) it is the responsibility of the party requiring the attendance for cross-examination of the expert by whom an expert's report has been prepared to procure that attendance, and

(b) the party requiring the expert's attendance must notify the expert at least 28 days before the date on which attendance is required.

(4) Except for the purpose of determining any liability for conduct money or witness expenses, an expert does not become the witness for the party requiring his or her attendance merely because his or her attendance at court has been procured by that party.

(5) A party who requires the attendance of a person as referred to in subrule (2)—

(a) must inform all other parties to the proceedings that the party has done so at least 28 days before the date fixed for hearing, and

(b) must pay to the person whose attendance is required (whether before or after the attendance) an amount sufficient to meet the person's reasonable expenses (including any standby fees) in complying with the requirement.

(6) If the attendance of an expert is required under subrule (2), the report may not be tendered under section 63, 64 or 69 of the *Evidence Act 1995* or otherwise used unless the expert attends or is dead or the court grants leave to use it.

(7) The party using an expert's report may re-examine an expert who attends for cross-examination under a requirement under subrule (2).

(8) This rule does not apply to proceedings on a trial with a jury.

31.31 Fees for medical expert for compliance with subpoena (cf SCR Part 36, rule 13BA)

(1) If a subpoena is served on a medical expert who is to give evidence of medical matters but is not called as a witness, the expert is, unless the court orders otherwise, entitled to be paid, in addition to any other amount payable to the expert, the amount specified in item 2 of Schedule 3.

(2) The amount payable under subrule (1) must be paid to the expert by the issuing party within 28 days after the date for the expert's attendance.

(3) A party that requires an expert's attendance under rule 31.29(2), but subsequently revokes it, must pay to the issuing party any amount paid by the issuing party under subrule (2), but otherwise such an amount is not recoverable by the issuing party from any other party unless the court so orders.

(4) In this rule, ***issuing party*** means the party at whose request a subpoena is issued.

31.32 Service of subpoena on medical expert (cf SCR Part 36, rule 13BB)

(1) Service of a subpoena on a medical expert may be effected, at any place at which the expert's practice is carried on, by handing it over to a person who is apparently engaged in the practice (whether as an employee or otherwise) and is apparently of or above the age of 16 years.

(2) If a person refuses to accept a subpoena when it is handed over, the subpoena may be served by putting it down in the person's presence after he or she has been told of its nature.

(3) If a subpoena requires a medical expert to attend court on a specified date for the purpose of giving evidence on medical matters, it must be served on the expert not later than 21 days before the date so specified unless the court orders otherwise.

(4) The parties may not by consent abridge the time fixed by or under subrule (3).

31.33 Subpoena requiring production of medical records (cf SCR Part 36, rule 13BC)

(1) A subpoena for production may require a medical expert to produce medical records or copies of them.

(2) A person is not required to comply with a subpoena for production referred to in subrule (1) unless the amount specified in item 3 of Schedule 3 is paid or tendered to the person at the time of service of the subpoena or a reasonable time before the date on which production is required.

(3) Rule 33.6 (Compliance with subpoena) does not apply to a subpoena to which subrule (1) applies.

(4) Rule 33.7 (Production otherwise than on attendance) applies to the photocopies in the same way as it applies to the records.

(5) If, after service of a subpoena for production referred to in subrule (1), the party who requested the issue of the subpoena requires production of the original medical records without the option of producing copies of them, the party must request the issue of, and serve, another subpoena requiring production of the original medical records.

31.34 Supplementary reports by expert witness (cf SCR Part 36, rule 13C; DCR Part 28, rule 9C; LCR Part 23, rule 1D)

(1) If an expert witness provides a supplementary report to the party by whom he or she has been engaged, neither the engaging party nor any other party having the same interest as the engaging party may use—

(a) the supplementary report, or

(b) any earlier report affected by the supplementary report,

unless all of those reports have been served on all parties affected.

(2) For the purposes of this rule, ***supplementary report***, in relation to an earlier report provided by an expert witness, includes any report by the expert witness that indicates that he or she has changed his or her opinion on a material matter expressed in the earlier report.

(3) This rule does not apply to a report prepared by a court-appointed expert.

31.35 Opinion evidence by expert witnesses (cf *Federal Court Rules*, Order 34A, rule 3)

In any proceedings in which two or more parties call expert witnesses to give opinion evidence about the same issue or similar issues, or indicate to the court an intention to call expert witnesses for that purpose, the court may give any one or more of the following directions—

(a) a direction that, at trial—

(i) the expert witnesses give evidence after all factual evidence relevant to the issue or issues concerned, or such evidence as may be specified by the court, has been adduced, or

(ii) the expert witnesses give evidence at any stage of the trial, whether before or after the plaintiff has closed his or her case, or

(iii) each party intending to call one or more expert witnesses close that party's case in relation to the issue or issues concerned, subject only to adducing evidence of the expert witnesses later in the trial,

(b) a direction that, after all factual evidence relevant to the issue, or such evidence as may be specified by the court, has been adduced, each expert witness file an affidavit or statement indicating—

(i) whether the expert witness adheres to any opinion earlier given, or

(ii) whether, in the light of any such evidence, the expert witness wishes to modify any opinion earlier given,

(c) a direction that the expert witnesses—

(i) be sworn one immediately after another (so as to be capable of making statements, and being examined and cross-examined, in accordance with paragraphs (d), (e), (f), (g) and (h)), and

(ii) when giving evidence, occupy a position in the courtroom (not necessarily the witness box) that is appropriate to the giving of evidence,

(d) a direction that each expert witness give an oral exposition of his or her opinion, or opinions, on the issue or issues concerned,

(e) a direction that each expert witness give his or her opinion about the opinion or opinions given by another expert witness,

(f) a direction that each expert witness be cross-examined in a particular manner or sequence,

(g) a direction that cross-examination or re-examination of the expert witnesses giving evidence in the circumstances referred to in paragraph (c) be conducted—

(i) by completing the cross-examination or re-examination of one expert witness before starting the cross-examination or re-examination of another, or

(ii) by putting to each expert witness, in turn, each issue relevant to one matter or issue at a time, until the cross-examination or re-examination of all of the expert witnesses is complete,

(h) a direction that any expert witness giving evidence in the circumstances referred to in paragraph (c) be permitted to ask questions of any other expert witness together with whom he or she is giving evidence as so referred to,

(i) such other directions as to the giving of evidence in the circumstances referred to in paragraph (c) as the court thinks fit.

31.36 Service of experts' reports in professional negligence claims (cf SCR Part 14C, rules 1 and 6; DCR Part 28, rule 9B)

(1) Unless the court orders otherwise, a person commencing a professional negligence claim (other than a claim against a legal practitioner) must file and serve, with the statement of claim commencing the professional negligence claim, an expert's report that includes an opinion supporting—

(a) the breach of duty of care, or contractual obligation, alleged against each person sued for professional negligence, and

(b) the general nature and extent of damage alleged (including death, injury or other loss or harm and prognosis, as the case may require), and

(c) the causal relationship alleged between such breach of duty or obligation and the damage alleged.

(2) In the case of a professional negligence claim against a legal practitioner, the court may order the plaintiff to file and serve an expert's report or experts' reports supporting the claim.

(3) If a party fails to comply with subrule (1) or (2), the court may by order made on the application of a party or of its own motion dismiss the whole or any part of the proceedings, as may be appropriate.

(4) Without limiting subrule (1) or (2), the court may, on the application of any of the parties, give directions as to the expert evidence to be adduced at trial.

(5) Directions under subrule (4) may be sought at any directions hearing or case management conference or by notice of motion.

(6) Unless the court otherwise orders, no party may adduce any expert evidence at trial unless the evidence—

(a) has been filed and served under subrule (1) or (2), or

(b) has been served pursuant to directions given under subrule (4).

Subdivision 4 Parties' single experts

31.37 Selection and engagement

(1) If an issue for an expert arises in any proceedings, the court may, at any stage of the proceedings, order that an expert be engaged jointly by the parties affected.

(2) A parties' single expert is to be selected by agreement between the parties affected or, failing agreement, by, or in accordance with the directions of, the court.

(3) A person may not be engaged as a parties' single expert unless he or she consents to the engagement.

(4) If any party affected knows that a person is under consideration for engagement as a parties' single expert—

(a) the party affected must not, prior to the engagement, communicate with the person for the purpose of eliciting the person's opinion as to the issue or issues concerned, and

(b) if the party affected has previously communicated with the person for that purpose, he or she must notify the other parties affected as to the substance of those communications.

31.38 Instructions to parties' single expert

(1) The parties affected must endeavour to agree on written instructions to be provided to the parties' single expert concerning the issues arising for the expert's opinion and concerning the facts, and assumptions of fact, on which the report is to be based.

(2) If the parties affected cannot so agree, they must seek directions from the court.

31.39 Parties' single expert may apply to court for directions

(1) The parties' single expert may apply to the court for directions to assist the expert in the performance of the expert's functions in any respect.

(2) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(3) A parties' single expert who makes such an application must send a copy of the request to the parties affected.

31.40 Parties' single expert's report to be sent to parties

(1) The parties' single expert must send a signed copy of his or her report to each of the parties affected.

(2) Each copy must be sent on the same day and must be endorsed with the date on which it is sent.

31.41 Parties may seek clarification of report

(1) Within 14 days after the parties' single expert's report is sent to the parties affected, and before the report is tendered in evidence, a party affected may, by notice in writing sent to the expert, seek clarification of any aspect of the report.

(2) Unless the court orders otherwise, a party affected may send no more than one such notice.

(3) Unless the court orders otherwise, the notice must be in the form of questions, no more than 10 in number.

(4) The party sending the notice must, on the same day as it is sent to the parties' single expert, send a copy of it to each of the other parties affected.

(5) Each notice sent under this rule must be endorsed with the date on which it is sent.

(6) Within 28 days after the notice is sent, the parties' single expert must send a signed copy of his or her response to the notice to each of the parties affected.

31.42 Tender of reports and of answers to questions

(1) Subject to rule 31.23(3) and unless the court orders otherwise, the parties' single expert's report may be tendered in evidence by any of the parties affected.

(2) Unless the court orders otherwise, any or all of the parties' single expert's answers in response to a request for clarification under rule 31.41 may be tendered in evidence by any of the parties affected.

31.43 Cross-examination of parties' single expert

Any party affected may cross-examine a parties' single expert, and the expert must attend court for examination or cross-examination if so requested on reasonable notice by a party affected.

31.44 Prohibition of other expert evidence

Except by leave of the court, a party to proceedings may not adduce evidence of any other expert on any issue arising in proceedings if a parties' single expert has been engaged under this Division in relation to that issue.

31.45 Remuneration of parties' single expert

(1) The remuneration of a parties' single expert is to be fixed by agreement between the parties affected and the expert or, failing agreement, by, or in accordance with the directions of, the court.

(2) Subject to subrule (3), the parties affected are jointly and severally liable to a parties' single expert for his or her remuneration.

(3) The court may direct when and by whom a parties' single expert is to be paid.

(4) Subrules (2) and (3) do not affect the powers of the court as to costs.

Subdivision 5 Court-appointed experts

31.46 Selection and appointment (cf SCR Part 39, rule 1; DCR Part 28A, rule 1; LCR Part 38B, rule 1)

(1) If an issue for an expert arises in any proceedings the court may, at any stage of the proceedings—

(a) appoint an expert to inquire into and report on the issue, and

(b) authorise the expert to inquire into and report on any facts relevant to the inquiry, and

(c) direct the expert to make a further or supplemental report or inquiry and report, and

(d) give such instructions (including instructions concerning any examination, inspection, experiment or test) as the court thinks fit relating to any inquiry or report of the expert or give directions concerning the giving of such instructions.

(2) The court may appoint as a court-appointed expert a person selected by the parties affected, a person selected by the court or a person selected in a manner directed by the court.

(3) A person must not be appointed as a court-appointed expert unless he or she consents to the appointment.

(4) If any party affected knows that a person is under consideration for appointment as a court-appointed expert—

(a) the party affected must not, prior to the appointment, communicate with the person for the purpose of eliciting the person's opinion as to the issue or issues concerned, and

(b) if the party affected has previously communicated with the person for that purpose, he or she must notify the court as to the substance of those communications.

31.47 Instructions to court-appointed expert

The court may give directions as to—

(a) the issues to be dealt with in a report by a court-appointed expert, and

(b) the facts, and assumptions of fact, on which the report is to be based,

including a direction that the parties affected must endeavour to agree on the instructions to be provided to the expert.

31.48 Court-appointed expert may apply to court for directions

(1) A court-appointed expert may apply to the court for directions to assist the expert in the performance of the expert's functions in any respect.

(2) Any such application must be made by sending a written request for directions to the court, specifying the matter in relation to which directions are sought.

(3) A court-appointed expert who makes such an application must send a copy of the request to the parties affected.

31.49 Court-appointed expert's report to be sent to registrar (cf SCR Part 39, rule 3; DCR Part 28A, rule 3; LCR Part 38B, rule 3)

(1) The court-appointed expert must send his or her report to the registrar, and a copy of the report to each party affected.

(2) Subject to rule 31.23(3) and unless the court orders otherwise, a report that has been received by the registrar is taken to be in evidence in any hearing concerning a matter to which it relates.

(3) A court-appointed expert who, after sending a report to the registrar, changes his or her opinion on a material matter must forthwith provide the registrar with a supplementary report to that effect.

31.50 Parties may seek clarification of court-appointed expert's report

Any party affected may apply to the court for leave to seek clarification of any aspect of the court-appointed expert's report.

31.51 Cross-examination of court-appointed expert (cf SCR Part 39, rule 4; DCR Part 28A, rule 4; LCR Part 38B, rule 4)

Any party affected may cross-examine a court-appointed expert, and the expert must attend court for examination or cross-examination if so requested on reasonable notice by a party affected.

31.52 Prohibition of other expert evidence (cf SCR Part 39, rule 6; DCR Part 28A, rule 6; LCR Part 38B, rule 6)

Except by leave of the court, a party to proceedings may not adduce evidence of any expert on any issue arising in proceedings if a court-appointed expert has been appointed under this Division in relation to that issue.

31.53 Remuneration of court-appointed expert (cf SCR Part 39, rule 5; DCR Part 28A, rule 5; LCR Part 38B, rule 5)

(1) The remuneration of a court-appointed expert is to be fixed by agreement between the parties affected and the expert or, failing agreement, by, or in accordance with the directions of, the court.

(2) Subject to subrule (3), the parties affected are jointly and severally liable to a court-appointed witness for his or her remuneration.

(3) The court may direct when and by whom a court-appointed expert is to be paid.

(4) Subrules (2) and (3) do not affect the powers of the court as to costs.

31.54 Assistance to court by other persons (cf SCR Part 39, rule 7; DCR Part 28A, rule 7; LCR Part 38B, rule 7)

(1) In any proceedings, the court may obtain the assistance of any person specially qualified to advise on any matter arising in the proceedings and may act on the adviser's opinion.

(2) Rule 31.53 applies to and in respect of a person referred to in subrule (1) in the same way as it applies to and in respect of a court-appointed witness.

(3) This rule does not apply to proceedings in the Admiralty List of the Supreme Court or to proceedings that are tried before a jury.

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Schedule 7

Schedule 7 Expert witness code of conduct

(Rule 31.23)

1 Application of code

This code of conduct applies to any expert witness engaged or appointed—

(a) to provide an expert's report for use as evidence in proceedings or proposed proceedings, or

(b) to give opinion evidence in proceedings or proposed proceedings.

2 General duties to the Court

An expert witness is not an advocate for a party and has a paramount duty, overriding any duty to the party to the proceedings or other person retaining the expert witness, to assist the court impartially on matters relevant to the area of expertise of the witness.

3 Content of report

Every report prepared by an expert witness for use in court must clearly state the opinion or opinions of the expert and must state, specify or provide—

(a) the name and address of the expert, and

(b) an acknowledgement that the expert has read this code and agrees to be bound by it, and

(c) the qualifications of the expert to prepare the report, and

(d) the assumptions and material facts on which each opinion expressed in the report is based (a letter of instructions may be annexed), and

(e) the reasons for and any literature or other materials utilised in support of each such opinion, and

(f) (if applicable) that a particular question, issue or matter falls outside the expert's field of expertise, and

(g) any examinations, tests or other investigations on which the expert has relied, identifying the person who carried them out and that person's qualifications, and

(h) the extent to which any opinion which the expert has expressed involves the acceptance of another person's opinion, the identification of that other person and the opinion expressed by that other person, and

(i) a declaration that the expert has made all the inquiries which the expert believes are desirable and appropriate (save for any matters identified explicitly in the report), and that no matters of significance which the expert regards as relevant have, to the knowledge of the expert, been withheld from the court, and

(j) any qualification of an opinion expressed in the report without which the report is or may be incomplete or inaccurate, and

(k) whether any opinion expressed in the report is not a concluded opinion because of insufficient research or insufficient data or for any other reason, and

(l) where the report is lengthy or complex, a brief summary of the report at the beginning of the report.

4 Supplementary report following change of opinion

(1) Where an expert witness has provided to a party (or that party's legal representative) a report for use in court, and the expert thereafter changes his or her opinion on a material matter, the expert must forthwith provide to the party (or that party's legal representative) a supplementary report which must state, specify or provide the information referred to in clause 3(a), (d), (e), (g), (h), (i), (j), (k) and (l), and if applicable, clause 3(f).

(2) In any subsequent report (whether prepared in accordance with subclause (1) or not), the expert may refer to material contained in the earlier report without repeating it.

5 Duty to comply with the court's directions

If directed to do so by the court, an expert witness must—

(a) confer with any other expert witness, and

(b) provide the court with a joint report specifying (as the case requires) matters agreed and matters not agreed and the reasons for the experts not agreeing, and

(c) abide in a timely way by any direction of the court.

6 Conferences of experts

Each expert witness must—

(a) exercise his or her independent judgment in relation to every conference in which the expert participates pursuant to a direction of the court and in relation to each report thereafter provided, and must not act on any instruction or request to withhold or avoid agreement, and

(b) endeavour to reach agreement with the other expert witness (or witnesses) on any issue in dispute between them, or failing agreement, endeavour to identify and clarify the basis of disagreement on the issues which are in dispute.

The effect of subsidence from long wall coal mining on the ecology and water quality of streams

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A thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Applied Science (Honours) at the University of Canberra

September 2016

Abstract

There has been much study as to the environmental effect of pollution from mining on freshwater systems, however, another potential impact of underground mining, subsidence, has been largely ignored from the public literature. Underground long wall coal mining has the potential to impact on surface aquatic environments via subsidence, cracking of underlying rock and increased connectivity between surface and ground water. This would result in reduced surface water, changes in water chemistry (water quality) as a result of water flowing over newly cracked rocks and these changes may ultimately affect biota living in surface streams.

The aim of this study is to investigate changes in macroinvertebrate, diatoms and water quality in streams which overlie long wall coal mining and thus potentially have subsidence. The study was conducted in headwater streams on the Woronora Plateau in eastern New South Wales, Australia where the geology is predominantly sandstone. I measured water depth and water chemistry, and sampled macroinvertebrate and diatom assemblages longitudinally downstream of underground mining areas as well as in reference catchments with no mining. The reference and mined areas were chosen because they were otherwise relatively undisturbed. I attempted to use trace metals as tracers of altered exchange between surface and ground waters as a result of subsidence. These metals are virtually absent from undisturbed streams but are released when groundwater flows through newly cracked sandstone of the study area.

Li was detected in significantly higher concentrations at mined than reference sites. Sites downstream of mining also had significantly higher temperature and electrical conductivity, and concentrations of bicarbonate, barium, calcium, sodium, iron, and chloride. Edge and riffle macroinvertebrate assemblages at both mined and reference sites were dominated by chironomid dipterans. Significantly lower EPT (Ephemoptera, Plecoptera and Trichoptera) taxa richness (3.4 vs 5.5 and 2.4 vs 5.4, in edge and riffle habitat respectively), number of Trichoptera genus (7 vs 19 and 8 vs 22, in edge and riffle habitat respectively) was observed at mined sites relative to reference sites. Diatom communities also differed between mined and non-mined sites with significant reductions in abundance but a greater number of genus observed at mined sites.

The differences in water quality and changes in flows following rainfall in streams overlying underground mining and those at reference sites is consistent with greater connection between the ground and surface waters. The changes in the stream macroinvertebrates observed in the current study are consistent with the one previously published study on subsistence. Water quality variables only partially explained these differences in macroinvertebrate and diatom assemblage. While it is impossible to rule out that the streams with mining under them had greater connection with the groundwater prior to mining, the areas were specifically chosen for their similarity. Consequently I conclude that the most likely explanation, is that underground mining has resulted in greater ground-surface water connection and this in turn has resulted in changes to the stream invertebrate and diatom assemblages. This study thus highlights an important poorly considered potential impact from underground long wall coal mining that should be urgently investigated further.

Certificate of Authorship of Thesis

Except as specifically indicated in footnotes and quotations, I certify that I am the sole author of the thesis submitted today entitled ***The effect of subsidence from long wall coal mining on the ecology and water quality of streams*** in terms of the Statement of Requirements for a thesis issued by the University Research Degrees Committee.

Signature ______________

Date 5/9/2016

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Appendices

1. Introduction

Long wall coal mining and surface subsidence

Long wall coal mining involves the extraction of large rectangular panels of coal by progressively shaving coal slices from an underground long wall face (IESC, 2014). Vast advances in mining machine technology and the use of temporary hydraulic supports from the 1990's have allowed for large long walls of coal to be extracted, up to 2km long and 300m wide (Holla and Barclay, 2000). At the same time pillar width has reduced, varying from 20-50 m wide, whilst maintaining worker safety. Land subsidence occurs when a sufficiently wide coal seam is mined and the overlying rock strata break and collapse into the extracted area, or goaf, by the influence of gravity and other forces. Above the goaf lies a fractured zone where rock permeability to water is increased to a lesser extent than in the collapse zone (ACARP, 2002). The fractured zone extends to a height above the seam of approximately 20 times the seam thickness, though in weaker strata this can be as high as 30 times the seam thickness (ACARP, 2002). Above this level, the surface strata will crack as a result of bending strains, with the cracks varying in size according to the level of strain, thickness of the rock stratum overlying the goaf and frequency of natural joints or planes of weakness in the strata (Holla and Barclay, 2000). Surface rock fractures associated with subsidence above a goaf have resulted in surface water to groundwater loss at several sensitive features including swamps and creek beds (Krogh, 2007; O'Kane, 2014).

1.1 Project aims

This project will look at the impact of surface water lost as a result of subsidence from long wall mining activity in the Woronora catchment in Southern Coalfields of New South Wales, Australia using several hypotheses:

- Firstly, that there is a loss of surface water lost beneath the creek bed and/or greater movement of water between surface and groundwater. This would occur as a result of rock fractures creating a conduit for water to travel into the groundwater. If this were to occur then water flow in stream would be expected to be lower following periods of rain and there would be greater concentrations of dissolved ions as a result of water flowing over newly cracked rock than in areas without mining.
- Secondly, that difference's in stream macroinvertebrate and diatom assemblages can be detected between streams above long wall coal mining and similar nearby streams.

- Finally, that correlating ecological health with water quality data can assist with determining long term impacts of stream surface water loss.

If the first hypothesis is correct then there should be elevated concentrations of four trace metals including molybdenum (Mo), beryllium (Be), chromium (Cr) and lithium (Li) in surface waters in the study region because they are potentially within minerals of local sandstone and have been exposed and released into the water from rock fractures.

International demand for coal

Many countries around the world rely on the burning of non-renewable coal for the majority of their energy production. Newly industrialised countries, including China and India, are continuing to increase their internal production and import coal to meet their rapidly expanding consumption needs (MCA, 2014). More developed countries including Canada, Australia and the United Kingdom extract coal at rates that exceed their internal needs to meet this export demand. Australia has the fourth-largest share of proven coal reserves in the world and by 2030 is predicted to be the biggest coal exporter in terms of volume (MCA, 2014). Australia currently ranks fourth in national proven coal reserves (8.0%) behind the US (27.6%), Russian Federation (18.2%) and China (13.3%) (BP, 2013). Coal accounts for 29% of the total international primary energy demand, predicted to only drop marginally to 25% by 2035 (MCA, 2014). Its demand currently lags behind oil, but ahead of gas, nuclear, biomass and renewable energy demands (MCA, 2014). At present, predictions on the growth of the renewables sector and reduction in non-renewable energy sources contradict between countries and international convening bodies. The International Energy Agency (IEA) predict renewable energy to meet 25% of global energy demand by 2020, yet the Minerals Council of Australia (MCA, 2014) predict renewables to not reach a total of 5% until 2035. These conflicts make planning and management difficult, but do indicate that the demand for the coal industry may remain strong in Australia and around the world for many decades to come.

In terms of resource life, current estimates of coal resources contributing to Australia's economic prosperity are 110 years for black coal and 510 years for brown coal (lignite) (MCA, 2014). As coal resources around the world are finite, more advanced techniques to extract the maximum possible coal from underground seams are being employed, often exacerbating environmental impacts. An understanding of the cumulative effects of these impacts is a leading theme in current research to help understand the sustainability of the coal industry. Cumulative impacts may result from complex environmental, economic, social and cultural interactions (Franks *et al* 2010) and a better understanding of management and assessment practices will enhance positive, and avoid and mitigate negative, cumulative impacts.

One of the international concerns raised in more recent decades is the impact of coal mining on headwaters and low order streams, and the implications of these impacts on water quality and ecological health, including biodiversity. These streams are increasingly being recognised for their important role in influencing the character and quality of downstream waters (Meyer *et al*, 2003). Small streams and wetlands play an important role in providing habitat for plant, animal and microbial life, and many species rely on these small water bodies at some stage in their life history (Meyer *et al*, 2003). Land-use changes in the vicinity of headwaters can alter these channels so they are less efficient at re-charging groundwaters, trapping sediments and recycling nutrients (Clarke *et al*, 2008). They are also extremely sensitive to degradation and any loss of water ultimately impacts their use as migration corridors throughout the systems (Meyer *et al*, 2007).

Coal mining and environmental impacts

There is much literature on the environmental impacts of coal mining. Different areas experience a unique suite of issues associated with the removal of coal, predominantly related to the depth of the coal seams present and the significance of over and under lying geological formations, including aquifers. International literature focusses on the investigation of a vast array of these problems in relation to their impact on the economy and worker safety rather than the environment within particular regions (Zhang, 2005; IESC 2014). Furthermore, as each region has a unique geology, climate and differing anthropogenic activity, predictive models and environmental impact monitoring that may be conducted are often only applicable to the associated area they were conducted in (ACARP 2004, 2011, 2012).

In the Appalachian forests of the USA, the presence of shallow coal seams in mountainous regions has led to the development of the relatively recent mountaintop mining with valley fill operations (MTVF). This technique involves complete removal of the mountain tops using explosives and pushing the debris into adjacent valleys. By 2011, 1.1 million hectares of forest had been reclaimed and converted to surface mines, resulting in the loss of forests, burial of 2,000km of freshwater streams and the downstream transport of sediment and chemical pollutants (Bernhardt & Palmer, 2011). A recent study found sustained ecological damage in terms of water quality and macroinvertebrates in headwater streams draining valley fills (VF) long after reclamation was complete (Pond *et al*, 2014).

In other areas of the US, Europe, South Africa and Australia both surface open-cut and underground long-wall mining techniques are used to extract coal from varying layers of the substratum (generally below 100m). Subsidence, as a result of long wall mining, is increasingly being linked to adverse environmental impacts (Sidle *et al*, 2000; Krogh, 2007; Jankowski *et al*, 2008). Again, impacts from subsidence differ in each area and predictions of subsidence impacts are difficult to determine in Australia based on international results (IESC, 2014). One American study in Utah found subsidence during three years of extraction had no impact on stream flow derived from sub-surface flow or near-channel landslides (Sidle *et al*, 2000). Further analysis of the geological condition of the area determined that mudstones present in the strata swell and act like fillers upon exposure to the atmosphere and thus most impacts from subsidence are short-lived as any apparent cracks in the ground tend to close quite rapidly. In Australia, initial predictions of subsidence were calculated as they were in the UK (IESC, 2014) which proved unsuitable for the sandstone dominated upper strata of the southern coalfields (within which this study was conducted). Cracks that appeared as a result of long wall mining were predicted to close after three to four years but still remain open and exposed decades later (Krogh, 2007).

Long wall coal mining effects on reduced water flow

Mining induced subsidence that occurs under swamps and creeks increases the interaction between surface and groundwater due to the enlargement of existing, and development of new fractures and fracture zones (Figure 1, Jankowski, 2008).

Figure 1 Evidence of long wall mining induced cracking from subsidence on the left bank (left) and right bank (right) at Waratah Rivulet (WR4), Woronora (April 2015)

A case study in the current study area by Jankowski (2008) drew two main conclusions: firstly, that a loss of surface water to subsurface flow through fractured stream beds causes downstream flow reductions during periods of low-flow; and secondly, changes in the chemical composition of the surface water along the rivulet are attributed to surface water flow into sub-surface aquifers and downstream discharge of the subsurface flow back to the surface. The effect of these two impacts on macroinvertebrate and diatom community assemblages will be further analysed within the aims of this study.

Aquatic ecosystems are highly dependent on the connectivity, quantity and quality of water in streams and groundwater (Boulton *et al*, 2014). Changes in water flow can affect water temperature and salinity, and the connectivity of stream habitats (Bunn *et al*, 2002; Krogh, 2007; Poff *et al* 2010). The effect of changes to this connectivity and flow regime, and subsequent impact on biological health has been researched with respect to river regulation (Bunn *et al*, 2002; Tharme, 2003; Arthington *et al*, 2006 & 2010).

When a permanent flowing stream loses a significant amount of baseflow water to the subsurface, as a result of subsidence induced cracking, the hydrological dynamic changes to that of a ponded stream. In worst cases where all baseflow is lost, it changes to that of a temporary stream. Temporary streams only flow for a period of time after rainfall and are more prone to invasion by non-native species, loss of native species and loss of habitat refuge from predators (Williams, 1996). Bunn *et al* (2002) also found the flow regime is a key driver of aquatic ecosystems and that natural flow regimes assist an ecosystem in maintaining biodiversity and resilience to invasion. The number and diversity of macroinvertebrate species has been shown to be considerably lower in temporary ponds (Collinson *et al*, 1995) and that depth, permanence, flow and altitude were the main drivers of community assemblages (Williams *et al*, 2004).

The increasing number of temporary rivers and high degree of flow intermittence were investigated by Larned *et al* (2010) and are commonly attributed to climate change and water extraction in some areas and, this trend may be increasing over the next century. Long wall mining is further adding to the cumulative impact of changes to the natural water flow but the extent and impact of this and long-term impact on the aquatic ecology has not clearly been established yet.

Long wall coal mining effects on water quality

A conceptual model of mining induced subsidence on rock fractures, water transport, river ecology and trace metal release and movement is illustrated in Figure 2.

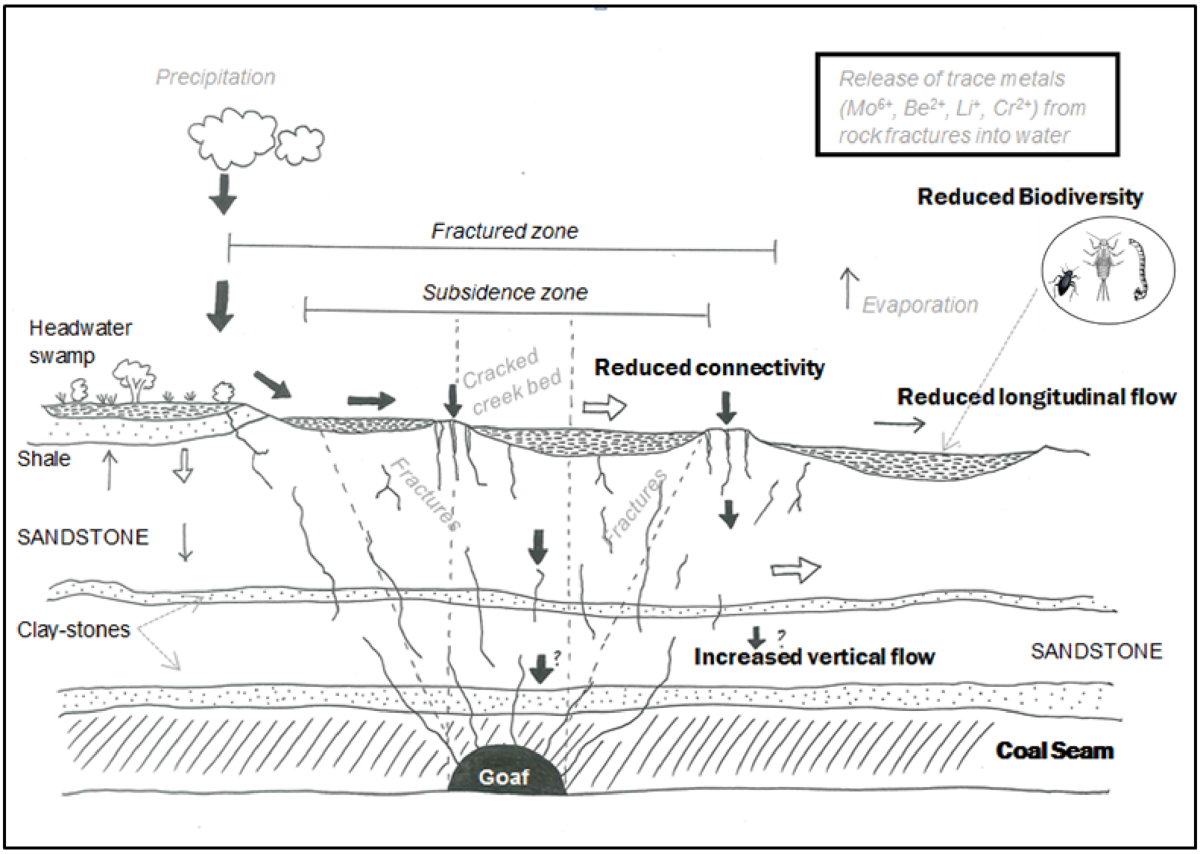


Figure 2 **Conceptual model of mining induced subsidence on rock fractures, water transport, stream ecology and trace metal release**

Adverse effects of long wall coal mining on water quality have been well documented and understood (Parsons Brinkerhoff, 2007). Increases in salinity, conductivity, heavy metals, iron, manganese, aluminium, sodium, calcium, barium, chloride and sulphate; lowering of pH and dissolved oxygen; and the conversion of carbonates to bicarbonate ions have been commonly reported as a result of the increased mixing of surface and groundwaters because of rock fractures (Weider *et al*, 1984; Tiwary, 2000; O'Kane, 2014). There are also reductions in depths of pools, gas releases and excessive microbial growth in long wall mined sites (Parsons Brinkerhoff, 2007). The impact of these pollutants, although not necessarily from coal mining, on water quality and biota is a major environmental issue worldwide (Tiwary *et al*, 1997; Demchak *et al*, 2004) with long term damage reported (Bhuiyan *et al*, 2010). The occurrence of iron precipitate and iron-oxidising bacteria is particularly evident in rivers where surface cracking has occurred (Jankowski, 2008). Anaerobic bacteria commonly occur in vast iron mats in Hawkesbury Sandstone areas, where seepage through the rock is often rich in iron compounds (Meyers *et al*, 1998) and are able to grow in water lacking dissolved oxygen. Where the bacteria grow as thick mats they reduce interstitial habitat, clog streams and reduce available food for higher order organisms (DIPNR 2003). Loss of native plants and animals may occur directly via iron toxicity, or indirectly via smothering.

Use of trace metals as tracers

The underlying rock in the current study area is sandstone, which consists of a mix of minerals and older rock fragments, of many types, as a result of erosion, and the total variety of rocks is usually represented in the nearby sediments (Pettijohn, 1972). The abundant minerals of sandstone belong to a few major groups and a variety of heavy minerals may be found, most in trace amounts, making up less than one percent of the total composition (Pettijohn *et al*, 2012). Sandstone minerals include tourmaline and zircon, which are resistant to mechanical and chemical attack, and amphiboles and pyroxenes, which show little resistance to decay. These minerals may be lost or modified in three ways: by weathering in the source area; transportation to the site of sedimentation; and, by the alteration of original pore type and geometry due to compaction, cementation and dissolution, otherwise known as diagenesis (Pettijohn *et al*, 2012). These modifications naturally tend to occur over long periods of time.

Chemical elements such as major ions, trace elements and metals occurring in the rock matrix are mobilised in freshly exposed rock fractures adding to the chemical composition of surface water (Jankowski, 2008). Subsidence as a result of long wall mining allows fresh rock to undergo chemical interaction with oxygenated surface waters. This can also result in discolouration associated with oxidation of the fresh sandstone and an increased chemical load in surface and ground waters in the immediate area (Pettijohn *et al*, 2012). Such impacts can also occur some distance downstream of the subsidence area and exposes rock to chemical alteration much faster than natural erosion does. Consequently it can be difficult to distinguish between natural and anthropogenic contributions to water chemistry in mined sites.

In aquatic environments, trace metals tend not to deteriorate chemically because of their low solubility and high partition coefficient within neutral pH conditions (Halim *et al*, 2012). Sedimentary dispersal of heavy minerals can be directly correlated to particular source areas undergoing tectonic evolution, or movement, thus making them incredibly useful as tracers (Pettijohn *et al*, 2012). Furthermore their use as geochemical tools for tracing groundwater sources was developed by Johannesson *et al* (1997) and proved especially useful in determining groundwater-rock interactions (Johannesson *et al*, 1997). More specifically beryllium (Be) has been used as a tracer to identify water masses in the Atlantic Ocean (Burton, 1988) and lithium (Li) has been especially useful in helping determine the fate of water through a drainage system (Zellweger, 1990).

To date no research has focussed on the use of four trace metals Mo, Be, Cr and Li but they would be considered useful as tracers for water transport associated with surface and ground water movements over fractured sandstone as a result of subsidence. Previous studies have indicated that elevated trace metal concentrations around mines in a wet climate are principally from non-anthropogenic sources and are readily attenuated by natural processes (Hewlett, *et al.*,2005). This will be further investigated by the collection of samples at six reference sites in the study area to determine natural baseline levels. In this study, their usefulness in determining how mining increases their mobilisation by creating new flow paths will be investigated.

The study is being conducted in the restricted zones within Sydney's drinking water supply because it lies within a near pristine catchment with minimal anthropogenic activity. If the study were conducted elsewhere it would be uncertain if elevated concentrations of the four elements were the result of mining or other human activities. However, in the study catchments any increase in the four selected trace metals, at extremely low detection limits (0.01µg/L), would be consistent with groundwater travelling through newly cracked sandstone and re-emerging to the surface downstream.

Long wall mining and macroinvertebrate health

Macroinvertebrates are good indicators of stream health as they are relatively easy to sample, have been extensively researched for their sensitivities and tolerances to varying types of pollution and occupy many areas of in-stream habitats due to their wide range of morphological adaptations across many taxa groups (Rosenberg *et al*, 1993; Lenat, 1993; Bonada *et al*, 2006). By analysing quantitative macroinvertebrate community assemblage across several geo-morphologically similar streams with varying spatial association to long wall coal mining, and comparing to reference streams, conclusions may be drawn on the impact long wall mining is exerting on the aquatic environment.

Despite the fact that long wall coal mining is conducted worldwide and impacts of wastewater discharge on receiving streams is well established (Decker-Hess, 1978; Wright *et al*, 2015), its quantitative effect on the aquatic environment is not well established. A review by DECC (2007) identified a clear lack of published, peer-reviewed studies of the impacts of mining-induced subsidence on riverine ecosystems.

They inferred from observed physical changes to aquatic habitat that no aquatic dependant biota can exist when fluvial systems are cracked as a result of long wall mining and all surface water is lost. When connectivity is restored, aquatic species can recolonise but, they concluded that in areas showing much longer impacts, the cracks do not naturally seal.

No quantitative studies solely linking physical subsidence from long wall mining with changes in species populations and/or community composition have been conducted globally (DECC 2007). Data that does exist as a result of mining monitoring is not publicly available, i.e. is protected by "commercial in confidence", is not collated or published in peer-reviewed journals.

International long wall coal mining research was further reviewed by Krogh (2007) and DECC (2007) and significant impacts (up to 50% loss) to headwater streams were noted in parts of West Virginia, USA (Stout 2004). Stout (2004), while a scientific document, is not published in a peer-reviewed journal, but remains one of the only study of this topic. It concluded:

1. *Aquatic macroinvertebrate communities in reference streams were ubiquitous across the region, rich in diversity and long-lived*
2. *Long wall mining resulted in a net loss of approximately one-half of all headwater streams in the region*
3. *Streams were particularly impacted near the source and flows re-emerged downstream*
4. *Macroinvertebrate abundance appeared to recover to reference conditions in lower reaches of long wall mined streams*
5. *Macroinvertebrate diversity and longevity did not recover downstream*
6. *There was no indication that the physical, chemical or biological impacts of long wall mined streams recover naturally over time.*

Stout (2004) found these effects may still be evident 12 years after mining and resulted in the complete halting of a long wall project due to its threat to water flow in West Virginia (Stout, 2004). A more recent study by Wright *et al* (2015), published during the production of this thesis, found decreased taxa richness, EPT abundance and Ephemeroptera abundance at sites impacted by subsidence from longwall coal mining.

Monitoring reports by mining companies and their contractors within the Southern Coalfields are available on the websites of main contractors engaged to complete the works but generally do not list detailed results and predominantly use rapid assessment (qualitative) family level macroinvertebrate identification data which are analysed with predictive observed/expected models (eg. https://www.south32.net/getattachment/our-operations/Australia/illawarra-coal/Regulatory-Document/Ilawarra-Coal,-Dendrobium/Dendrobium-Area-3B-Longwall-11-End-of-Panel-Report.pdf). Further research and reports by the Australian Coal and Research Projects (ACARP) are not publicly available and have generally focused on increasing extraction yields, while maintaining safety to workers and protection of groundwater systems. Reports can be purchased from ACARP with varying price depending if purchaser is associated with a research institution or not.

Long wall mining and diatoms

Diatoms are good indicators of stream health, especially in understanding the ecological effects of flow regulation on streams (Growns & Growns, 2001). They are useful because of their sensitivity to specific environmental disturbances or pollution and they have been shown to correlate more strongly with changes in water quality measurables than changes to physical habitat (Walsh *et al*., 2001). No data exists on the effect of subsidence from long wall mining on diatom assemblages, rather the literature has focused on diatom response to changes in water quality associated with varying levels of river regulation. Growns & Growns (2001) found that periphytic diatoms differed downstream of flow regulated rivers when compared to upstream sites and sites on un-regulated rivers. Recovery downstream of regulation has been shown to occur in diatom assemblages (Cortez *et al*., 2012), with increased recovery corresponding to decreased regulation. Genus identification was deemed a suitable taxonomic level due to the limited number of species belonging within each genus and similarity of the data when analysed at both species and genus level in previous studies (Growns, 1999).

The potential for increased surface water and groundwater connectivity in streams, as a result of subsidence, to alter hydrology and impact on diatom community assemblages were investigated in this study. This was to help further understand whether changes in water quality or flow regimes were the main drivers of any change which was made possible in the study area because of the lack of additional anthropogenic influence other than the long wall mining.

1.2 Project background

The idea for this project arose after an initial enquiry into researching the possible impact of coal seam gas extraction on stream water quality in the restricted areas of Sydney’s drinking water catchment, now managed by WaterNSW (formerly Sydney Catchment Authority, SCA). Further investigation revealed that staff at both

WaterNSW and Office of Environment & Heritage (OEH) indicated their concern at the complete lack of quantitative studies on the impact of long wall coal mining on aquatic ecosystems. They were of the concern that long term impacts of long wall coal mining on the aquatic health were at present far greater than any yet posed by coal seam gas extraction.

Further review of the literature did indeed reveal a depauperate understanding of quantitative impacts of long wall coal mining and subsequent subsidence on aquatic ecosystems including on macroinvertebrate and diatom community assemblages. Internationally, the impacts of subsidence vary according to climate, geology and mine depth. This thesis studied impact of long wall coal mining occurring at depths of 400 to 800m underground on streams above the Hawkesbury sandstone strata that may have been cracked as a result of subsidence in the Southern Coalfields of NSW.

1.3 Study Area

This study took place in the Woronora River catchment and adjoining O'Hares and Cataract River catchments. These catchments are located approximately 50km south of Sydney, New South Wales, Australia (Figure 3). This area was targeted for this research within the restricted access zone of Sydney's drinking water supply catchment. Having sites in this zone ensured that other than long wall coal mining, the area had extremely minimal local anthropogenic activities. While effects due to regional and global anthropogenic activities (e.g. climate change, vegetation clearing, polluted stormwater runoff, transport of toxicants) may have affected reference and test sites equally.

I was granted access into these special areas by Water NSW under approval no. D2015/50283 and D2016/38818.

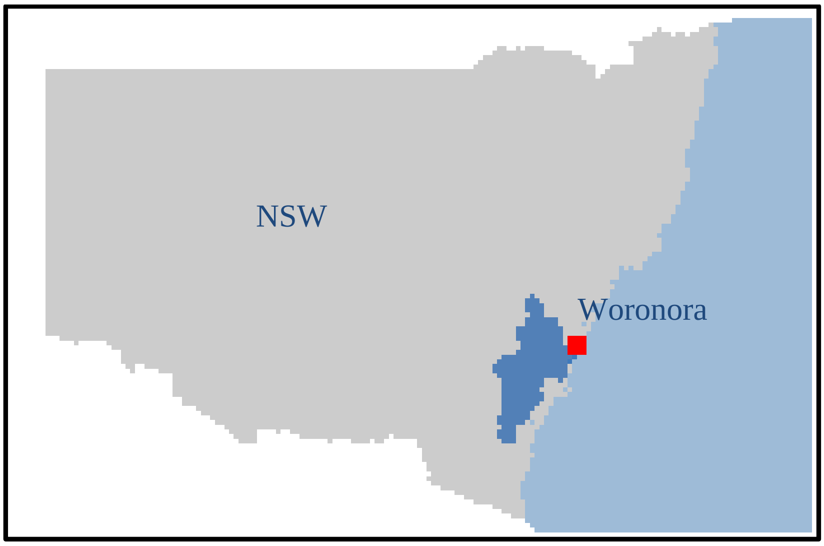


Figure 3 **Woronora catchment location south of Sydney, NSW (*source: Alec Davie, Water NSW*)**

Four streams were selected for this study (Figure 5). Two streams potentially impacted by longwall coal mining with a combination of decade old, recent and current mining:

1. Waratah Rivulet – 10-14 years since mining and recent (2 years) mining activity
2. Eastern Tributary – 10-14 years since mining, recent and current mining activity

And, two reference streams nearby in which no mining had occurred or was proposed to occur:

3. O'Hares Creek
4. Loddon River

O'Hares Creek lies within the Dharawal Nature Reserve in the upstream reaches of the Georges River catchment (Figure 5). This catchment lies approximately 4km to the west of the Woronora River catchment and has similar climate, geology and altitude.

The Loddon River drains to the Cataract River, approximately 8km south-west of the Woronora River catchment (Figure 5), also within similar climate, geology and altitude ranges.

On each river, three sites were selected approximately 0.5 to 3.5km apart longitudinally along the streams. On each of the two rivers with long wall mining, all three sites were located downstream of mining activity. Sites on the two non-mined reference rivers were similarly located and these rivers have been included as a reference to compare with the mined streams.

Figure 4 **Non-mined O'Hares Creek (left) and mined Waratah Rivulet (right)**

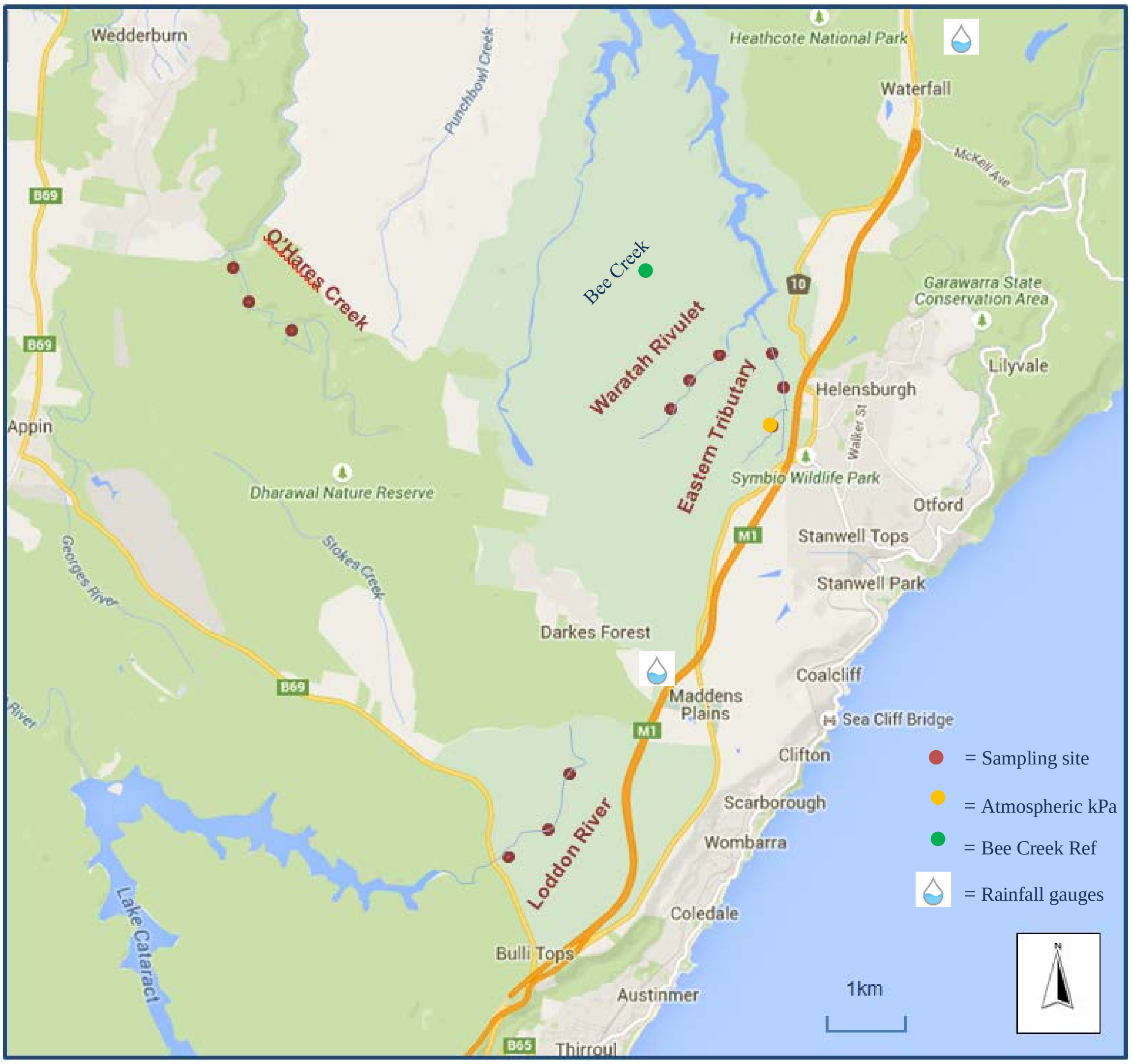


Figure 5 **Woronora catchment including Waratah Rivulet and location of reference sampling sites (source: www.Nearmap.com)**

Table 1 Site codes, potential impact, latitude and longitude (obtained from a GPS) and distance from source for all sites

Creek	Site Code	Latitude	Longitude	Distance from source (km)
Eastern Tributary (mined)	WR1	-34.196930	150.955541	2.540
	WR2	-34.185483	150.961761	4.109
	WR3	-34.183308	150.961740	4.409
Waratah Rivulet (mined)	WR4	-34.197197	150.933523	3.169
	WR5	-34.189370	150.942686	4.558
	WR6	-34.185603	150.943998	5.250
O'Hares Creek (non-mined)	OH1	-34.238956	150.918408	3.832
	OH2	-34.234506	150.906461	7.422
	OH3	-34.230061	150.892574	10.063
Loddon River (non-mined)	LR1	-34.281745	150.916100	2.834
	LR2	-34.284690	150.913702	3.649
	LR3	-34.285269	150.910076	4.354

1.4 Licenses

NPWS

A National Parks and Wildlife Service license was required for macroinvertebrate sampling in areas operated by the NSW Office of Environment and Heritage. O'Hares Creek partially falls within this jurisdiction and as such I have included my NPWS licence below.

License No: SL100638, Catherine Cunningham

NSW Fisheries

A NSW Fisheries license was obtained for the collection of any macroinvertebrates from water courses in NSW (*License No: F93/527-5.0 & OUT15/11731, Catherine Cunningham)*. A condition of this license is the assurance that *'no endangered animals will be collected, and if they inherently are sampled in a collection net, that they are safely returned to their habitat as soon as possible*'.

Animals listened on the NSW Threatened Species List likely to occur in study area include:

Sydney Hawk Dragonfly: *Austrocordulia leonardi*
Adams Emerald Dragonfly: *Archaeophya adamsi*
Spiny Crayfish: *Euasticus dharawalus*

Animal fact sheets (www.DPI.nsw.gov.au/primefacts) were carried into the field as visual guide for easy identification.

Animal Ethics

An animal ethics approval was not required for this project as macroinvertebrates are exempt from the NSW list of animals requiring ethics approval.

2. Materials and Methods

2.1 Rainfall

So as to investigate the potential for rain to influence water quality results, I sourced daily rainfall data (mm at 9am for the preceding 24 hours) from April 2015 to February 2016 from the Bureau of Meteorology (BOM) rain gauge at Darkes Forest (gauge no. 68024) and Sydney Water (SW) HYSTRA rain gauge at Yarrawarrah (gauge no. 566056) (Figure 8). These gauges were selected due to their proximity (less than 10km) and similar rainfall patterns to the Woronora catchment. Monthly averages from these gauges for the last 20 years (1995-2015) were also compiled and compared with rainfall over the study period.

2.2 Water Level

To enable a better understanding of the upstream and downstream connectivity within each creek, the potential of cease to flow events occurring, and whether this varied between creeks and non-mined and mined sites (non-mined and mined), I used continuously monitored water level data.

To determine this, I used data loggers (HOBO ® U20L-4) placed inside plastic tubes within upstream and downstream locations of creeks (Figure 5) to collect temperature (^{o}C) and pressure (kPa) data every 30 minutes during the course of the project. An additional data logger was placed at -34.193616, 150.949885 (Figure 5) to measure pressure of the air on top of the water. The Barometric Compensation Assistant (BCA) tool within HOBOware PRO (V2.2 http://www.onsetcomp.com/hoboware-free-download) was used to calculate the water depth based on the following equation:

$$p = h \rho g$$

where:

p = pressure in fluid (kPa)

h = height of fluid column, or depth in the fluid at which the pressure is measured (m)

ρ = density of liquid (freshwater is 1000 kg/m^3)

g = acceleration of gravity (9.81 m/s^2)

Further flow and discharge data were available from Water NSW and Peabody Energy but was deemed unsuitable for this project due to single gauge placement, on only Loddon River and Waratah Rivulet, and location far downstream of study area.

Deployment of four HOBO® U20L-4 water level loggers at the upstream and downstream sites on Loddon River and Eastern Tributary sites was not successful. Third party removal of the downstream (WR3) water level logger on the Eastern Tributary, within the first two weeks of deployment, and slow approval from catchment managers to place loggers in the Loddon River, along with numerous restricted access periods due to bushfire and rainfall, resulted in failed deployment at these sites.

Additionally, the first attempt to download data from the remaining in-stream and atmospheric loggers from O'Hares Creek and Waratah Rivulet, after 6 months deployment, also failed due to a low battery error. All battery issues had to be referred to, and subsequent battery replacement, had to be conducted by the manufacturer to avoid warranty issues. The five faulty loggers had to be sent to the Australian distributer in Adelaide, battery replacement had to occur in the United States of America (US) and no replacement HOBO® U20L-4 water level loggers were available for deployment. As a result, considerable delay occurred, and data loggers were only redeployed for a 2 month period at upstream and downstream sites on O'Hares Creek and Waratah Rivulet, and the additional logger to compensate for barometric pressure.

2.3 Sampling Events

Physicochemical properties of water (water quality) and macroinvertebrates were sampled at all sites on two occasions in August and November, 2015. August sampling proceeded a slight rainfall event, defined as <20 mm in the last 5 days and November proceeded a moderate rainfall event, defined as >20 mm to 70 mm in the last 5 days and as soon as possible once able to gain access to the catchments, which have restricted access following rainfall. I was aiming to collect samples during both wet and dry periods because I hypothesised that the ecological impact of any loss of surface water from long wall mining would be greater during dry periods than during wet periods. Unfortunately, due to restrictions placed on authorised access into the catchment and lack of suitable extended dry periods I was able to sample only following slight and moderate rainfall events, in the winter and spring seasons of 2015. From herein, the two sampling events are referred to as winter (S1) and spring (S2).

Algae (diatom) samples were collected only once during the first sampling event in winter 2015 due to time and cost restraints.

2.4 Sampling Design

The overall design of the project for statistical comparison was consistent for all chemical and biological variables (Figure 6), except diatoms which were only analysed using the first two levels due to their single sampling event in winter.

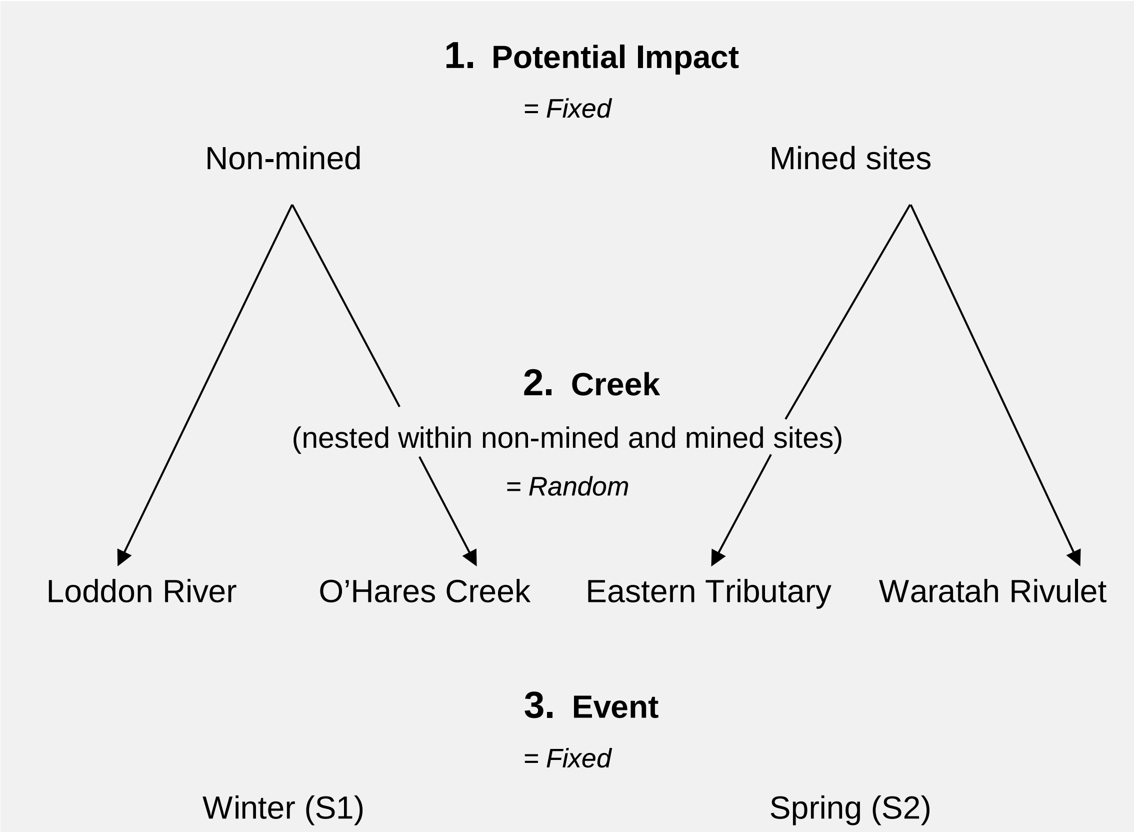


Figure 6 Overall project design and nesting of factors for statistical analysis. See also Figure 5 for a map and Table 1 for site locations. Replicates = water quality x 2, macroinvertebrates x 4 (per habitat) and diatoms x 3.

2.5 Water Quality

Sampling Methodology

Duplicate water samples were collected and subsequently analysed at ANSTO or Sydney Water laboratories (Table 2), and other variables were measured directly in the field (Table 3). Concentrations of Cr, Mo, Li and Be were used as tracers to determine if groundwater to surface water interactions had increased through newly cracked sandstone. Extremely low detection limits of 0.01µg/L were required. To avoid contamination aseptic techniques were used (SW, 2015[1]) and sample bottles without preservative were rinsed before filling.

Table 2 Water chemistry variables, detection limits and analysis method

Analyte	Detection limit	Method, laboratory, bottle
Part I - Trace metals (USEPA, 1998)		
Chromium (Cr)	0.01 µg/L	Modified method ANSTO VI 2809, Super acid washed 250ml
Molybdenum (Mo)	0.01 µg/L	Modified method ANSTO VI 2809, Super acid washed 250ml
Lithium (Li)	0.01 µg/L	Modified method ANSTO VI 2809, Super acid washed 250ml
Beryllium (Be)	0.01 µg/L	Modified method ANSTO VI 2809, Super acid washed 250ml
Part II – Major ions (APHA, 1998)		
Bicarbonate	0.1 mg/L	WC01TIM, SW, 500 mL PET no preservation
Sulphate	0.1 mg/L	WC0221, SW, 500 mL PET no preservation
Calcium	0.01 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Iron	0.02 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Manganese	0.001 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Aluminium	0.01 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Sodium	0.05 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Barium	0.005 mg/L	TM50ML, SW, 250 ml polyethylene pH < 2 with nitric acid
Chloride	0.1 mg/L	WC0221, SW, Plastic 500 ml no preservation
Carbonates	0.1 mg/L	WC01TIM, SW, Plastic 500 ml no preservation

Table 3 Field water chemistry variables and instrumentation

Analyte	Instrument
Dissolved Oxygen (%)	WTW Multilinear Universal Meter
Dissolved Oxygen (mg/L)	WTW Multilinear Universal Meter
Conductivity (µS/cm @25^{o}C)	WTW Multilinear Universal Meter
pH (pH units)	WTW Multilinear Universal Meter
Temperature (^{o}C)	WTW Multilinear Universal Meter
Turbidity (NTU)	HACH Turbidimeter

Laboratory Analysis

Trace metals

Trace samples (Table 2, Part I) were analysed using a Varians 820-MS inductively coupled plasma mass spectrophotometer (ICP-MS) at the Australian Nuclear Science and Technology Organisation (ANSTO) laboratories at Lucas Heights, NSW. A modification to their existing standard method, VI 2809 (ANSTO, 2015), was used to determine trace concentrations of Cr, Mo, Li and Be. This modification involved dosing individual samples for each element with a differing ratio of the international standard (IS) as shown in Figure 7b.

The IS used for each element for correction of instrument drift and sample matrix were selected because they were absent from the samples analysed but were very close to each target elements mass. They were:

- Isotopic $^{6}\delta$ Lithium for $^{7}\delta$ Li and Be
- Isotopic $^{103}\delta$ Rhodium for Cr and Mo

The average of three readings was reported for each duplicate sample at each site and sampling occasion. Recovery spikes (using known concentrations of Cr, Mo, Li and Be) were reported separately as concentrations and percentages, respectively. Reliable results within 85%-115% recovery were regarded as reliable. Results outside this range are reported but not considered further in this study.

Care was taken to avoid cross contamination during laboratory analysis to achieve the highest quality analysis with reproducible results. Gloves were worn at all times and, all tubing and cones in the ICP-MS were replaced between samples to avoid any contamination. The ICP-MS machine was also set to high sensitivity mode and tuned between each sample to gain the maximum sensitivity.

As quality assurance, a field blank, filled with ultrapure milli-Q water in the field each season, was analysed to help determine detection limits and sources of possible contaminants from the atmosphere or the sampling process.

Variation to the standard method, VI 2809 (ANSTO, 2015), involved dosing individual samples for each element with a differing ratio of the international standard (IS) as shown in Figure 7b. This modification was possible because the environmental samples were from clean water in a near pristine catchment (Figure 3).

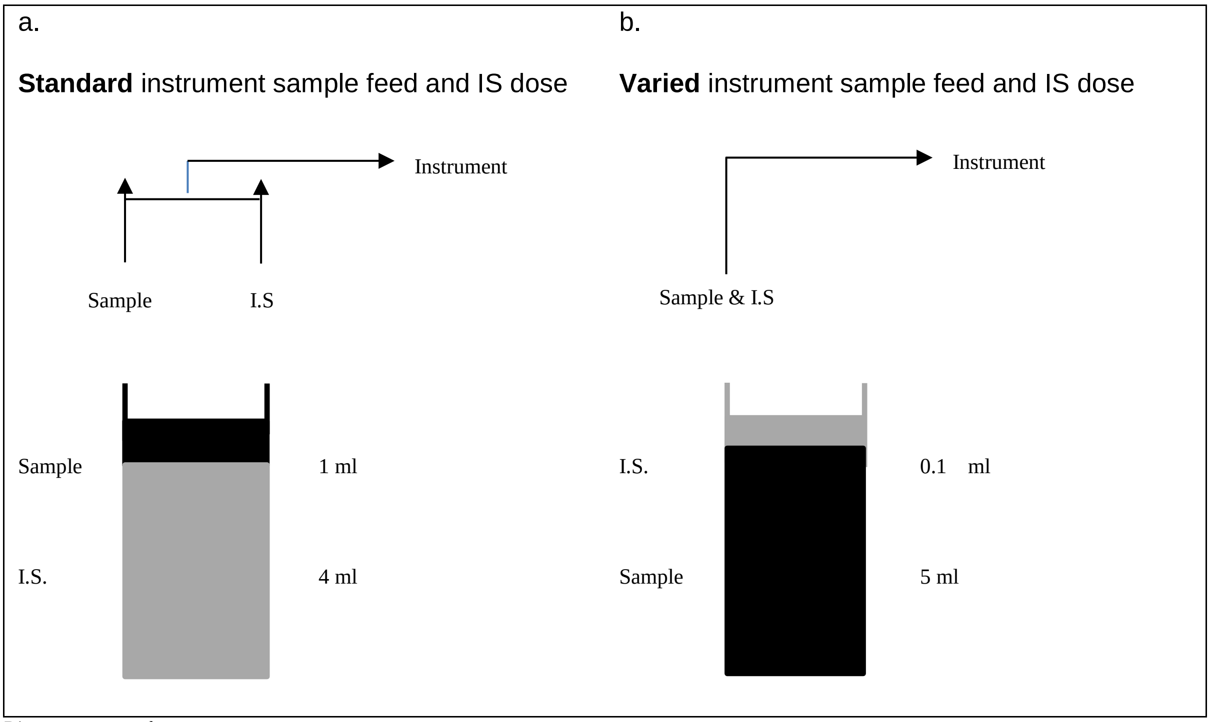


Diagram not to scale

Figure 7 Existing ANSTO method VI 2809 (a) and variation (b) to achieve new detection limits

Other variables

All other samples (Table 2, Part II) were delivered to the Sydney Water Analytical Services laboratories within 24 hours of sampling and processed with current methods (APHA, 1998).

2.6 Macroinvertebrates

Macroinvertebrate Sampling

Semi-quantitative macroinvertebrate samples were collected to indicate instream aquatic health. Four replicates from both edge and riffle habitats were collected using a 35 by 35cm square opening hand-held dip net with 250µm mesh. Boothroyd & Stark (2000) suggest that between three and six replicates from each habitat should adequately characterise macroinvertebrate communities.

Edge habitats are defined as areas with little or no current. The sampling net was swept rapidly four times within a 1.0m^2 quadrat section of edge from open water towards the stream bank based on method developed by Growns (in draft , 2015). The substratum was then disturbed by foot and a further two sweeps collected. During the process, deposits of silt and detritus on the stream bottom were stirred up so that benthic animals were suspended and caught in the net.

Riffles were considered a habitat of value with unique fauna to help distinguish community assemblage differences among sites. Riffles at all sites were near 100% bedrock areas with fast flowing water but was usually limited in size and availability. The net was held downstream of four bedrock 1.0 x 0.5m quadrats, clearly marked, which was cleared of all macroinvertebrates and debris using a gloved hand rubbed over the rock surface. Starting at the downstream edge, the net was slowly moved upstream after each small area was cleared, taking special care to clear any crevices. This sampling was modified from Surber (Waters & Knapp, 1961) due to the inability to wedge a Surber sampler into the bedrock substrate.

Macroinvertebrate samples were then tipped into a 250µm mesh sieve, washed to remove fine silt and transferred to 500 ml plastic labelled specimen jars containing 70% un-denatured ethanol as preservative. Clean nets were used for each site and thoroughly washed between field trips to prevent cross-contamination of samples.

Macroinvertebrate Processing and Analysis

Macroinvertebrates were identified and enumerated to the genus level with the aid of Leica M10 stereo and Leica DC1000 compound microscopes. They were identified as per latest Australian published keys (Hawking & MDFRC, 2013) and Sydney Water in-house keys (SW, 2015[2]), reference specimens and photographs.

Biotic indices calculated on macroinvertebrate results include:

- Total abundance i.e. the total number of individual macroinvertebrates
- Taxa (genus) richness - Indeterminate and small immature specimens were removed from data set and life-stages were combined before analysis. Except, where an immature/small specimen was recorded for a family not already represented at a site it was retained in dataset at unique family level.
- EPT (Ephemoptera, Plecoptera and Trichoptera) taxa abundance and richness -. Again, immature and indeterminate specimens were removed from the dataset before analysis.
- SIGNAL-SG score (Sydney, genus) (Chessman and Besley, 2007) - to determine whether stream health, as indicated by sensitivity to increasing pollution (1 = tolerant, 10 = sensitive). An abundance weighted calculation (square root) was performed on raw data before analysis. Results were compared to the stream health range in Table 4.

Table 4 Signal SG score range

SG score range	Interpretation
>6.5	Indicative of clean water
5.2 – 6.5	Slightly impacted stream health
3.8 - 5.2	Moderately impacted stream health
<3.8	Severely impacted stream health

In addition, abundance data were amalgamated to overall Order (taxa) and functional feeding group (FFG) percent composition. Individual Orders and functional feeding groups that contributed ≤1% of the total abundance across all samples were removed when graphing results.

2.7 Diatoms

Diatom Sampling

Diatom sampling was conducted as per Growns and Growns (2001). Three diatom replicate samples were collected from three separate submerged rocks (at least 20cm below surface) within pools. These triplicate samples were collected from upper, mid and lower reaches at each site.

Each diatom sample consisted of scraping from a 2.5 x 2.5cm quadrat on the upper exposed side of the rock using a flat, sharpened stick and placed in a jar containing 20ml water and 7 drops of Lugol's iodine.

Diatom Processing and Analysis

Diatom samples were vortexed for two minutes to break up any clumps and then diluted to 100ml before analysis. Eight 0.5ml^3 volume Lund cell transects were performed from each sample using both 10x and 40x magnification under a compound microscope as per methods (MA51) outlined in Sydney Water (2015[3)]. Within each transect only live frustules were identified and enumerated to genus level where possible and dilution factors were applied to the results to calculate whole sample counts.

Indeterminate and immature genera were removed from data set and life-stage combined before analysis.

2.8 Statistical Analysis

Individual water quality, macroinvertebrate and diatom (hereafter response variables) were averaged (with +/- 2 standard deviation from the mean) and graphed for each creek by:

- Non-mined and mined sites nested within season, and
- Position on stream (upstream, midstream and downstream) nested within non-mined and mined sites.

Test for statistically significant differences were performed using PERMANOVA (Clarke & Warwick, 2001) as per the nested design in Figure 6. Monte Carlo tests for significance (*P(MC)<0.05)* were added to each PERMANOVA due to the reduced size of the data set when >100 permutations could not be run. It also accounted for asymmetry in the design. Diatom replicates were combined for each site and analysed among non-mined and mined sites and stream position only, as sampling occurred only once in winter.

All water quality variables were analysed with principal components analysis (PCA) using Euclidean distance to geometrically best fit combined water quality samples in a 2D plane. A draftsman's plot (PRIMER V6) was first developed to check for highly collinear variables and only one variable was kept where two variables expressed a mutual correlation in excess of 0.95.

Two sample t-Test (two tailed) assuming unequal variance from the mean were used on macroinvertebrate order abundance data only.

Multivariate analysis of weighted individual macroinvertebrate and diatom replicates was performed using PRIMER V6 on square root transformed abundances. Cluster analysis were performed on macroinvertebrate and diatom samples and, further analysed with non-metric multi-dimensional scaling (nMDS) using Bray-Curtis similarity, including visual presentation of 2D and 3D graphics. The water quality PCA was aligned with macroinvertebrate and diatoms nMDS for a BEST (BIOENV) (Clarke & Warwick, 2001) fit correlation.

SIMPER analysis (Clarke and Warwick, 2001) was also performed on biological variables (macroinvertebrates and diatoms) to look at the similarity percentage breakdown by genera.

3. Results

3.1 Rainfall

The first sampling event followed the month of July where no rain event was greater than 20mm (Figure 8), whereas the second event followed a single rainfall event of greater than 60mm (Figure 8). Both sampling events were both preceded by a period of slightly below-average rainfall (Figure 9).

Three months prior to the first sampling event in April, rainfall was three times higher than its historical average from the last twenty years (436mm and 134mm, Figure 9).

Due to the above-average rainfall experienced in January and early February 2016 (278mm, Appendix 1), further sampling events were halted due to the time constraints around final thesis delivery.

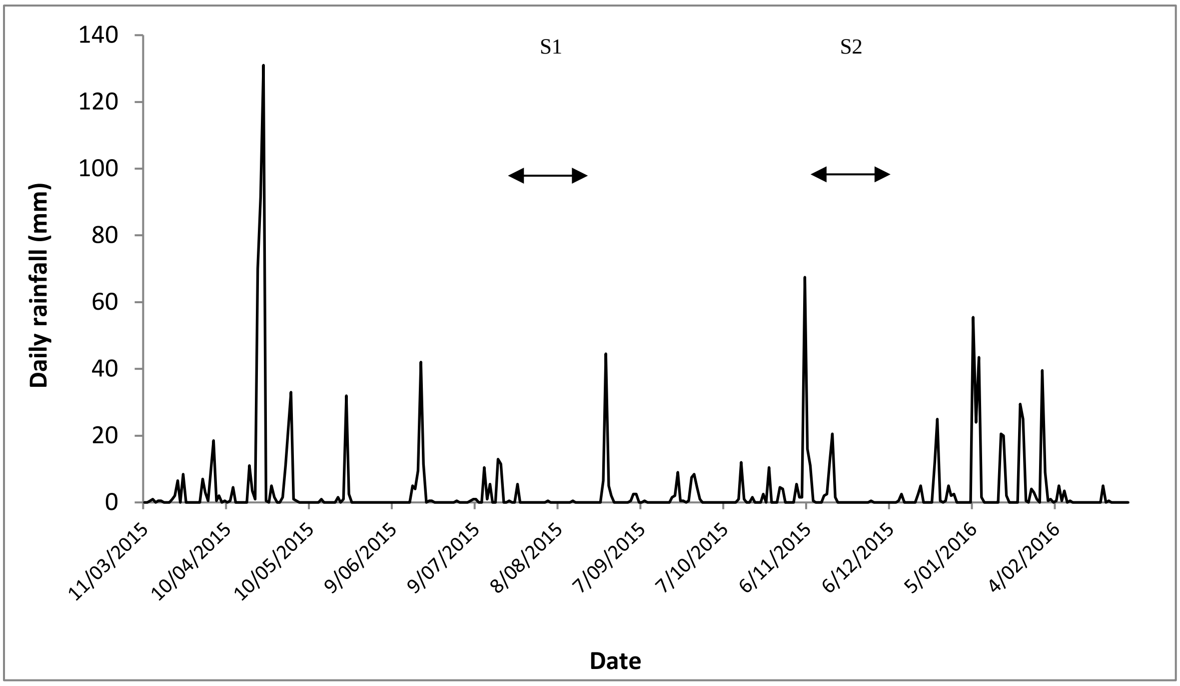


Figure 8 Daily rainfall in mm (Darkes Forest #68024 and Yarrawarrah #566056)

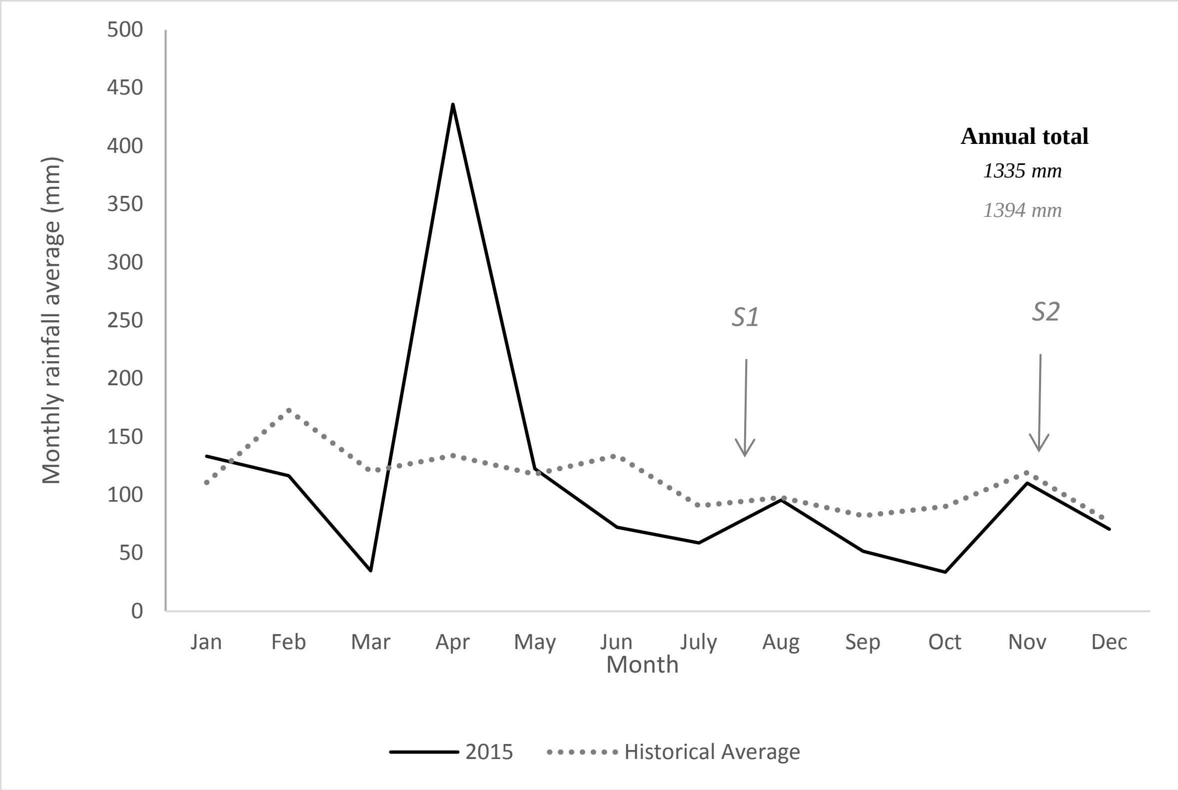


Figure 9 Average monthly rainfall for 2015 and 20 year historical average in mm (Darkes Forest #68024 and Yarrawarrah #566056)

3.2 Data Loggers

Pressure (kPa) and temperature (°C) results downloaded from data loggers (Figure 10a, b and Figure 12a, b) indicate a consistently higher daily water temperature fluctuation at the mined upstream Waratah Rivulet site (Figure 12c) compared to other sites. These fluctuations reduced during and for a small period after rainfall, similar to those observed consistently at other sites, including non-mined upstream and downstream sites on O'Hares Creek (Figure 10a, b) and downstream on Waratah Rivulet (Figure 12d).

(a) Upstream

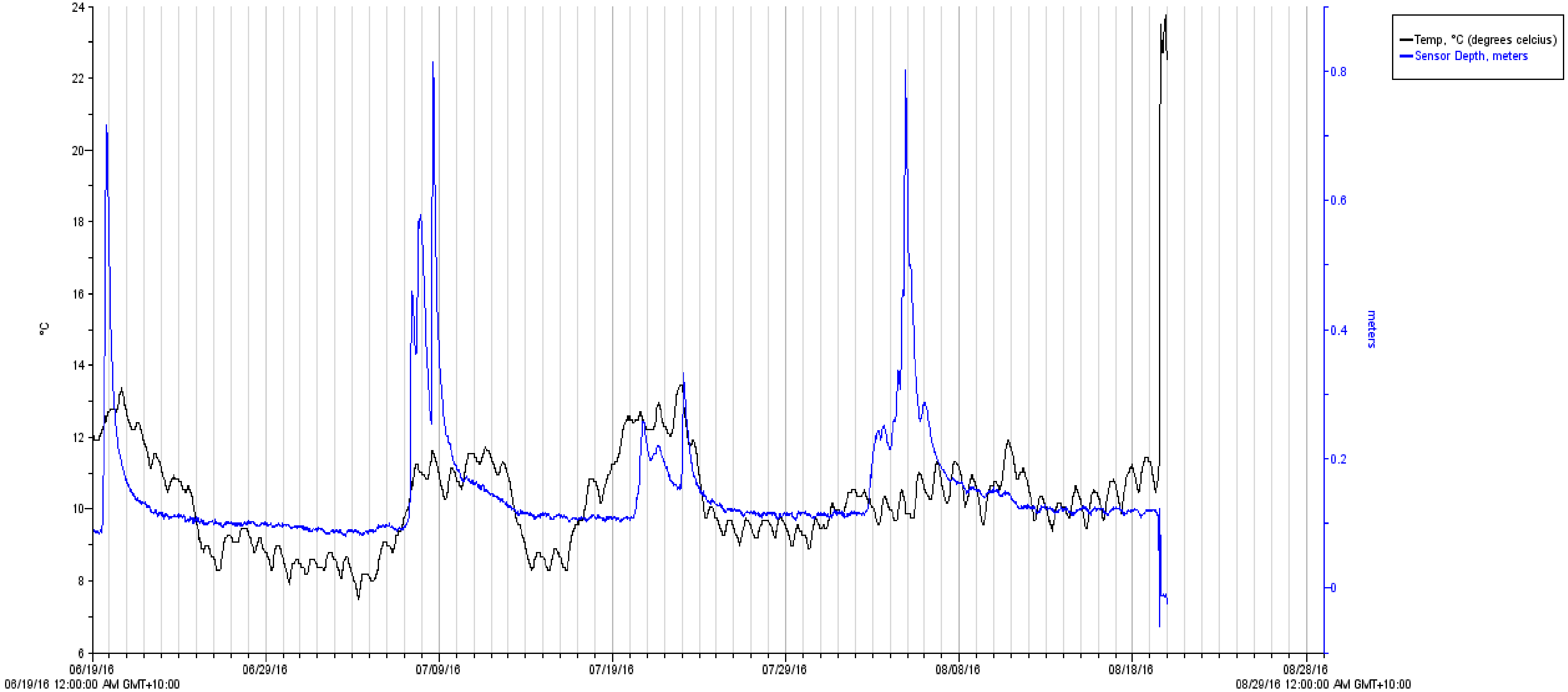


Figure 10a Temperature and water level results from (a) upstream sites on non-mined O'Hares Creek

(b) Downstream

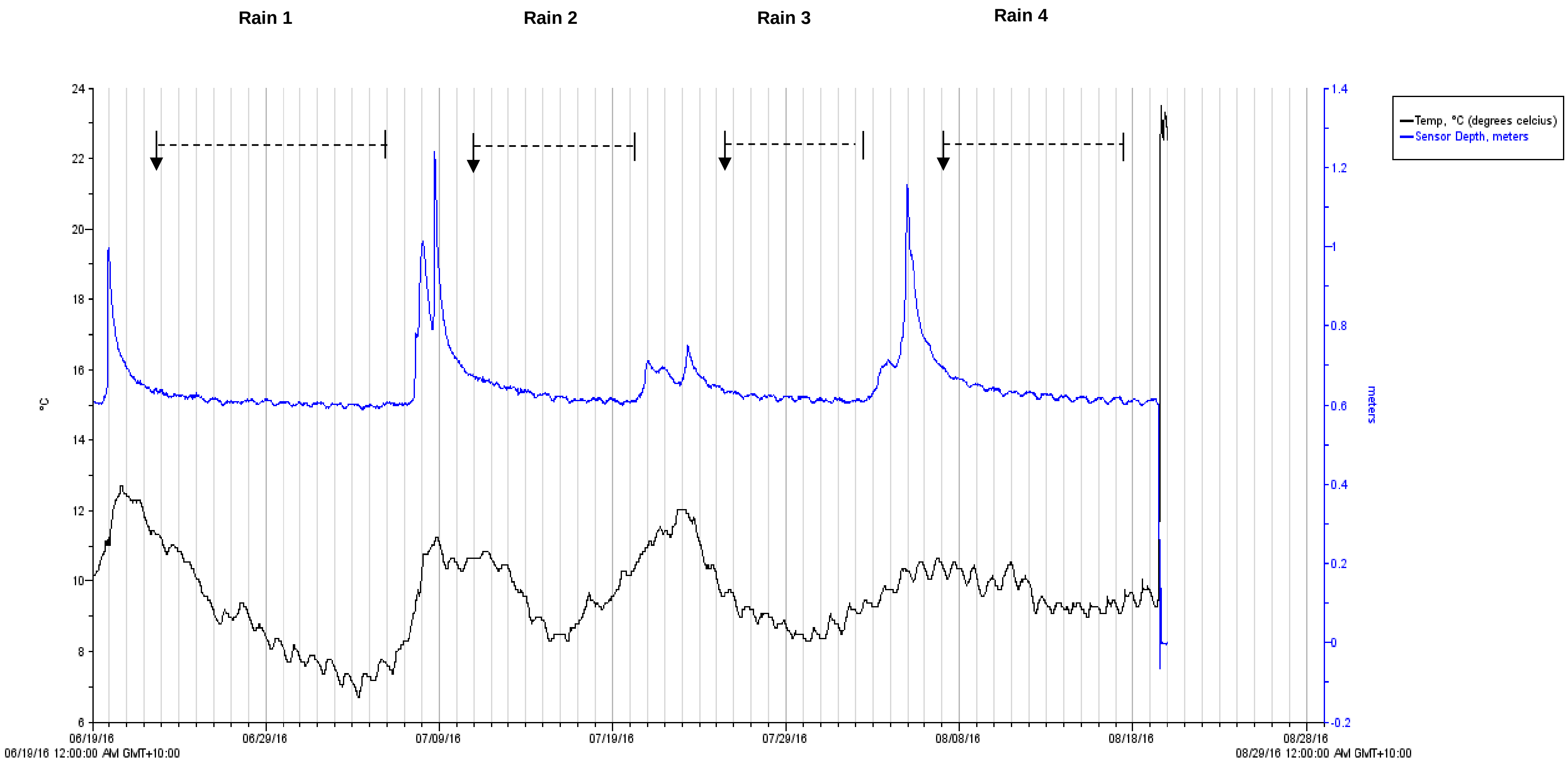


Figure 10b **Temperature and water level results from (b) downstream sites on non-mined O'Hares Creek**

(a) Upstream

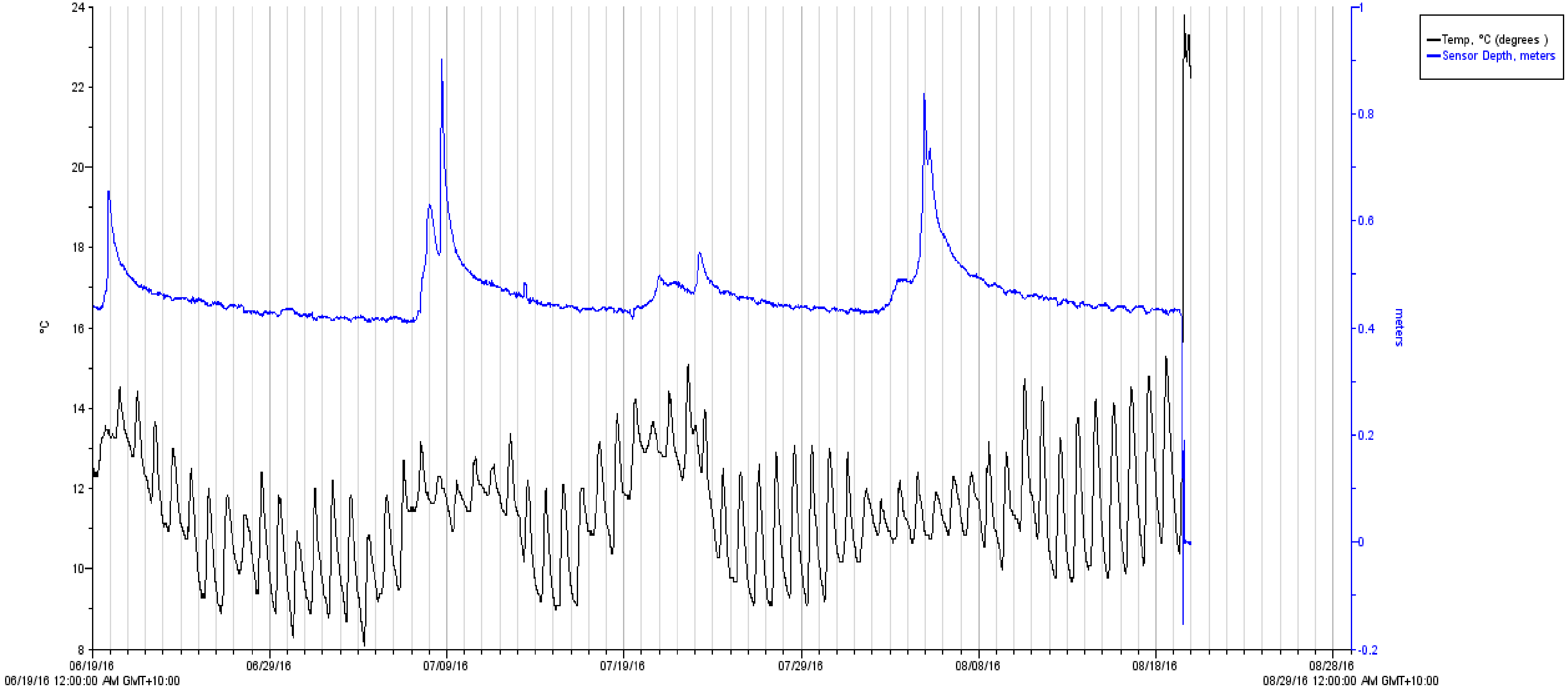


Figure 11 **Temperature and water level results from (a) upstream sites on mined Waratah Rivulet**

(b) Downstream

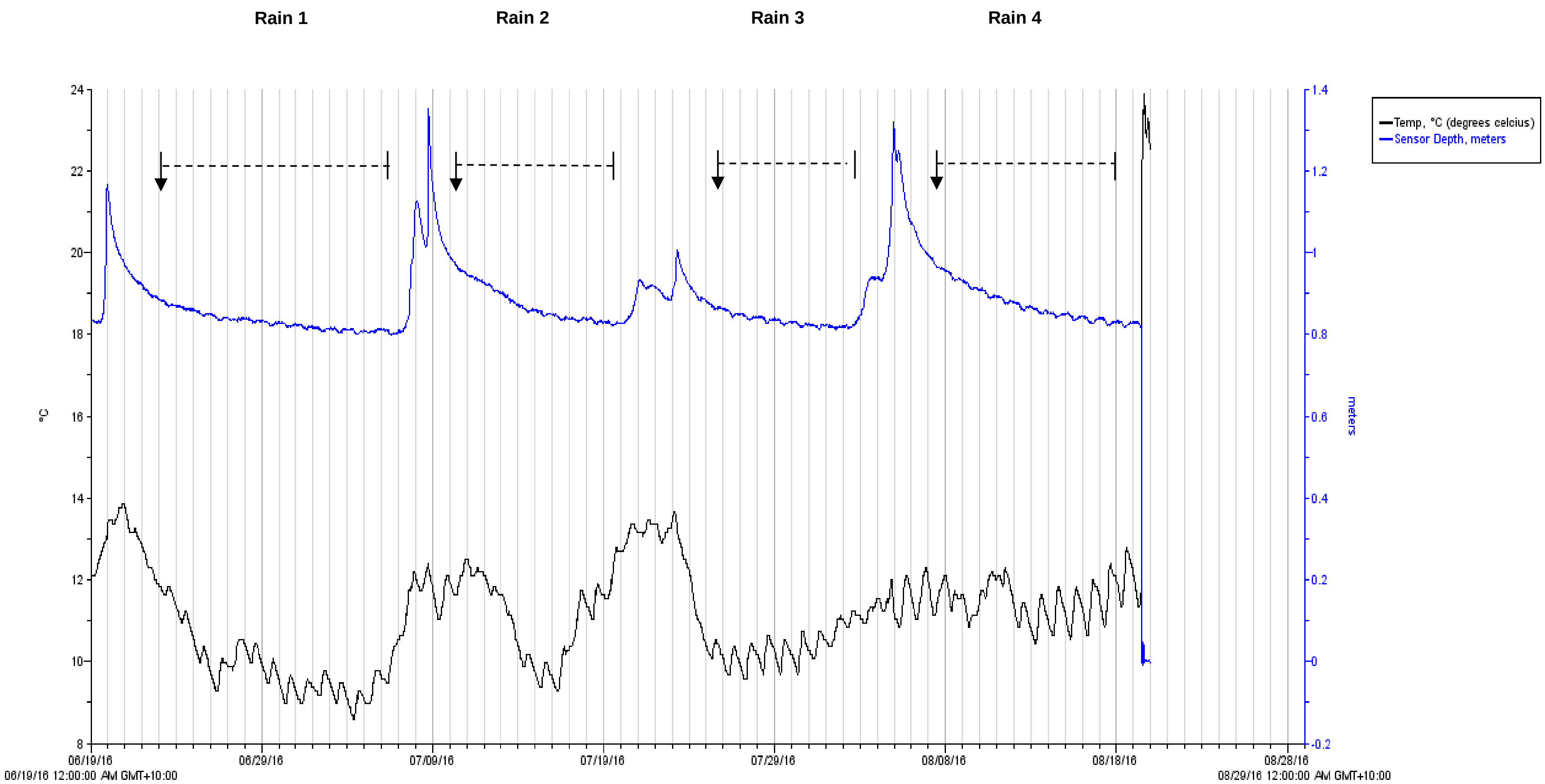


Figure 12 **Temperature and water level results from (b) downstream sites on mined Waratah Rivulet**

Water level results after four rain events (Rain 1,2,3 and 4) was extracted three days after each event until one day before the next rain event (black arrows and dashed line, Figure 10b and Figure 12b) to compare water level recovery after rain between non-mined and mined sites as shown in Figure 13a,b,c and d. The non-mined O'Hares Creek sites indicate more constant water level and gradual recovery after rain between upstream and downstream sites (Figure 13a and b). Whereas, the mined Waratah Rivulet, observed a greater water level reduction between upstream and downstream sites as indicated by the steeper trend-lines downstream (Figure 13c and d).

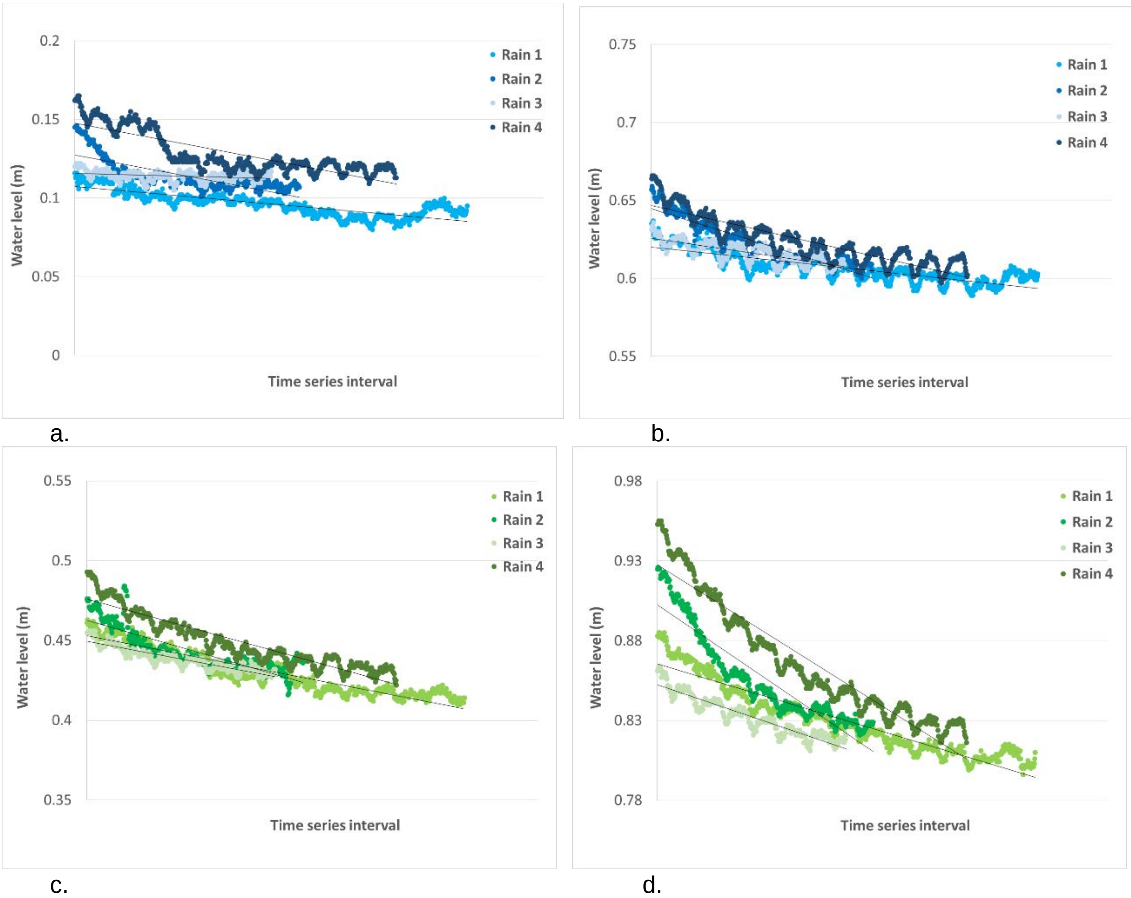


Figure 13 Water level in metres (with overlying trend-lines) three days after rain ceases for four different events at: (a) upstream and (b) downstream of non-mined O'Hares Creek; and, (c) upstream and (d) downstream of mined Waratah Rivulet

These results were consistent with aerial photos on 15th December 2015, after several weeks of no rain, supporting evidence of the non-mined O'Hares Creek retaining stream connectivity but the mined Waratah Rivulet indicating increased signs of dewatering and potential habitat fragmentation (Figure 14).

Figure 14 Aerial photos of non-mined O'Hares Creek (left) and mined Waratah Rivulet (right) in December 2015 (www.Nearmap.com)

3.3 Water quality

Field Variables

Bee Creek was not considered a suitable reference site due to its pH, 4.6 to 5.0, being well outside that at the other sites (Figure 15) and typical values in Australian freshwaters of 6.5-8.0 (ANZECC, 2000) and this site would likely have different biota to the other sites regardless of mining. Bee Creek pH is likely due to 'humic' water from its close proximity to headland swamps and associated high organic content. For this reason Bee Creek results were not considered further in this study.

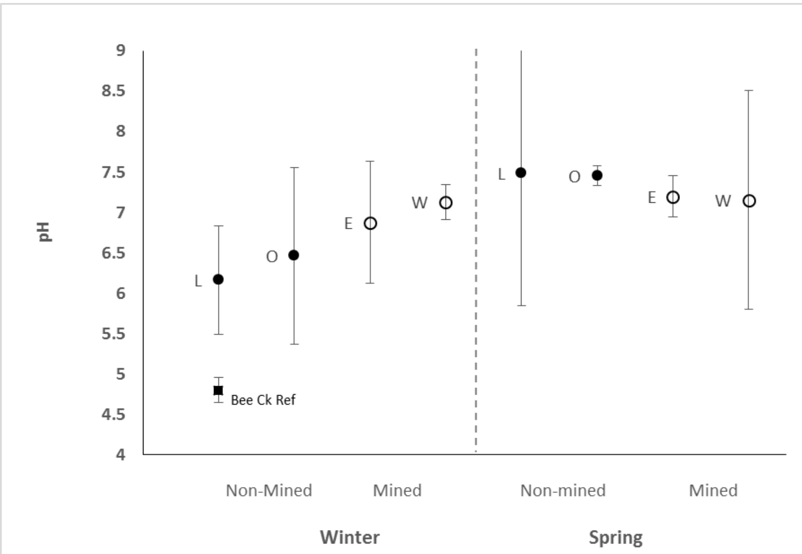


Figure 15 Mean pH of creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Combined field water quality PERMANOVA results from all other sites (Table 5, Appendix 2) indicate significant differences between non-mined and mined sites

(*P(MC)=0.0115)*, between creeks nested within non-mined and mined sites (*P=0.0288)* and between season (*P=0.0307).*

Table 5 PERMANOVA table of results for all field water quality variables

Source	df	Pseudo-F	P(perm)	P(MC)
Mined/Non-mined	1	8.4231		0.0115
Creek (Mined/Non-mined)	2	2.2965	0.0288	
Season	1	9.7754	0.0307	
Creek (Mined/Non-mined) x Season				

Individual field variable PERMANOVA's further analysed to investigate differences are listed in Table 6. pH (Figure 15) and dissolved oxygen (Figure 16a) differed between seasons (*P=0.0306, and 0.0351),* temperature and conductivity (Figure 16b and c) were both significantly higher at mined than non-mined sites (*P(MC)=0.0249 and P(MC)=0.0275)* and, conductivity and turbidity (Figure 16d) significantly differed among creeks within non-mined and mined sites (*P=0.0439 and P=0.0011).*

Table 6 PERMANOVA table of results for selected field water quality variables

Analyte	Source	df	Pseudo-F	P(perm)	P(MC)
DO	Season	1	24.392	0.0351	
Temp	Mined/Non-mined	1	37.096		0.0249
Cond	Mined/Non-mined	1	34.226		0.0275
	Creek (Mined/Non-mined)	1	3.8279	0.0439	
pH	Season	1	47.89	0.0306	
Turb	Creek (Mined/Non-mined)	2	9.2964	0.0011	

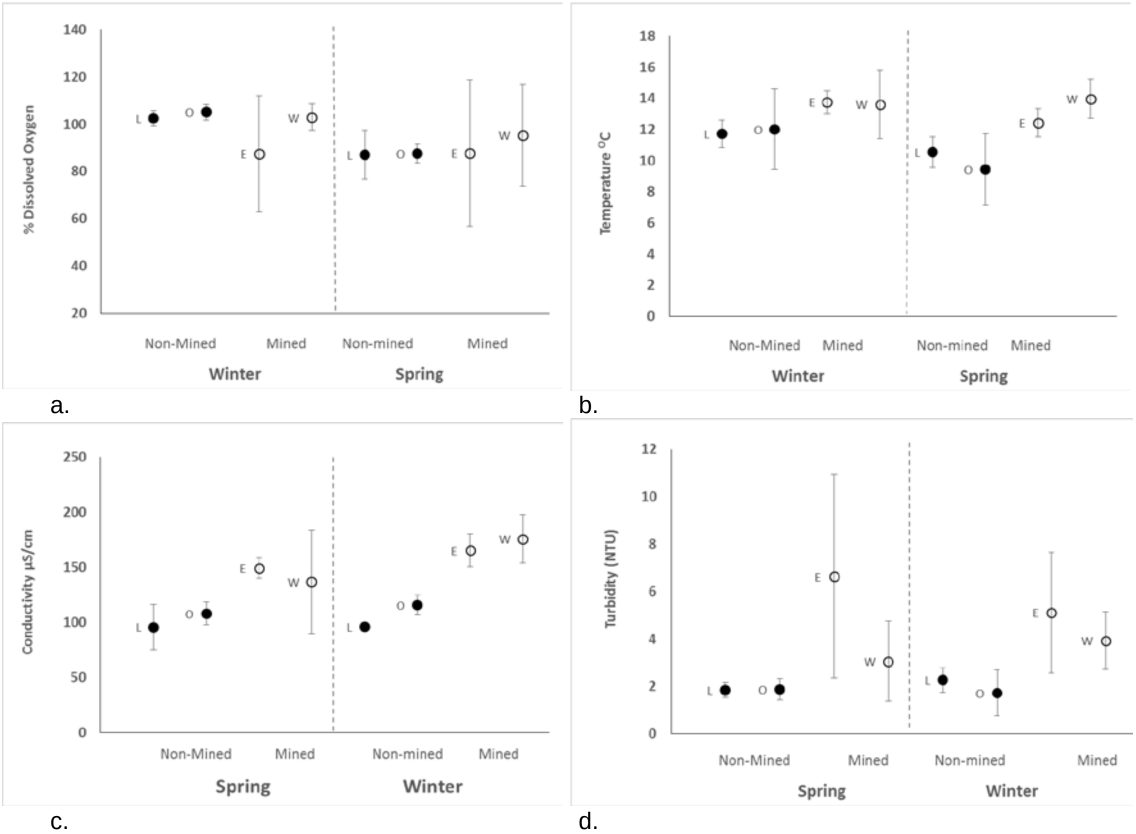


Figure 16 Mean (a) dissolved oxygen, (b) water temperature, (c) electrical conductivity and (d) turbidity of creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Trace Metals

Field blanks for chromium (Table 7) did not return satisfactory results (>0.1µg/L), hence laboratory results are not useful for indicating increased groundwater and surface water connectivity. All other elements including beryllium, lithium and molybdenum, returned acceptable field blanks (<0.01µg/L), indicating no contamination or processing issues.

Table 7 Estimated trace metal concentrations

Creek	Non-mined/ Mined	Site	Trace metal µg/L							
			Be		Cr		Li		Mo	
			S1	*S2*	*S1*	*S2*	*S1*	*S2*	*S1*	*S2*
Field blank	**-**		**<0.01**	**<0.01**	**0.1885**	**0.225**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
O'Hares Creek	**Non-mined**	**OH1**	**0.0185**	**0.0265**	**0.1595**	**0.5605**	**0.1795**	**0.261**	**0.01**	**0.012**
	Non-mined	**OH2**	**0.017**	**0.0245**	**0.1445**	**0.546**	**0.176**	**0.2465**	**0.01**	**0.012**
	Non-mined	**OH3**	**0.015**	**0.023**	**0.1315**	**0.583**	**0.1705**	**0.2285**	**0.01**	**0.0155**
Loddon River	**Non-mined**	**LR1**	**0.0235**	**0.031**	**0.1655**	**0.6055**	**0.246**	**0.296**	**0.01**	**0.0175**
	Non-mined	**LR2**	**0.029**	**0.0465**	**0.136**	**0.6625**	**0.252**	**0.3215**	**0.01**	**0.017**
	Non-mined	**LR3**	**0.022**	**0.0565**	**0.138**	**0.6245**	**0.2575**	**0.377**	**0.01**	**0.015**
Eastern Tributary	**Mined**	**WR1**	**0.019**	**0.0245**	**0.124**	**0.4115**	**0.6035**	**0.655**	**0.01**	**0.0175**
	Mined	**WR2**	**0.01**	**0.0845**	**0.093**	**0.922**	**0.577**	**0.3805**	**0.01**	**0.026**
	Mined	**WR3**	**0.0125**	**0.0805**	**0.146**	**0.8685**	**0.4935**	**0.361**	**0.0135**	**0.024**
Waratah Rivulet	**Mined**	**WR4**	**0.0165**	**0.065**	**0.0925**	**0.6755**	**0.647**	**0.292**	**0.0155**	**0.013**
	Mined	**WR5**	**0.015**	**0.065**	**0.089**	**0.6865**	**0.6165**	**0.343**	**0.023**	**0.0205**
	Mined	**WR6**	**0.016**	**0.017**	**0.1015**	**0.4355**	**0.6715**	**0.7015**	**0.022**	**0.052**
Recovery with 0.2 µg/L spike			114.50 %	142.00%	109.50%	60.00%	Not spiked	95.50%	97.75%	125.50%
Quantification limit			***0.01***	***0.01***	***0.05***	***0.1***	***0.05***	***0.01***	***0.01***	***0.01***

Recovery results from the 0.2µg/L spike for trace metals (Table 7) produced varying results. Beryllium and molybdenum were within an acceptable range of 85-115% for winter but were outside the acceptable range for spring. Unfortunately, lithium samples were not spiked in winter but had an acceptable recovery of 95.5% in spring. Results for beryllium, molybdenum and lithium were further analysed using PERMANOVA (Table 8) and implications of the poor part-recovery of beryllium and molybdenum discussed later.

Table 8 Combined trace Be, Mo and Li PERMANOVA table of results

Source	df	Pseudo-F	P(perm)	P(MC)
Mined/Non-mined	1	9.2995		0.0185
Creek (Mined/Non-mined)	2	2.8464	0.0211	
Season	1	25.036	0.0218	

The strongest overall significant difference among trace metal concentrations was found between non-mined and mined sites *(P(MC)=0.0185).* Differences were also found between creeks nested within non-mined and mined sites (*P=0.0211)* and between season (*P=0.0218).*

Further analysis of each individual trace metal PERMONOVA (Table 9) reveal lithium was the only individual trace metal which significantly differed between non-mined and mined sites (Figure 17, *P(MC)=0.0246*). Strong significant differences within creeks between season (*P=0.0366 and P=0.339)* were found for beryllium and molybdenum (Figure 18a and b), and for molybdenum between creeks nested within non-mined and mined sites (*P=0.0242).*

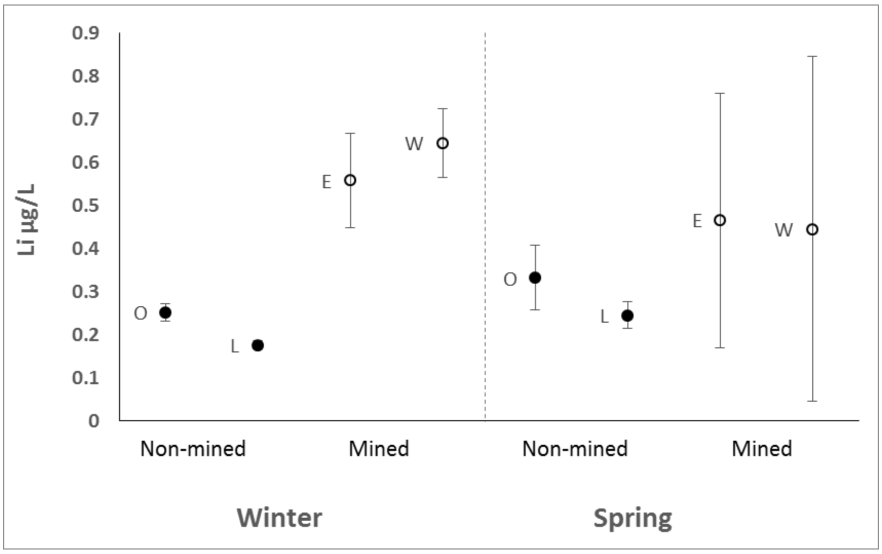
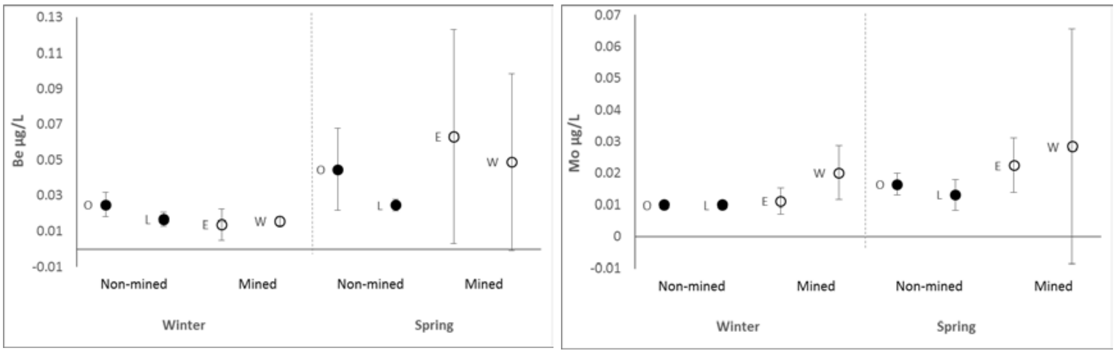


Figure 17 Mean lithium concentrations in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Overall the mined Eastern Tributary and Waratah Rivulet sites showed the greatest variability between replicates within seasons, as indicated by the longer error bars.



a b

Figure 18 Mean beryllium and molybdenum concentrations in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Further analysis of mean lithium concentrations in winter at mined sites (0.60µg/L) were almost three times the non-mined concentrations (0.21µg/L, Figure 17). This separation reduced in spring where the mean lithium concentration at mined sites was 0.46µg/L, and 0.28µg/L at non-mined sites. The spring sampling event was preceded by moderately wet conditions (Figure 2), which may have acted to dilute and hence reduce the lithium concentrations at mined sites.

Table 9 Selected trace metal PERMANOVA table of results

Metal	Source	df	Pseudo-F	P(perm)	P(MC)
Li	Mined/Non-mined	1	39.81		0.0246
Be	Season	1	29.94	0.0366	
Mo	Creek (Mined/Non-mined)	2	3.5521	0.0242	
	Season	1	42.785	0.0339	

Other Water Chemistry Variables

Overall PERMANOVA results for all other water quality variables indicate significant difference between non-mined and mined sites (*P(MC)=0.0071,* Table 10*).*

Table 10 PERMANOVA able of results for all other water quality variables

Source	df	Pseudo-F	P(MC)
Mined/Non-mined	1	15.152	0.0071

Further analysis of each individual variable using PERMANOVA (Table 11) found several that most contributed to the differences between non-mined and mined sites, including two of the strongest: bicarbonate (Figure 19a, *P(MC)=0.0086*) and barium (Figure 19b, *P(MC)=0.006*); followed by calcium, sodium, iron and chloride (*P(MC)=0.0236 to 0.0495).* Barium and calcium also indicated significant difference within creeks between seasons (Table 11). Compared to their individual non-mined and mined site differences, barium returned a weaker difference (*P=0.0385)* and calcium a slightly stronger difference (*P=0.0304).*

Manganese solely contributed to a significant difference between creeks nested within non-mined and mined sites by season (Figure 19f, *P=0.0039)* but this was not strong enough to be evident in the overall combined PERMANOVA (Appendix 5).

Table 11 PERMANOVA able of results for all other water quality variables

Analyte	Source	df	Pseudo-F	P(perm)	P(MC)
CaCO3	Mined/Non-mined	1	114.71		0.0086
Ba	Mined/Non-mined	1	153.72		0.006
	Season	1	104.67	0.0385	
Ca	Mined/Non-mined	1	17.59		0.0495
	Season	1	630.09	0.0304	
Na	Mined/Non-mined	1	20.215		0.0465
Fe	Mined/Non-mined	1	41.335		0.0236
Mn	Season	1	18.06	0.0001	
	Creek (Mined/Non-mined) x Season	1	7.4995	0.0039	
Cl	Mined/Non-mined	1	44.041		0.0242

Again, much greater variability within all water quality variables was observed at mined sites compared to non-mined sites, as indicated by longer error bars (Figure 19a to h), except manganese in winter and, chloride and sulphate in spring ((Figure 19).

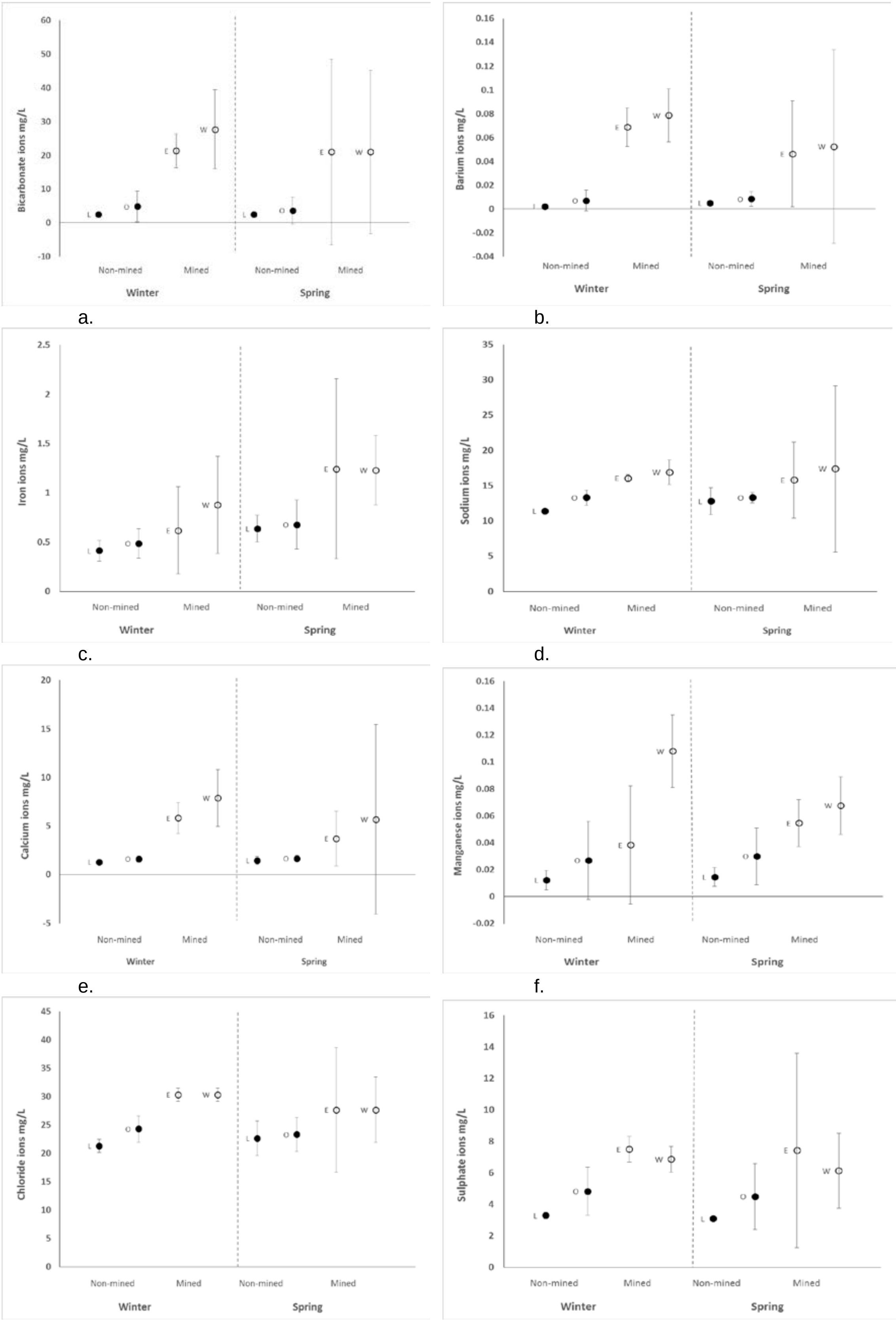


Figure 19 Mean water quality variable concentrations in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Water Quality PCA

It was necessary to conduct absolute value logarithmic (*log(10)* transformation of calcium, sodium, aluminium, beryllium and molybdenum concentrations (Appendix 5) due to clumped distribution in correlation with other water quality variables. These transformations resulted in a more even distribution of water quality variables (Figure 20). Barium and calcium were highly inter-correlated in the underlying Bray-Curtis resemblance matrix (0.9653, see Appendix 5), so barium was removed and calcium was retained for the PCA. Chromium was also removed due to the unreliable results from failed spike recovery obtained from ANSTO laboratory analysis (Table 7).

Combined water quality variables using a PCA indicated potential environmental links between samples (Figure 21). The first principal component explained 46.7% of the total variation between samples and was correlated with bicarbonate, calcium, sodium, chloride, sulphate, lithium and conductivity results (Appendix 5). The second principal component explained a further 21.9% of the variation and was correlated with aluminium, iron, beryllium and rainfall. The PCA show a clear separation of the non-mined and mined sites (Figure 21), greater at the non-mined sites while the mined sites were more dispersed (Figure 21).

Water quality variables that showed significant difference between mined and non-mined sites were overlaid as vectors onto the PCA (Figure 21) including bicarbonate, calcium (which also represented barium), calcium, sodium, iron, manganese, chloride, lithium, temperature and conductivity. The longest vector length, represented in Figure 21 by chloride and bicarbonate ions, indicate more significant contribution to difference between non-mined and mined sites. Samples in Figure 21 were also coded by creek as PERMANOVA water quality results for conductivity and turbidity (Table 5), molybdenum (Table 8) and manganese (Table 11) indicated significant difference among creek nested within non-mined and mined sites.

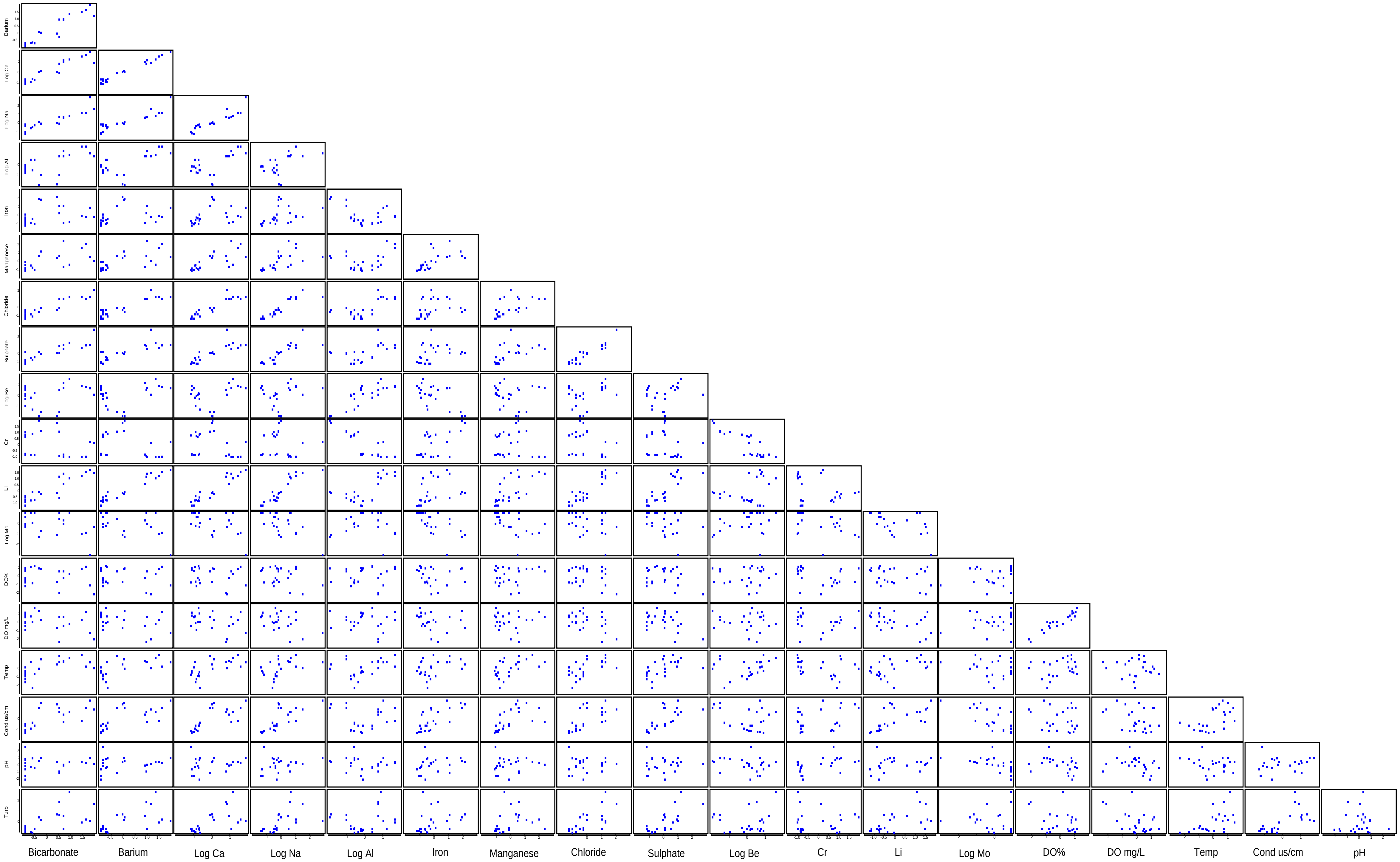


Figure 20 **Draftsman plot of all water quality variables, including log transformed Ca, Na, Al, Be and Mo**

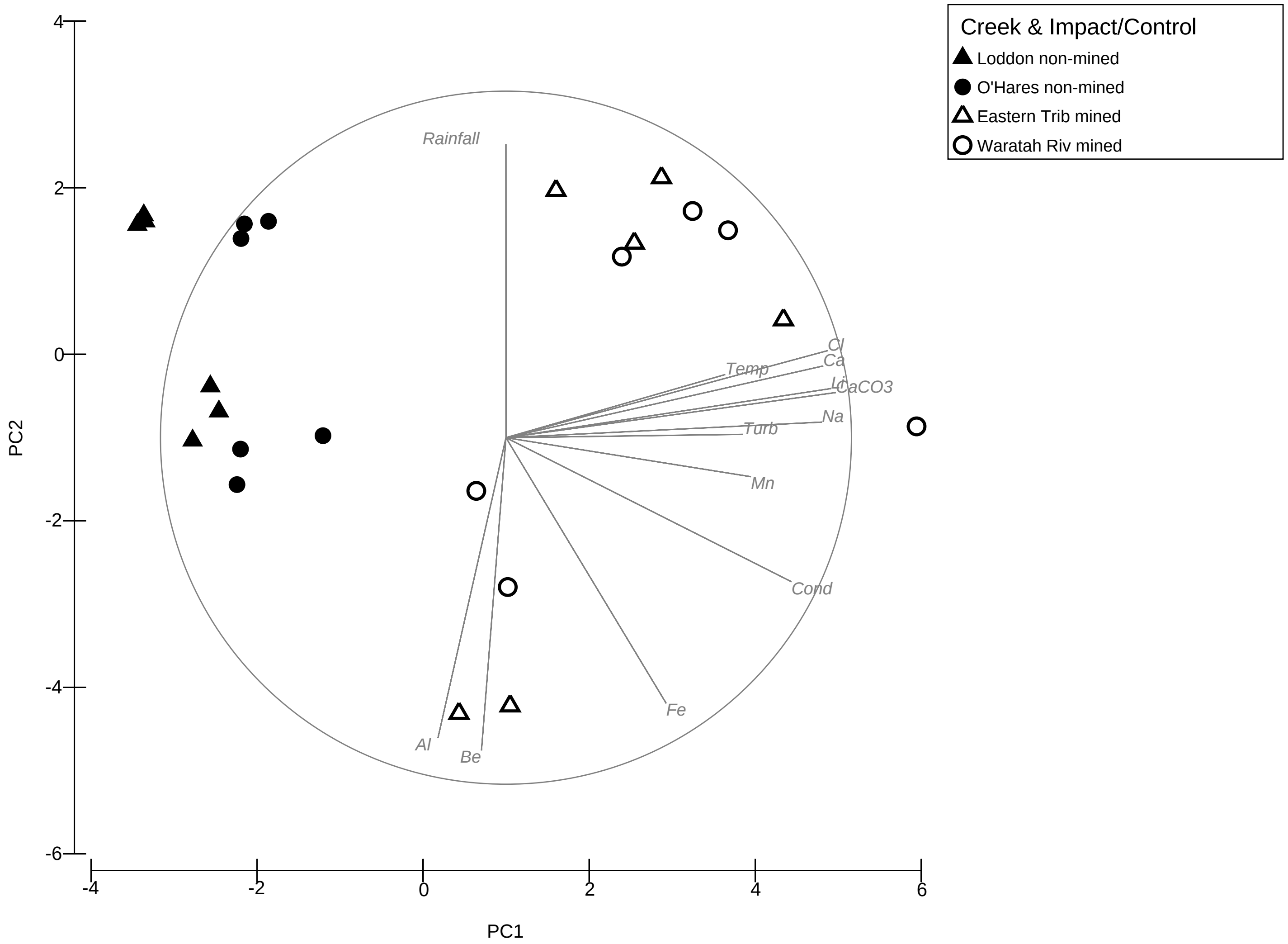


Figure 21 **Principal component analysis of rainfall and all water quality variables, with significantly different (*P<0.05*) variables as overlay vectors**

3.4 Macroinvertebrates

A total of 31,404 macroinvertebrates within 135 genera were identified from edge and riffle habitats across two sampling episodes (Appendix 5).

Order Taxa Charts

Slight differences between percent proportional abundance of orders was evident between edge and riffle habitats (Figure 22 and Figure 23). Dipteran's dominated both habitats, with a similar composition between non-mined and mined sites in edge habitats (55% and 51%, Figure 22), and a slight increase at mined sites compared to non-mined sites in riffle habitats (65% and 55% respectively, Figure 23).

Edges

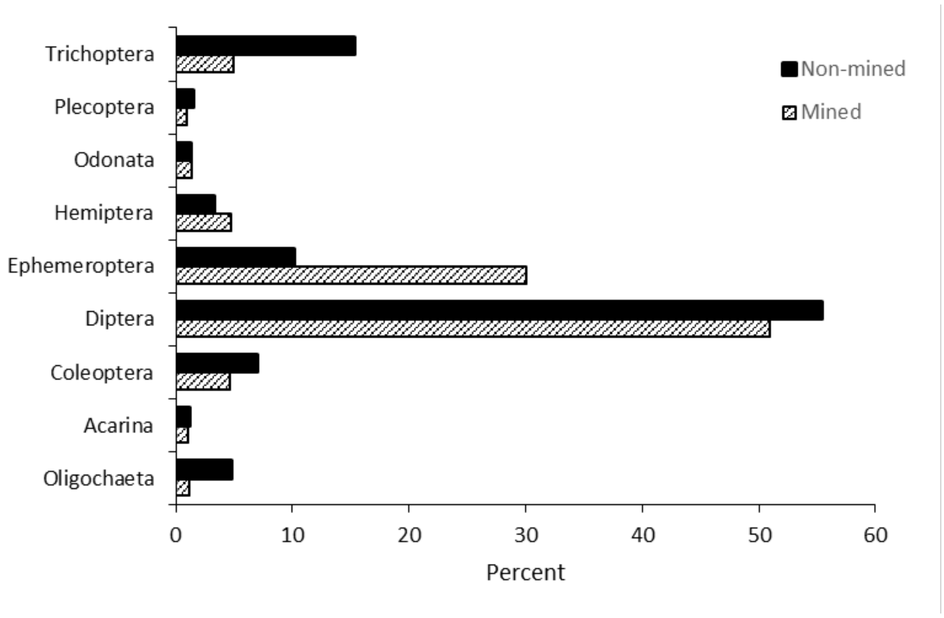


Figure 22 **Proportional abundance of stream macroinvertebrate order in the edge habitat**

The next most dominant macroinvertebrate orders in the edge habitat of non-mined and mined sites respectively comprised Ephemoptera (10% and 30%), Trichoptera (15% and 5%) and Coleoptera (7% and 5%), as shown in Figure 22. Ephemoptera were clearly more dominant, but not significantly different (*P=0.11)*, in edges at mined than non-mined sites. The opposite was observed for the order Trichoptera, three times more predominant at the non-mined than mined sites (Figure 22), and strongly significantly different (*P=0.00007,* Table 12).

Significant differences were also found within percent proportional abundance of Oligochaete and Coleopteran orders between non-mined and mined edge samples (*P =0.0047 and P=0.0073,* Table 12).

Table 12 ANOVA of individual order abundance in edges from non-mined and mined sites

Order	Source	df	F	*P*	*F critical*
Oligochaeta	Mined/Non-mined	1	7.49	***0.0073***	3.94
Coleoptera	Mined/Non-mined	1	8.36	***0.0047***	3.94
Trichoptera	Mined/Non-mined	1	22.46	***0.00007***	3.94

Riffles

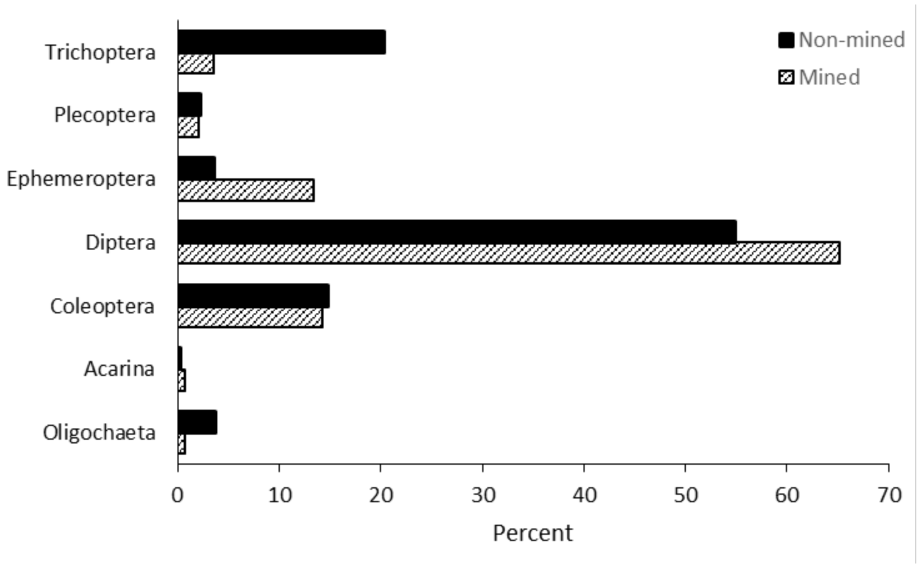


Figure 23 Proportional abundance of stream macroinvertebrate order in the riffle habitat

Following the predominant Diptera in the riffle habitat of non-mined and mined sites were the percent proportional abundance of orders Coleoptera (15% and 14%) Trichoptera (20% and 4%) and Ephemoptera (4% and 13%). Again, Ephemoptera were more predominant, but not significantly different (*P=0.39)* in riffles between mined and non-mined sites. Trichoptera were over five times more predominant and more strongly significantly different in riffles than in edges (*P=0.00043,* Table 13*)* at non-mined than mined sites (Figure 23).

Significant differences were also found within percent proportional abundance of Oligochaete and Dipteran orders between non-mined and mined riffle samples (*P=0.0019 and P=0.03,* Table 13).

Differences within Trichoptera genus diversity and abundance between non-mined and mined sites was further investigated within EPT Indicator Taxa.

Table 13 ANOVA of individual order abundance in riffles from non-mined and mined sites

Order	Source	df	F	*P*	*F critical*
Oligochaeta	Mined/Non-mined	1	5.01	***0.03***	4.09
Diptera	Mined/Non-mined	1	5.63	***0.019***	3.94
Trichoptera	Mined/Non-mined	1	13.57	***0.00043***	3.97

Taxa Richness

Edges

There was a decline in macroinvertebrate genus richness within edge habitats from mined sites for both winter and spring seasons (Figure 24a, Appendix 5) compared to non-mined sites. Mined sites were 5.2 genera lower on average than non-mined sites (Figure 24b). Although PERMANOVA results indicate these differences are not significant (*P(MC)*=0.3217). A significant difference in average edge genus richness was observed between creeks nested within non-mined and mined sites (*P=0.0002*,

Table 14 and Appendix 6). The greatest individual difference between edge genus taxa richness occurred between non-mined O'Hares Creek site (OH2) and mined Waratah Rivulet (WR2) with 10 less genera on average at the mined site.

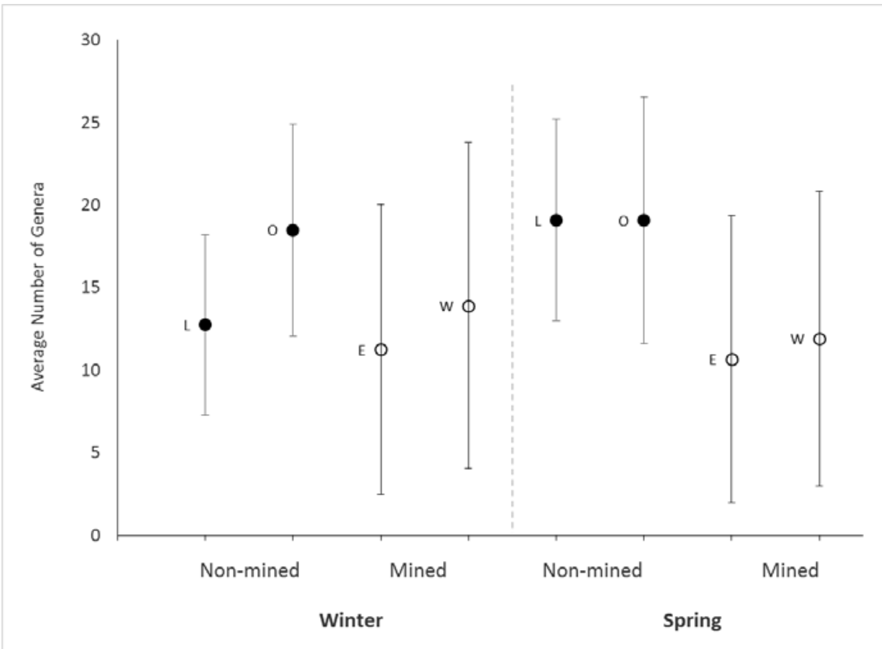


Figure 24 Mean edge genus richness in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Table 14 PERMANOVA table of results for edge genus richness

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	9.3027	0.0002

Riffles

Genus richness results from riffles indicate a slightly smaller but stronger difference between non-mined and mined sites than edge habitats (Figure 25). On average, 4.6 fewer genera were found at mined sites within riffle habitats than at non-mined sites, and although PERMANOVA results indicate no significant difference (*P(MC)>0.0832*, Figure 25, Table 15 and Appendix 6) the difference was much stronger than in edges.

A significant difference was also observed among average riffle genus richness between creeks nested within non-mined and mined sites (*P=0.0097*, Table 15). The largest observed individual difference was observed between the non-mined O'Hares Creek (OH1) and mined Eastern Tributary (WR1), with 11 genera less on average at the mined site.

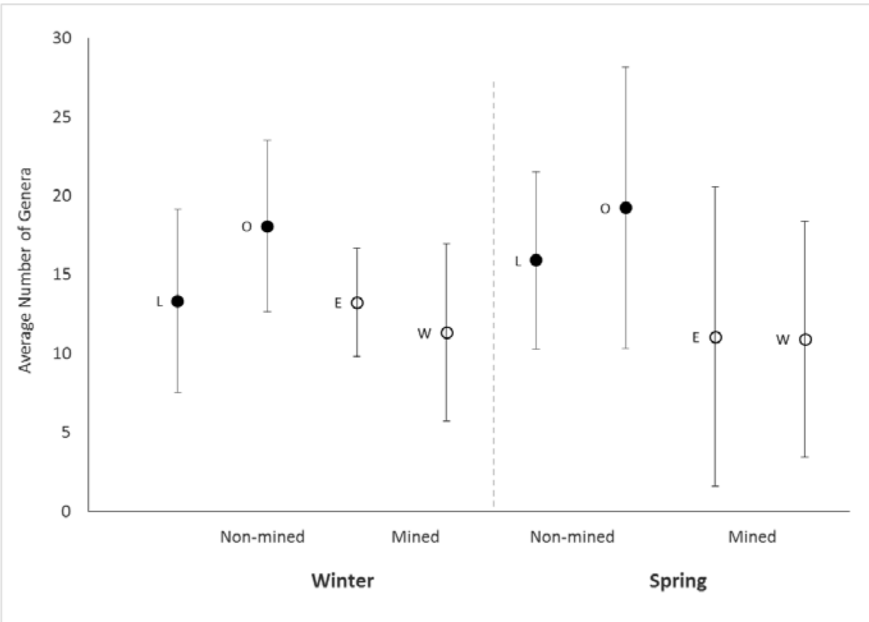


Figure 25 Mean riffle genus richness in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

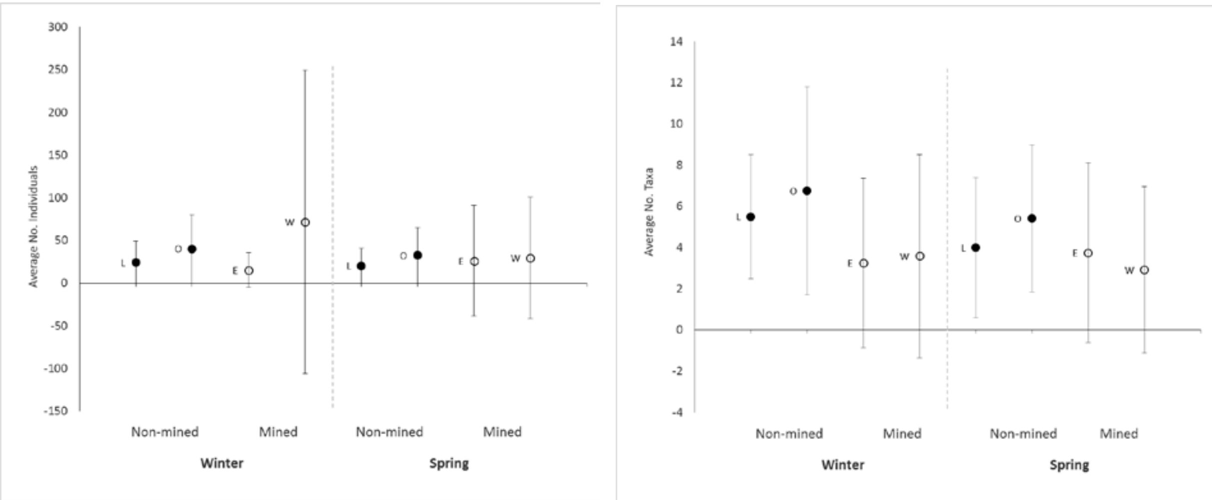
Table 15 PERMANOVA table of results for riffle genus richness

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	4.7194	0.0097

EPT Indicator Taxa

Edges

A greater average number of EPT individuals was found within edges at the Waratah Rivulet mined sites in winter than at non-mined sites (Figure 26a) but the individuals were from a smaller number of taxa (Figure 26b). Overall, the average number of EPT individuals in edges was not significantly different between non-mined and mined sites (*P(MC)=0.7221*), but was significantly different among the average number of EPT taxa between non-mined and mined sites (*P(MC)=0.015*, Table 17). On average, the mined Eastern Tributary sites in winter had 3.5 less EPT taxa than at the non-mined O'Hares Creek sites (Figure 26b).



a. b.

Figure 26 Mean edge EPT total number of (a) individuals and (b) taxa in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Further analysis of PERMANOVA results (Appendix 6) for average edge EPT total number of individuals found significant differences between creeks nested within non-mined and mined sites (*P=0.0009*, Table 16, Figure 26a).

Table 16 PERMANOVA table of results for edge EPT total number of individuals

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	4.7974	0.0009

Table 17 PERMANOVA table of results for edge EPT total number of taxa

Source	df	Pseudo-F	P(MC)
Mined/Non-mined	1	6.3174	0.015

The greatest individual difference between average edge EPT taxa occurred between the mined Waratah Rivulet (WR5) site and the non-mined O'Hares Creek site (OH2) with 5.3 less taxa on average at the mined site (Appendix 5).

Significant difference within Trichoptera (*P=0.0001,* Table 12) and difference within Plecoptera edge order composition were further investigated in Figure 27 and Figure 28.

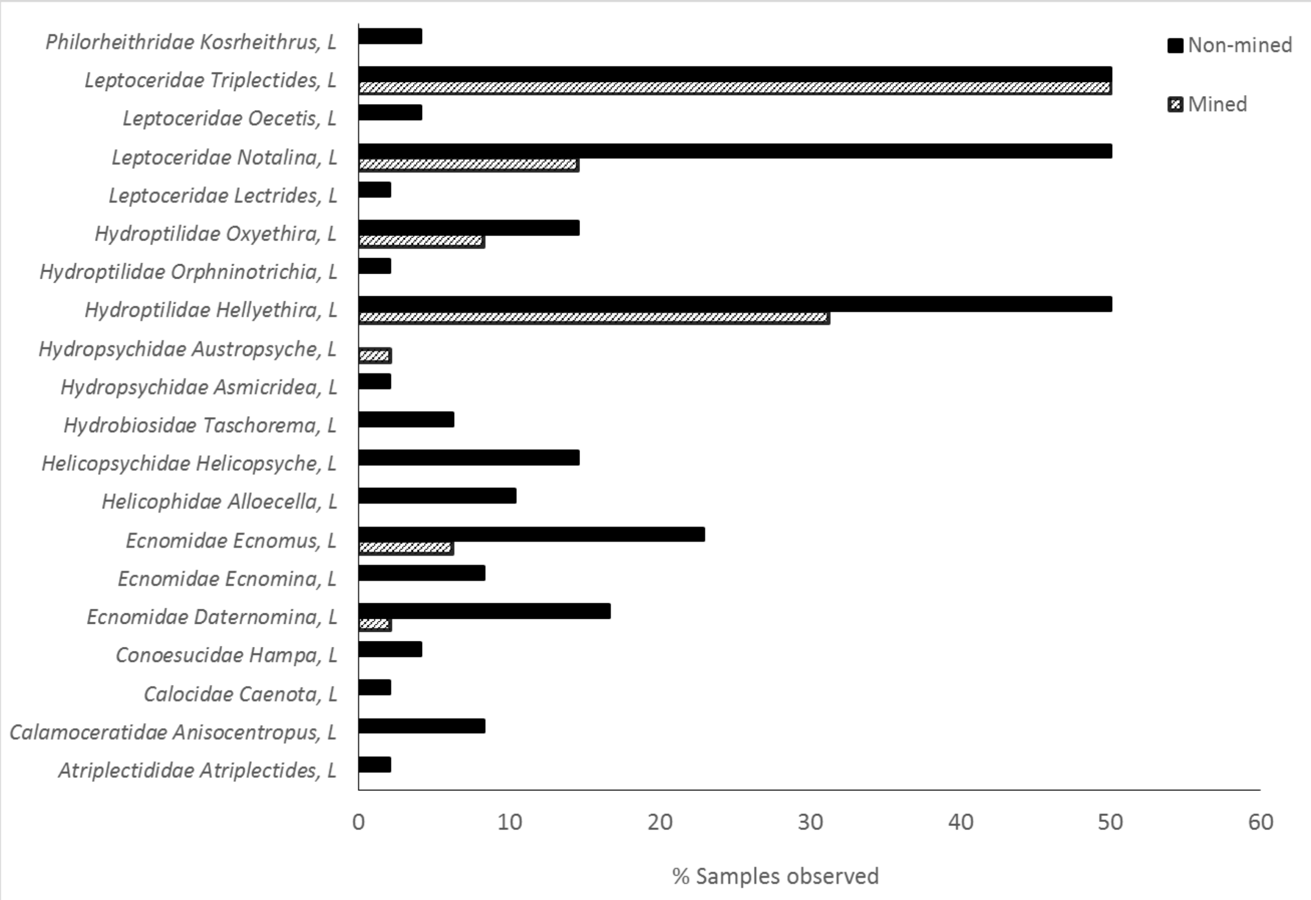


Figure 27 Trichoptera genera present within edges at non-mined and mined sites

Trichopterans were represented by 20 different genera in the edge habitat of non-mined and mined sites (Figure 27). Trichopteran diversity was greatest at non-mined sites, with 19 genera observed in edges at non-mined sites, compared to seven genera from mined sites (Figure 27). Thirteen of the genera were present only at non-mined sites, including the individual most prevalent *Helicopsyche* (Helicopshychidae), observed at 15% of the non-mined edges. Other Trichoptera genera found within more than 5% of non-mined edges only include *Helicophidae* (Alloecella), *Ecnomus (*Ecnomidae), *Anisocentropus* (Calamoceratidae), Taschorema (Hydrobiosidae), Kosrheithrus (Philorheithridae), *Oecetis* (Leptoceridae) and *Hampa* (Conoesucidae). Five further Trichopeterans were found within 4% of edges from only non-mined sites, compared to only one genus, *Austropsyche* (Hydropsychidae) found within 4% of edges at only mined sites (Figure 27).

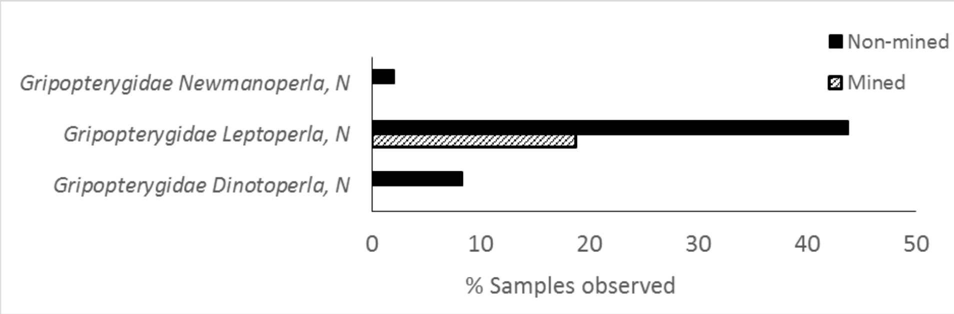
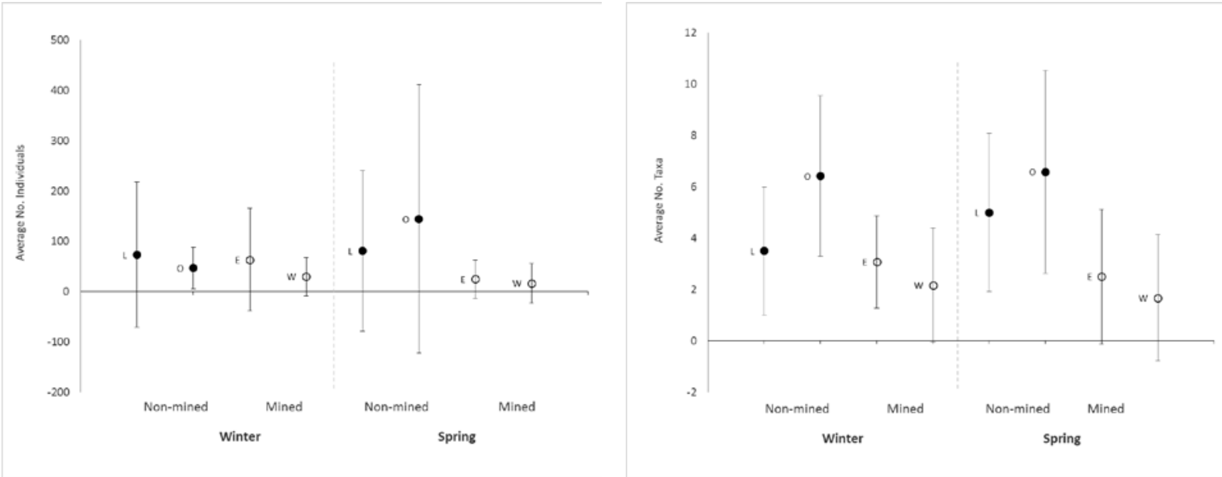


Figure 28 Plecoptera genera present within edges at mined and non-mined sites

Plecopterans were represented by three different genera within edge habitats at non-mined sites (Figure 31). Only one of these, *Leptoperla* (Gripopterygidae), was present at just under half of the number of mined edges compared to non-mined edges. Two Gripopterygidae genera present at non-mined edges, *Newmanoperla and Dinotoperla,* were absent from any of the mined edges.

Riffles

In contrast to edges, the average number of EPT individuals in riffles were greatest at non-mined sites in spring (Figure 29a). The higher number of individuals also aligned with a higher average number of EPT taxa within the non-mined than mined riffles in winter and spring (Figure 29b). Significant differences were found between both the average EPT number of individuals and taxa, and non-mined and mined sites (*P(MC)=0.0106 and 0.0239,* Table 18 and Table 19). On average, 3.9 less EPT taxa were found at mined than non-mined riffles in winter and spring (Figure 29b).



a. b.

Figure 29 Mean riffle EPT total number of (a) individuals and (b) taxa in creeks by potential impact and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Further analysis of the riffle PERMANOVA (Table 18 and Table 19, Appendix 6) reveals further significant differences of average number of EPT taxa between creeks within non-mined and mined sites, (*P=0.0001*, Table 19).

Table 18 PERMANOVA table of results for riffle EPT total number of individuals

Source	df	Pseudo-F	P(MC)
Mined/Non-mined	1	10.593	0.0106

Again, the greatest difference occurred between non-mined O'Hares Creek and mined Waratah Rivulet riffles with an average of 4.2 and 4.9 less taxa in winter and spring (Figure 29b).

Table 19 PERMANOVA table of results for riffle EPT total number of taxa

Source	df	Pseudo-F	P(perm)	P(MC)
Mined/Non-mined	1	5.9512	-	0.0239
Creek (Mined/Non-mined)	2	3.5883	0.0001	-

A similar ratio of missing Trichoptera taxa occurred in mined riffles compared to mined edges (Figure 30). Overall, Trichopterans in riffle habitats were represented by 24 different genera (Figure 30). Trichoptera diversity was greatest at non-mined sites, with 22 genera within riffle habitats observed at non-mined sites, compared to eight genera from mined sites (Figure 30). Sixteen of the genera were present at non-mined sites only, including the three most prevalent, *Alloecella (*Helicophidae), *Helicopsyche* (Helicopshychidae) and *Hampa* (Conoesucidae), observed at 15% of the non-mined riffles. Other Trichoptera genera found within more than 5%

of non-mined riffles include *Oecetis* (Leptoceridae), *Daternomina* (Ecnomidae), *Diplectrona (*Hydropschidae) and *Triplectides* (Leptoceridae). Nine further Trichopeterans were found within less than 5% of non-mined riffles, compared to only two genera found at mined sites only (Figure 30).

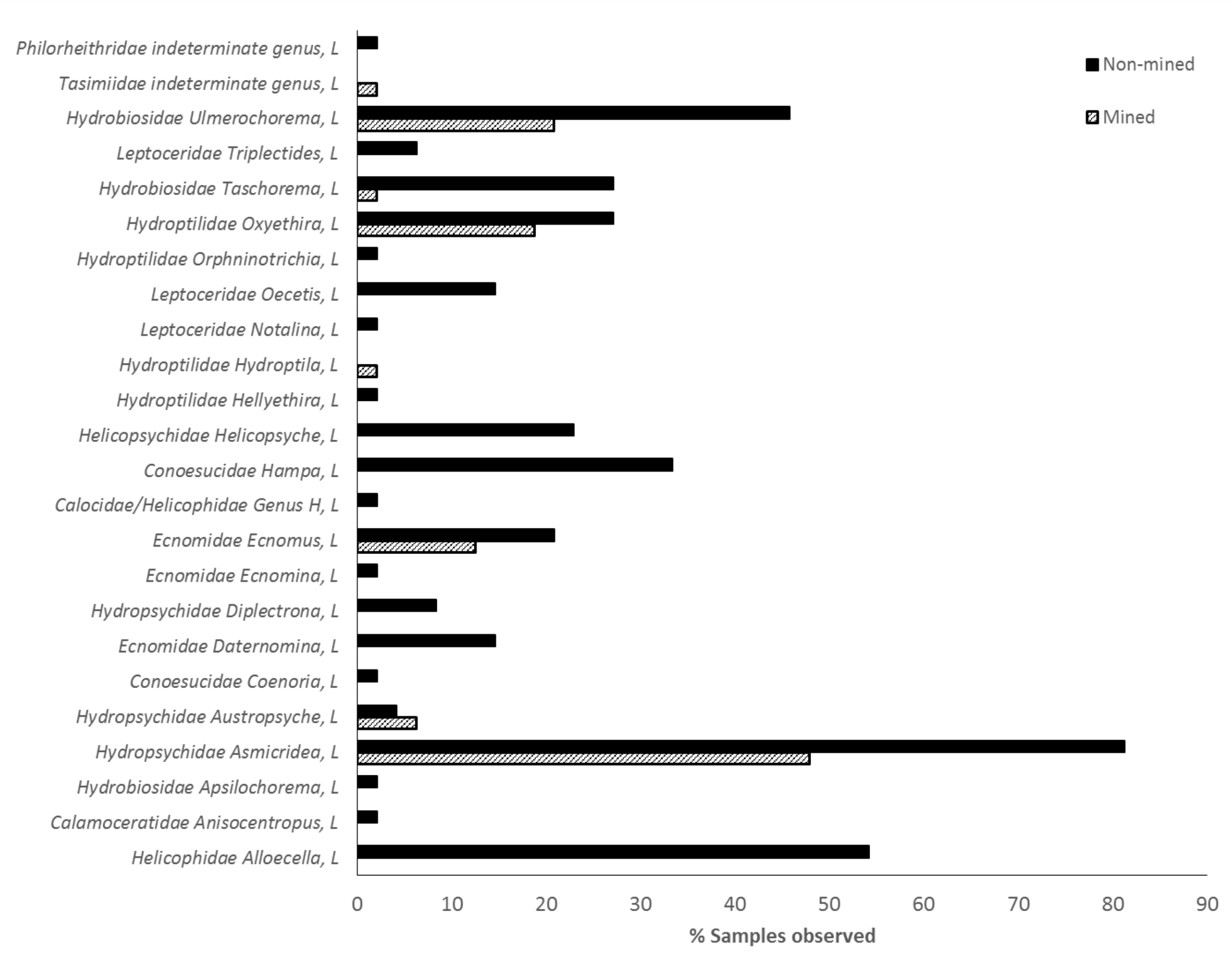


Figure 30 **Trichoptera genera present within riffles at mined and non-mined sites**

Plecoptera were represented by three different genera within non-mined riffles (Figure 31). Only one of these, *Dinotoperla* (Gripopterygidae), was present at over half of the number of mined compared to non-mined riffles. Two Gripopterygidae genera, *Leptoperla and Illiesoperla*, were absent from any of the mined sites (Figure 31).

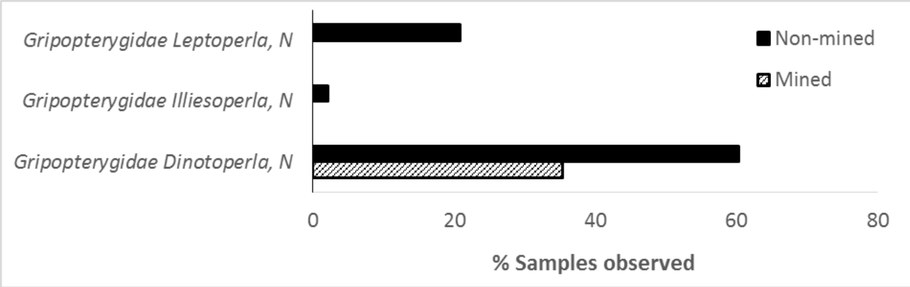


Figure 31 **Plecoptera genera present within riffles at mined and non-mined sites**

Multivariate Analysis

Edges

Cluster analysis and multi-dimensional scaling (MDS)

Cluster analysis of edge macroinvertebrate assemblages indicated separation of non-mined and mined replicates, with several Waratah Rivulet replicates the least similar to all others (Figure 32).

The first split separates one midstream mined edge replicate (WR5) from all others at less than five percent similarity (Figure 32). The following two splits at just under and over 15% similarity separate a further three midstream mined Waratah Rivulet replicates.

The next split, at approximately 20% similarity, separates two further mined replicates from up and downstream Eastern Tributary, one each from winter and spring (WR3 and WR1), and one downstream non-mined replicate from O'Hares Creek in spring (OH3). Following this, at just under 25% similarity, was the separation of all eight (winter and spring) upstream non-mined replicates from O'Hares Creek (OH1) and, at just over 25% similarity, the remaining four midstream mined Waratah Rivulet replicates.

Between 25% to 30% similarity, a separation of an additional non-mined midstream O'Hares Creek (OH2) replicate occurred, along with seven replicates from mined upstream Eastern Tributary sites (WR1 and WR2). No further separation occur between these replicates.

The last few separations under 50% similarity divide the remaining replicates into three main groups:

1. 23 of the 24 non-mined Loddon River replicates from all stream positions separate at approximately 30% similarity, except for one winter downstream replicate

2. All remaining mined replicates from all stream positions separate at just over 30% similarity. Several non-mined mid and downstream replicates (OH2 and OH3) from spring also combine with replicates in this similarity group indicating similarity.
3. All four non-mined, downstream, winter samples at OH3 separate in one of the final splits at justover 40% similarity.

In summary, the first two sites replicates to separate from all other sites include those from the mined midstream Waratah Rivulet and the non-mined upstream O'Hares Creek (Figure 32).

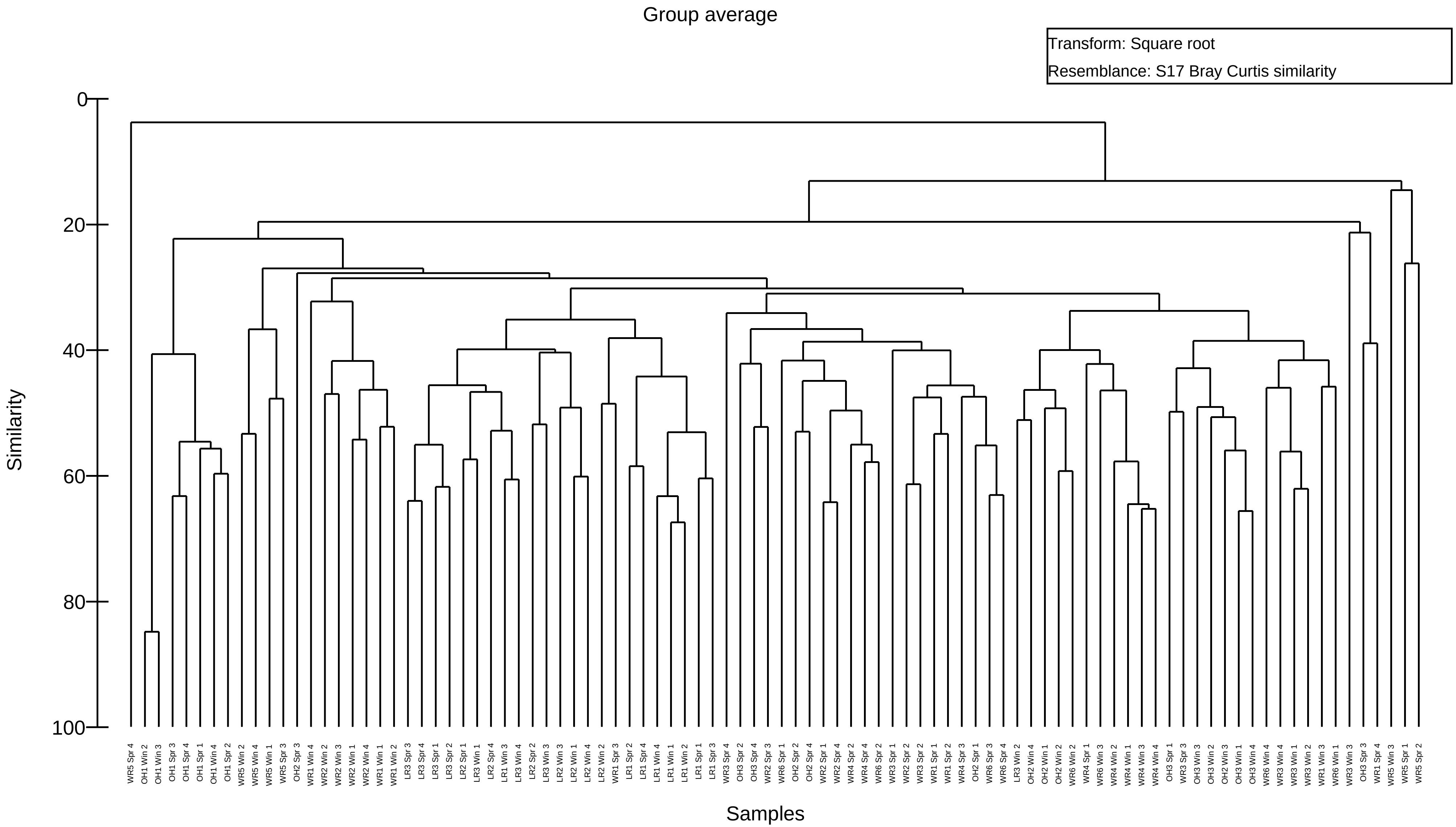


Figure 32 **Cluster analysis of macroinvertebrate community composition from edge replicates**

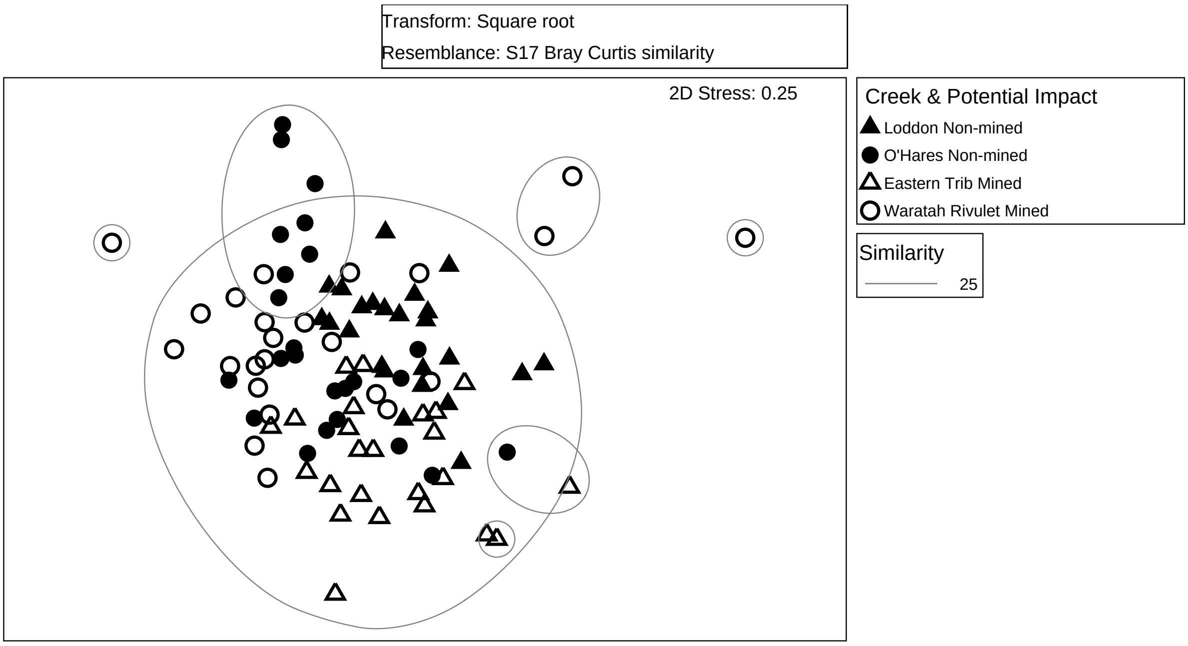


Figure 33 2D Non-MDS of edge macroinvertebrate replicates

The 2D multi-dimensional ordination (Figure 33) is in agreement with the cluster analysis (Figure 32). Separation of four of the midstream mined Waratah Rivulet replicates from all others, and all of the non-mined upstream O'Hares Creek replicates is evident in the 2D ordination (Figure 33). Stress reduced in the 3D ordination (Figure 34) and clearly presented the separation of Waratah Rivulet replicates from each other and from all other replicates.

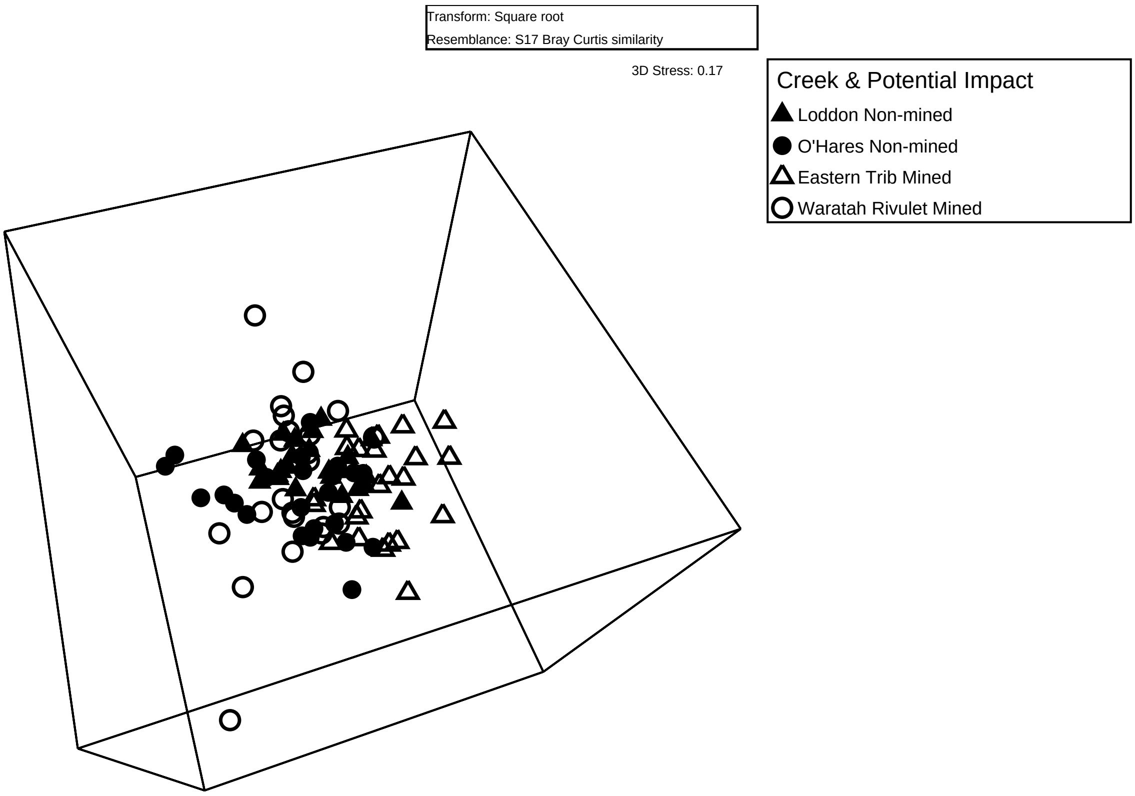


Figure 34 3D Non-MDS of edge macroinvertebrate replicates

SIMPER

Overall similarity of edges at non-mined sites was greater than mined sites (Figure 24). Non-mined Loddon River had the highest similarity between edge replicates (42.79%) of all four creeks, and mined Waratah Rivulet the lowest at 28.43% similarity (Figure 24, Appendix 7). Further investigation of edge macroinvertebrates that dominated over 4% of total genus contributions within SIMPER analysis reveal differences between non-mined and mined creeks (Appendix 7).

The non-mined Loddon River and O'Hares Creek edges were most dominated by three non-biting midge (Chironomidae) sub-families, including *Chironominae* (15.99%), *Tanypodinae* (12.07%) and *Orthocladiinae* (11.64%), followed by the freshwater shrimp *Paratya (*Atyidae, 11.92%). The next most dominant genera above 4% contribution was the EPT caddis fly *Triplectides* (Leptoceridae, 5.26%).

In contrast, the mined Eastern Tributary and Waratah Rivulet edges were most dominated by the freshwater shrimp *Paratya (*Atyidae, 14.49%) and two chironomids, *Chironominae* (13.97%) *and Tanypodinae* (9.45%). These were followed by two mayflies - immature Baetidae nymphs (8.24%) and, both mature *Koornonga (*Leptophlebiidae, 7.96%) and immature Leptophlebiidae nymphs (7.19%). A further four genera were found contributing to more than 4% of the total including: immature backswimmers (Notonectidae, 4.40%), *Orthocladiinae* (Chironomidae, 4.30%), *Triplectides* (Leptoceridae, 4.30%) and *Centroptilium* (Baetidae, 4.21%) nymphs.

Table 20 SIMPER analysis of macroinvertebrate similarity within edges

Creek Similarity %	**Non-mined** (37.44)		**Mined** (30.97)	
	Loddon River	O'Hares Creek	Eastern Tributary	Waratah Rivulet
Similarity %	42.79	32.97	33.51	28.43

BEST

The water quality variables analysed using BEST routine (PRIMER V7) found to correlate and potentially contribute to edge macroinvertebrate assemblage include manganese, turbidity and rainfall (Appendix 7). Although, correlations were weak reaching a maximum of 0.285 when including all three variables.

Riffles

Cluster analysis and multi-dimensional scaling (MDS)

Cluster analysis of riffle macroinvertebrate assemblages indicated separation of all mined upstream Eastern tributary replicates in spring from all others at approximately 10% similarity (Figure 35).

The second split at just over 30% separates all upstream non-mined Loddon River and O'Hares Creek replicates (LR1 and OH1, Figure 35). Four further splits occurred between approximately 32 to 40% similarity and the groups included:

1. All eight spring replicates from the mined upstream and midstream Waratah Rivulet sites (WR4 and WR5)
2. All twelve winter mined replicates from midstream and downstream Eastern Tributary and downstream Waratah Rivulet (WR2, WR3 and WR6)
3. All winter replicates from mined upstream and midstream Waratah Rivulet and upstream Eastern Tributary (WR4, WR5 and WR1) and, midstream and downstream non-mined O'Hares Creek (OH2 and OH3)
4. Contains the highest number of replicates, approximately one third overall, from a mixture of all creeks from both seasons.

In summary, a greater degree of separation between non-mined and mined replicates occurred in riffles than edges, the most dissimilar from upstream Eastern Tributary and upstream and midstream Waratah Rivulet (Figure 35).

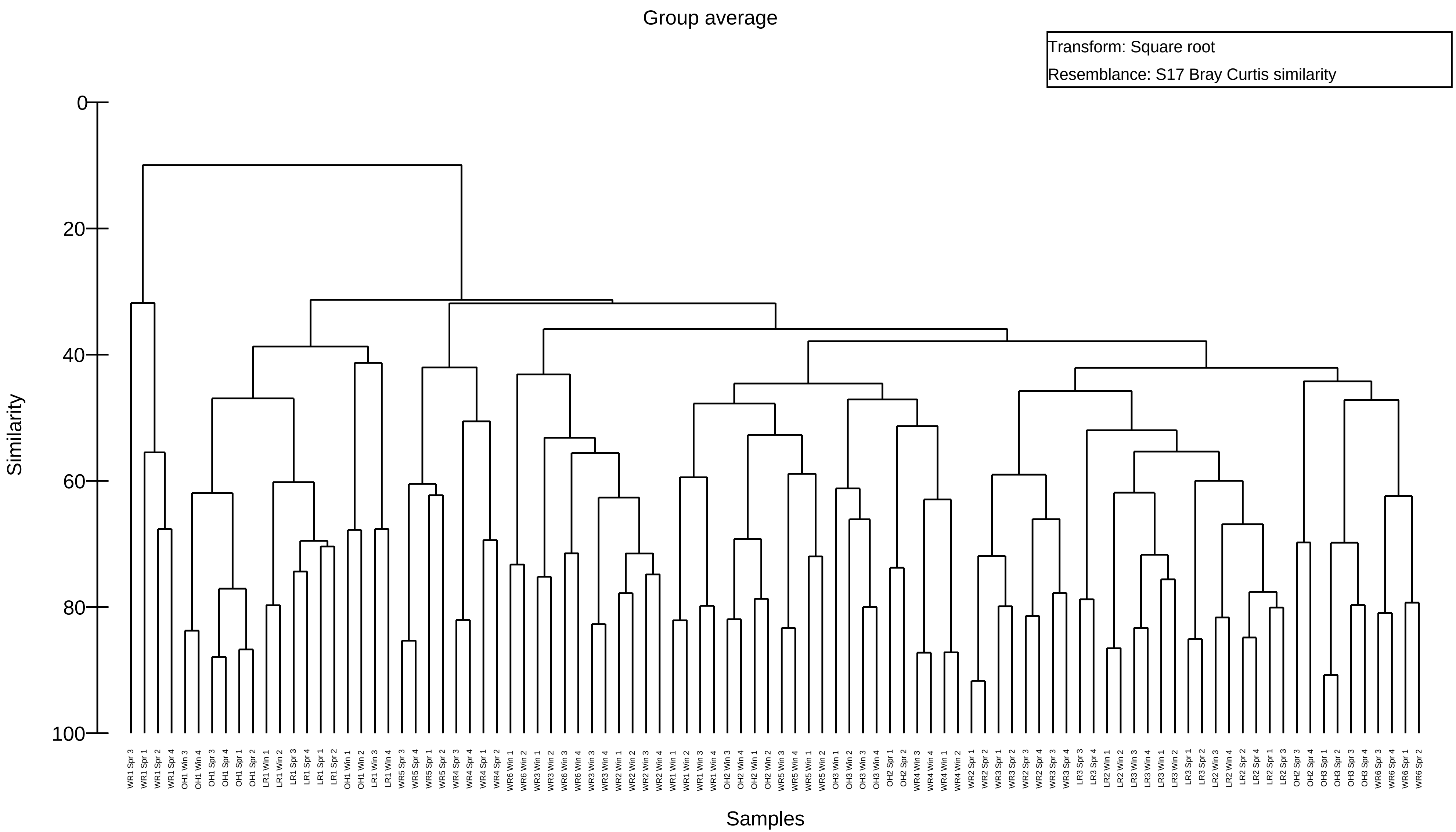


Figure 35 **Cluster analysis of macroinvertebrate community composition from riffle replicates**

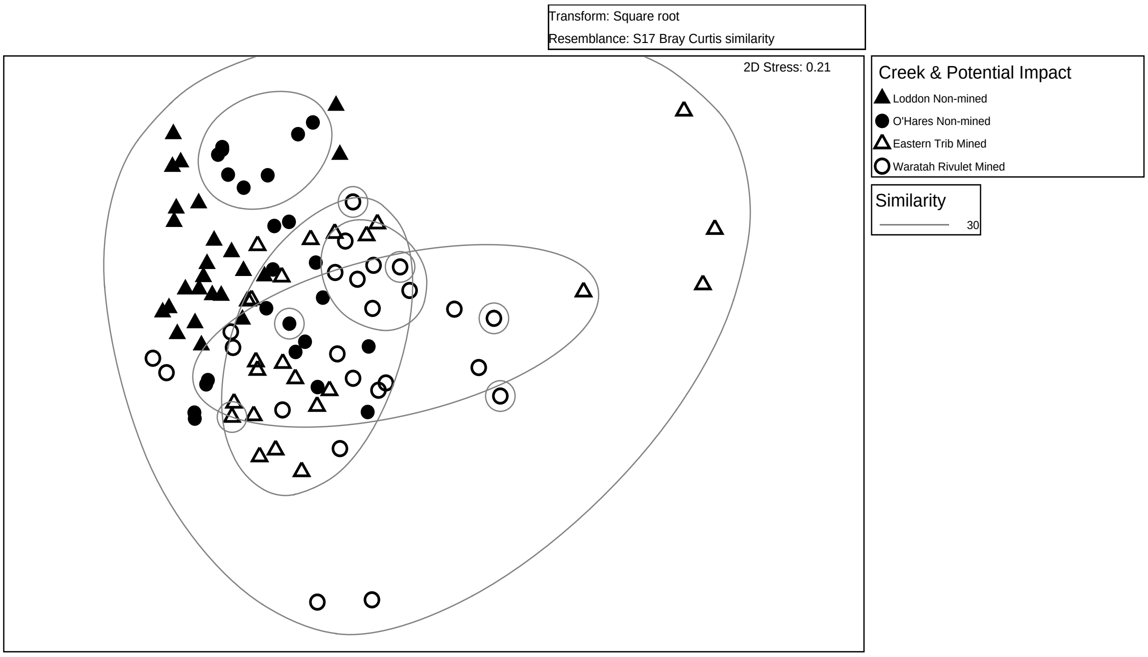


Figure 36 2D Non-MDS of riffle habitat macroinvertebrate replicates

The riffle 2D multi-dimensional ordination (Figure 36) is in agreement, as for edges, with the cluster analysis (Figure 35). Separation of four of the upstream mined Eastern Tributary replicates from all others, and some of the mined upstream and midstream Waratah Rivulet replicates is evident in the 2D ordination (Figure 36). Stress reduced in the 3D ordination (Figure 37) and also clearly indicated the separation of upstream mined Eastern Tributary replicates from all other replicates.

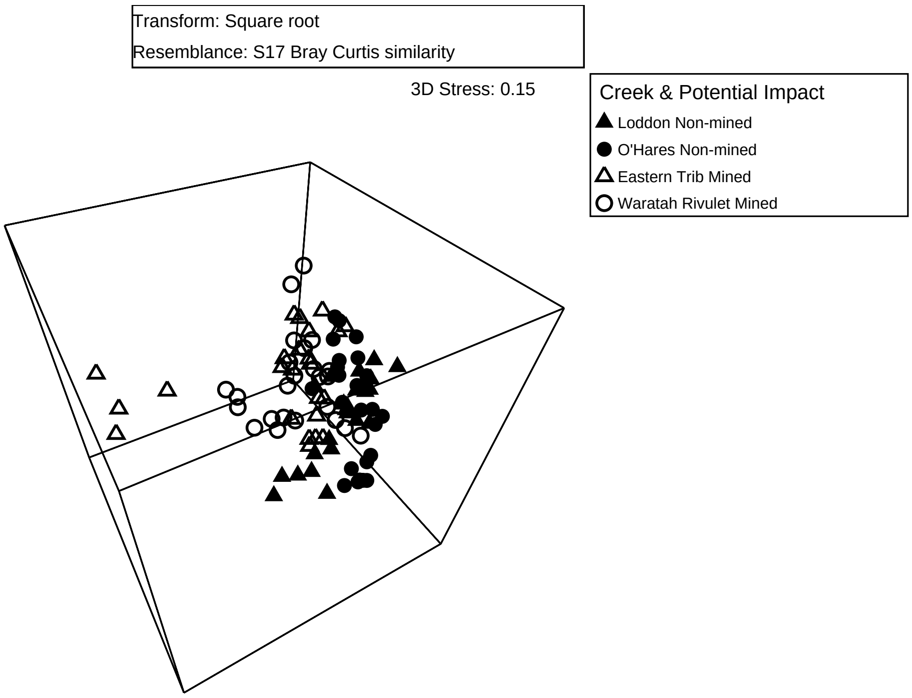


Figure 37 3D Non-MDS of riffle habitat macroinvertebrate replicates

SIMPER

Overall similarity of non-mined riffles was greater than mined sites, as for edges, and greater in non-mined riffles than non-mined edges (Table 21). Again, the non-mined Loddon River had the highest similarity between riffles (48.91%) of all four creeks, but the mined Eastern Tributary the lowest at 37.74% similarity (Table 21, Appendix 7). Further investigation of riffle macroinvertebrates that dominated over 4% total genus contributions within SIMPER analysis reveal differences between non-mined and mined creeks (Appendix 7).

The non-mined Loddon River and O'Hares Creek riffles were most dominated by two non-biting midge (Chironomidae) sub-families, including *Orthocladiinae* (19.34%) *and Chironominae* (18.29%), followed by the caddis fly *Asmicridea* (Hydropsychidae, 9.02%). Three additional genera dominant above 4% contribution were two Elmidae riffle beetles *Austrolimnius* (5.85%) and *Kingolus* (4.08%), and another chironomid sub-family, *Tanypodinae* (4.35%).

The mined Eastern Tributary and Waratah Rivulet riffles were also most dominated by the same two chironomid sub-families as non-mined sites, including *Orthocladiinae* (19.67%) *and Chironominae* (19.38%). But were followed by the mayfly, *Offadens* (Baetidae, 8.24%), a crane fly, *Antocha* (Tipulidae 7.20%) and a riffle beetle, *Kingolus* (Elmidae, 5.61%).

Table 21 SIMPER analysis of macroinvertebrate similarity within riffles

Creek Similarity %	**Non-mined** (45.79)		**Mined** (38.20)	
	Loddon River	O'Hares Creek	Eastern Tributary	Waratah Rivulet
Similarity %	48.91	42.92	37.74	38.66

BEST (BIOENV)

The water quality variables analysed using BEST routine (PRIMER V7) found to correlate and potentially contribute to riffle macroinvertebrate assemblage include bicarbonate, sulphate, temperature and rainfall (Appendix 7). Correlations were moderately strong, reaching a maximum of 0.417 when including all four variables and were stronger than any water quality variable correlations within edges.

Further analysis of only the Trichoptera taxa and re-running the BEST routine failed to improve correlations. Correlations were weak at 0.320 and included only two variables, dissolved oxygen and manganese (Appendix 7).

SIGNAL-SG

Edges

The only significant difference within signal-SG scores in edges occurred between creek nested within non-mined and mined sites (*P=0.0017*, Table 22). Average signal-SG scores from all non-mined and one mined edges lay within the moderately impacted stream health range (Table 4), and all other mined average signal-SG scores lay within the severely impacted stream health range (Figure 38).

Table 22 PERMANOVA table of results for signal-SG in edges

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	5.0584	0.0017

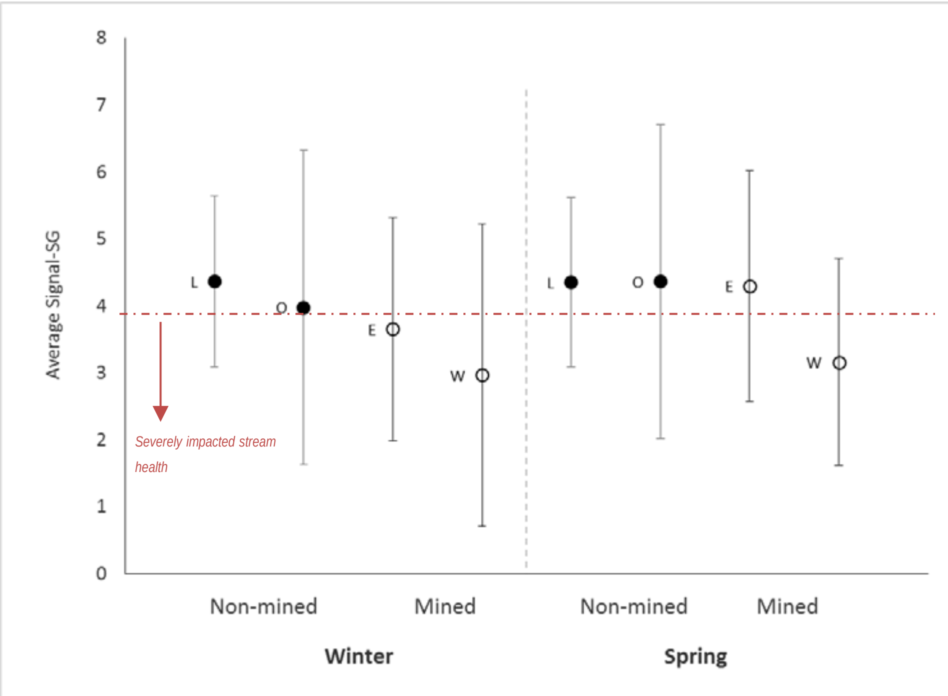


Figure 38 Mean edge Signal-SG scores by non-mined and mined sites and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Riffles

Significant signal-SG differences were also observed in riffles, as for edges, between creeks nested within non-mined and mined sites (*P=0.0001*, Table 23).

Table 23 PERMANOVA table of results for Signal-SG in riffles

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	14.945	0.0001

Further investigation revealed the greatest average signal-SG score difference of 2.2 and 2.0 between the mined Eastern Tributary and Waratah Rivulet riffles (Figure 39).

Average signal-SG scores from one non-mined and two mined riffles lay within the severely impacted stream health range (Table 4) and all others lay on the borderline or within the moderately impacted stream health range (Figure 39).

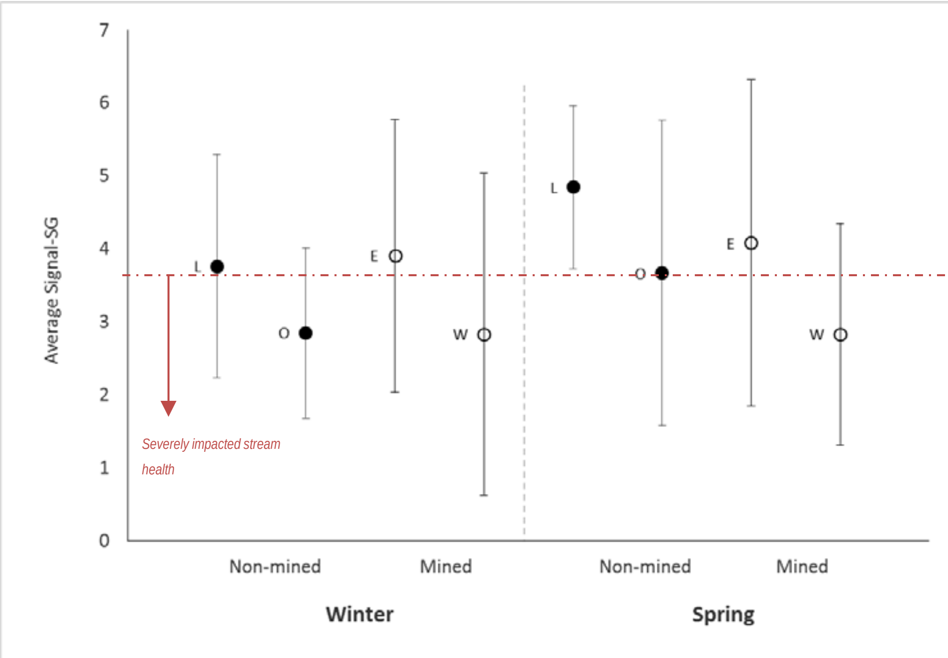


Figure 39 Mean riffle Signal-SG scores by non-mined and mined sites and season (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Functional Feeding Groups (FFG)

Edges

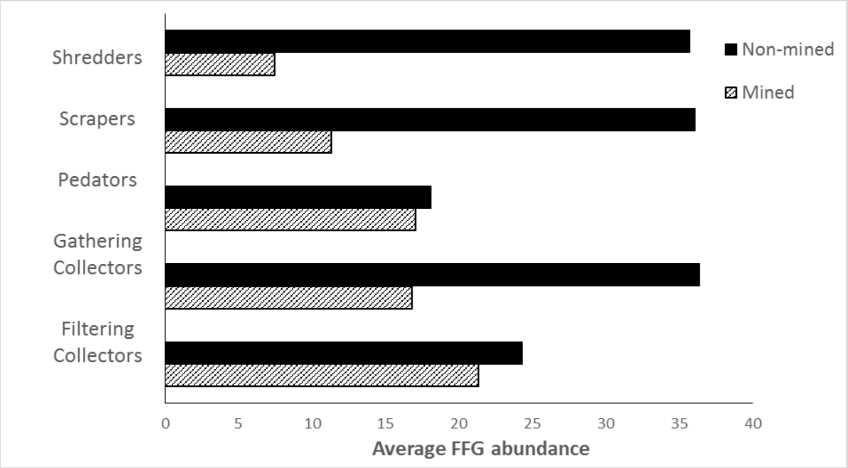


Figure 40 Average abundance of functional feeding groups of macroinvertebrates within edges

A reduction in abundance of all functional feeding groups within edge habitats occurred within mined compared to non-mined edge habitats, including over 75% reduction in average abundance of scrapers (Sc) (Figure 40). Over 50% reduction was also observed in average abundance for gatherer/collectors (GC) and shredders (S) between mined compared to non-mined edge habitats (Figure 40). Statistically, only shredders and scrapers showed significant differences between mined and non-mined sites (*P=0.011 and P=0.0039),* Table 24.

Table 24 ANOVA of individual FFE abundance in edges from non-mined and mined sites

FFG	**Source**	df	F	***P***	*F critical*
Shredders	Mined/Non-mined	1	6.65	***0.011***	3.94
Scrapers	Mined/Non-mined	1	8.79	***0.0039***	3.94

Riffles

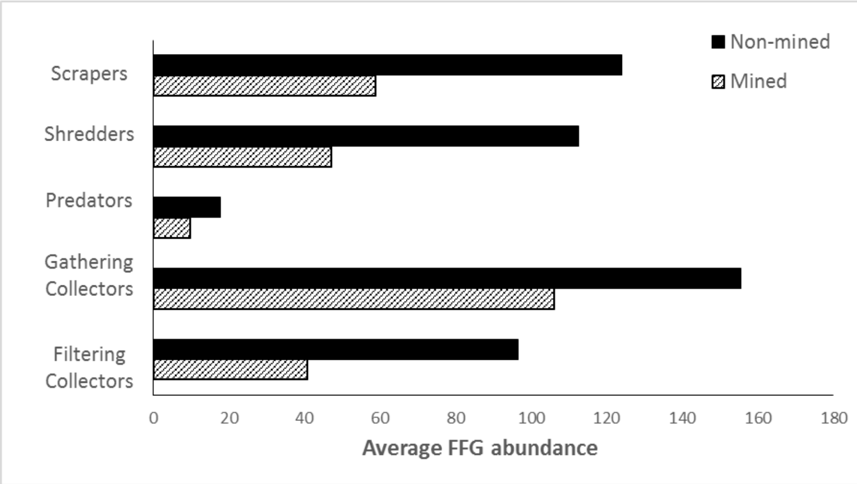


Figure 41 Average abundance of functional feeding groups of macroinvertebrates within riffles

As with edges, a reduction in abundance of all functional feeding groups occurred within mined compared to non-mined riffle habitats (Figure 41). The most significant difference between mined and non-mined riffle habitats, in decreasing order of strength, occurred within filtering collectors (P=0.0001), shredders (P=0.0007), predators (P=0.0089) and scrapers (P=0.0013, Table 25 and Figure 41).

Table 25 ANOVA of individual FFE abundance in riffles from non-mined and mined sites

FFG	**Source**	df	F	***P***	*F critical*
Filterer Collectors	Mined/Non-mined	1	16.455	***0.0001***	3.94
Predators	Mined/Non-mined	1	7.13	***0.0089***	3.94
Shredders	Mined/Non-mined	1	12.12	***0.0007***	3.94
Scrapers	Mined/Non-mined	1	12.11	***0.0013***	3.94

3.5 Diatoms

Abundance and Taxa Richness

A total of over 1.2 million epilithic diatoms from fifteen genera were extrapolated from laboratory analysis of samples (Appendix 8). In particular, four genera were found in relatively small numbers at only mined sites: *Navicula, Cocconei, Pinnular* and *Amphora;* and, no genera were unique to non-mined sites (Table 24). *Naviculoid* diatoms were the most abundantly dominant genus, followed by *Gomphonema* which were both more abundant at non-mined than mined sites (Figure 42).

Table 26 **Presence/absence of diatom genera at non-mined and mined creeks**

Diatom genera	Non-mined		Mined		Total collected
	Loddon	O'Hares	Eastern	Waratah	
Gomphonema	√	√	√	√	326,825
Encyonem	√	√	√	√	49,400
Diatomella	√	√	√	√	21,425
Naviculoid	√	√	√	√	774,457
Eunotia	√	√	√	√	21,297
Synedra	√	√	√	√	6,333
Diatoma			√	√	3,056
Tabellar	√	√	√	√	21,579
Nitzschi	√	√	√	√	9,754
Achnantm	√	√	√	√	18,844
Navicular			√	√	351
Cocconei			√		68
Pinnular			√	√	750
Surirell	√	√	√	√	233
Amphora				√	68

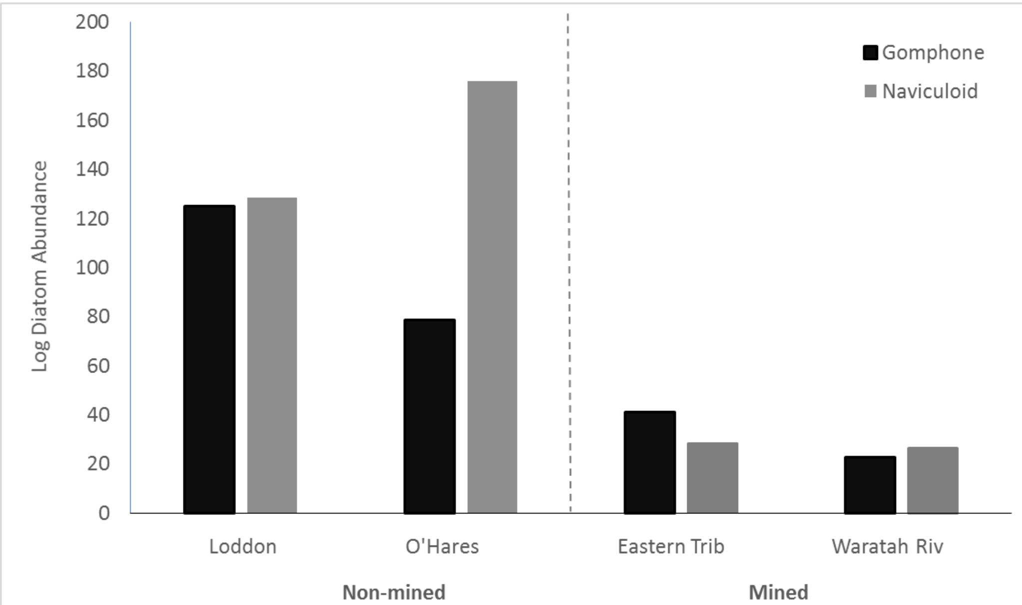
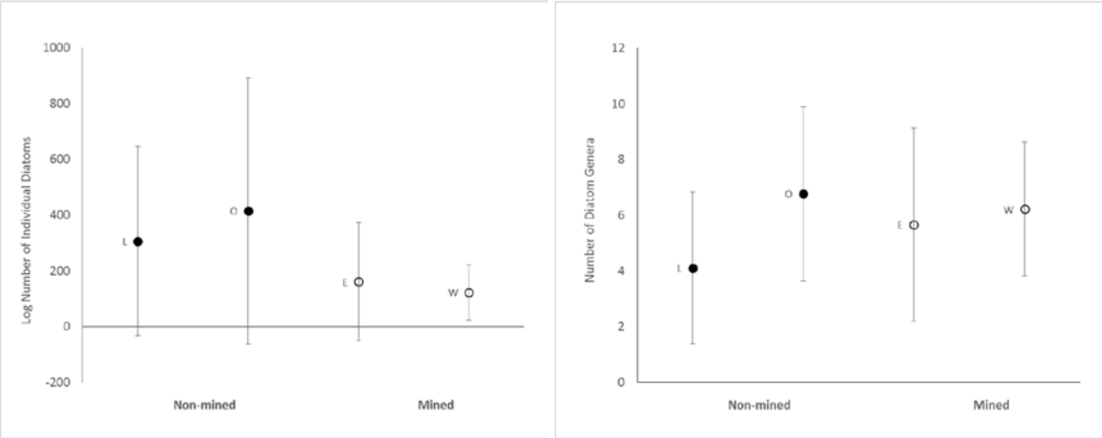


Figure 42 **Mean total abundance of two diatom genera within stream by season at non-mined and mined sites**



a. b.

Figure 43 Mean diatom (a) log abundance and (b) average taxa richness by non-mined and mined sites (error +/- 2 standard deviation from the mean). *L=Loddon River, O=O'Hares Creek, E=Eastern Tributary and W=Waratah Rivulet.*

Average diatom abundance varied between non-mined and mined sites (Figure 43a), and PERMANOVA analysis indicated this was statistically significant (*P(MC)=0.0148*, Figure 27). A significant difference was also observed in average diatom taxa between creeks nested within non-mined and mined sites (*P=0.0004*, Figure 43b and Table 28), indicating more variability between creeks within same potential impact that between them.

Table 27 PERMANOVA table of diatom abundance

Source	df	Pseudo-F	P(MC)
Creek (Mined/Non-mined)	2	8.7726	0.0148-

Table 28 PERMANOVA table of diatom taxa richness

Source	df	Pseudo-F	P(perm)
Creek (Mined/Non-mined)	2	8.7726	0.0004

Multivariate Analysis

Cluster analysis and multi-dimensional scaling (MDS)

Cluster analysis of epilithic diatom community asssemblage indicates clear separation of most of the non-mined from mined replicates (Figure 44). Only one unmined replicate (from a possible total of eighteen) from downstream O'Hares Creek lies within the majority of mined samples, and only three mined replicates from various stream positions lies with the majority of non-mined samples. Separation of these two main non-mined and mined site groups occurred at 30% similarity indicating samples from non-mined sites are more similar than those from mined sites.

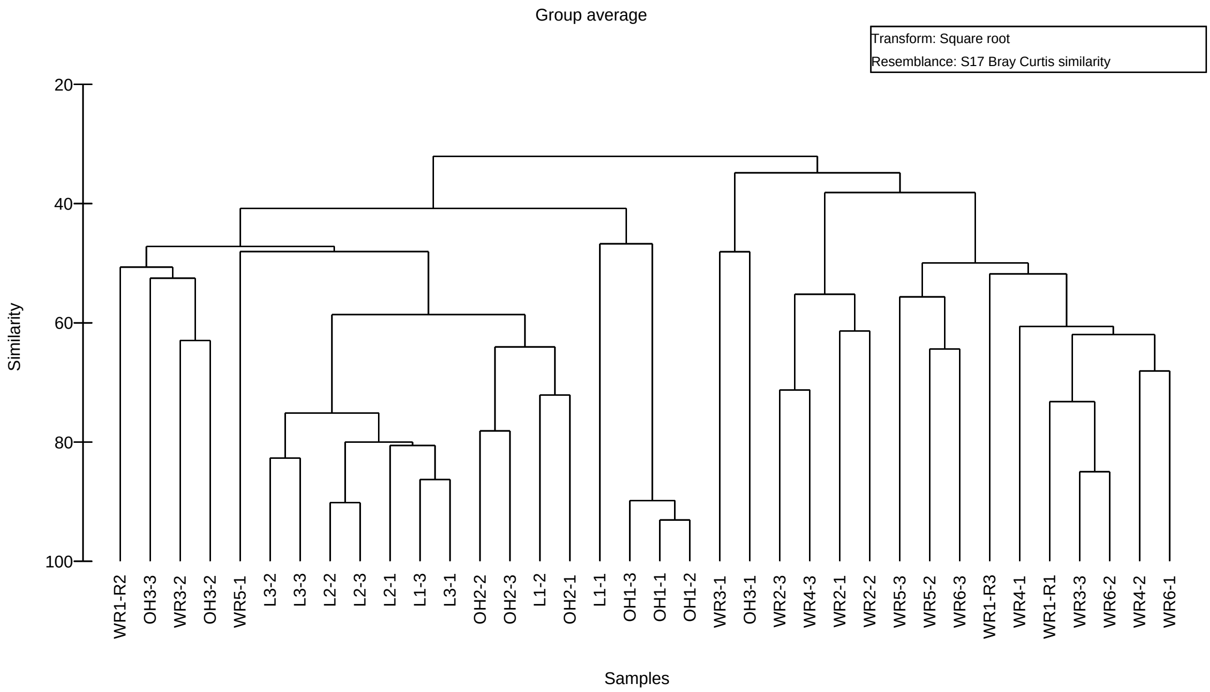


Figure 44 **Cluster analysis of epilithic diatom community assemblage from sites**

Visual representation of the results 2D non-MDS clearly shows four distinct groups at 40% similarity (Figure 45). The low stress value (0.17) indicates a potentially useful interpretation of the results. The cluster overlay again indicates diatom assemblages from the same non-mined and mined sites are more similar than those between non-mined and mined sites.

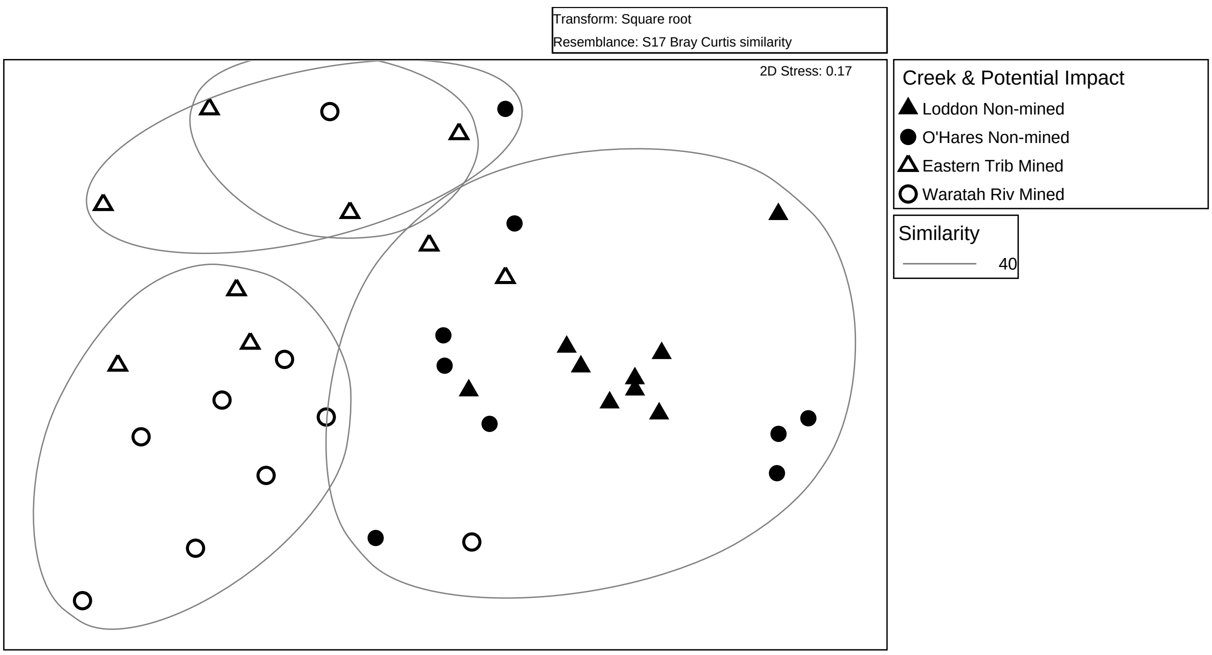


Figure 45 **2D Non-MDS of epilithic diatom community replicates**

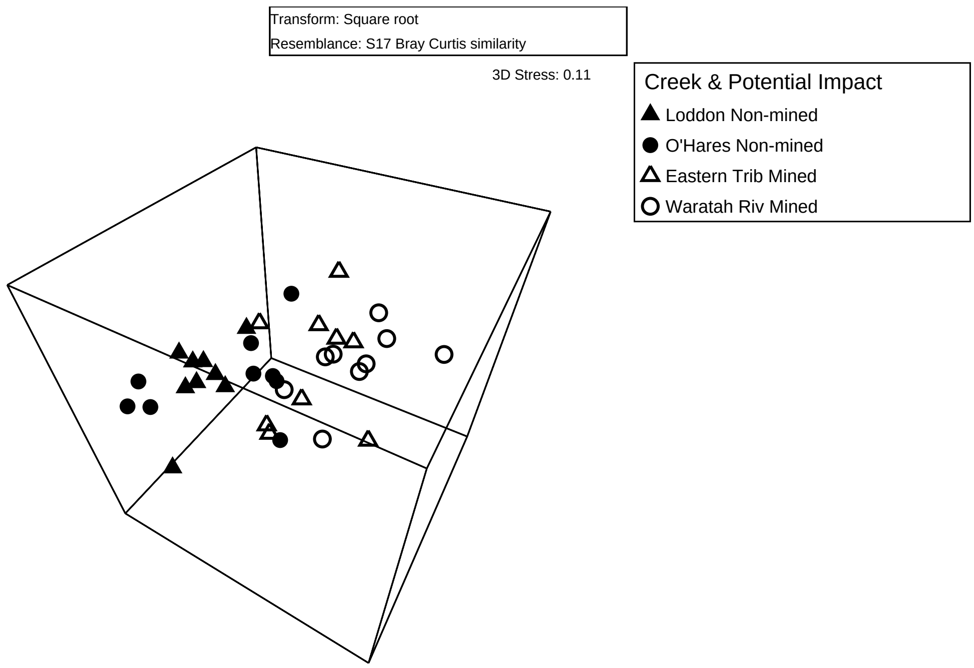


Figure 46 3D Non-MDS of epilithic diatom community replicates

Further analysis of the 3D non-multi-dimensional scale further supports the separation of mined and non-mined replicates from each other, most likely due to the presence of four extra genus of diatoms and loss of abundance of *Gomphone* and *Naviculoid* diatoms at mined sites (Figure 46, Table 24 and Figure 42). A stress of 0.11 supports a good ordination.

Overall PERMANOVA indicates diatom assemblages significantly differed between non-mined and mined sites (*P(MC)=0.0251,* Table 27) and between creeks nested within non-mined and mined sites (*P=0.0001).*

Table 29 PERMANOVA table of results for diatoms

Source	df	Pseudo-F	P(perm)	P(MC)
Mined/Non-mined	1	3.8582	-	0.0251
Creek (Mined/Non-mined)	2	3.5038	0.0001	-

SIMPER

Diatom SIMPER analysis (Table 28, Appendix 10) indicate non-mined diatom replicates are more similar (58.40%) than mined replicates (47.22%). Further analysis indicates this is contributed predominantly by the non-mined Loddon River, with diatom similarity between replicates the highest of all four creeks (67.63%, Table 28).

The lowest similarity, 44.48%, was observed between diatom replicates from the mined Eastern Tributary.

Table 30 SIMPER analysis of diatom similarity within sites

Creek Similarity %	**Non-mined** (58.40)		**Mined** (47.22)	
	Loddon River	O'Hares Creek	Eastern Tributary	Waratah Rivulet
Similarity %	67.63	49.17	44.48	49.97

Gomphone and *Naviculoid* were the two most predominant diatom genera from all creeks, contributing to between 45 to 94% overall composition, except Eastern Tributary which was dominated by *Gomphone* (46%) and *Diatomella* (19%) (Appendix 10). Diatom composition from Waratah Rivulet were contributed to the lowest by *Naviculoid* and *Gomphone* (23.47% and 21.89%), but were almost equally dominated by two additional genera, *Achnantm* and *Euryonem*, 20.43% and 19.86% - the highest of all other genera across all sites (Appendix 10).

BEST

The water quality variables analysed using BEST routine (PRIMER V7) found to correlate and potentially contribute to diatom assemblage include bicarbonate, chloride, % dissolved oxygen, pH and turbidity (Appendix 7). Correlations were moderately strong, reaching a maximum of 0.530 when including the latter four variables, stronger than macroinvertebrate correlations.

4. Discussion

In order for subsidence from underground long wall coal mining to affect the assemblages of stream biota, it would be necessary for cracking of underling rocks to cause greater downwards flow of surface water below the ground which results in either, or both, of the following: (a) Reduced flow of surface water because cracking of rocks has caused a conduit permitting greater flow of surface water into the groundwater; (b) A change in the water chemistry of the surface water because of return of (some) of this groundwater to the surface after having dissolved minerals while flowing through newly cracked rock. The findings of this thesis are consistent with both of these processes occurring. I will discuss these changes below.

4.1 Water level

Water levels in streams overlying underground mining reduced more quickly following rainfall, relative to those in reference sites. This is consistent with a greater amount of surface water being lost underground because of cracking caused by subsidence. There would be increased confidence in this finding with a greater length of water depth record (and the data loggers have been left recording to obtain this). Nevertheless, this finding is consistent with a number of reports (Holla & Barclay, 2000; Krogh, 2007; BHP, 2014) and unpublished studies (Stout, 2004). These studies have found an increase in frequency of dry events in areas impacted by subsidence overlying underground long wall coal mining.

Flow in headwater streams is often critical for maintaining stream health in larger rivers downstream via attenuation of floods, preventing siltation downstream and maintaining water supplies (Alexander *et al*, 2007; Gomi *et al,* 2002; Meyer *et al,* 2007). Degradation and loss of headwaters and their connectivity to ecosystems downstream threaten the integrity of entire river networks. So any changes in the flow of the headwater streams studied could have implications for larger rivers downstream.

Temporal variability of the ecology in ephemeral streams is understudied but Botwe *et al* (2015) suggest sustenance of seasonal flows and maintenance of critical refuge habitats is important for maintaining biological and chemical health of headwater streams. Naturally ephemeral streams may support rich and distinctive biological communities because of their slow formation through long evolutionary periods supporting increased adaptation and resilience to predictable dry periods (Meyer *et al.*,2007). Altered water levels in perennial streams caused by mining subsidence would be expected to be too rapid to allow for similar adaptation and subsequent maintenance of water quality and ecology to mimic those of more intermittent streams.

4.2 Water quality

Significant differences were observed between water quality variables between streams overlying underground long wall mining compared to those with no mining. In particular there were significant increases in temperature and electrical conductivity and concentrations of lithium, bicarbonate, barium, calcium, sodium, iron and chloride. These differences are consistent with increased groundwater to surface water connectivity, as groundwaters typically have higher electrical conductivity, pH and concentrations of major, minor and trace elements (Jankowski *et al.*,2008). As groundwater is travelling through newly cracked rock there would be expected to be even greater increases in dissolved ions and thus electrical conductivity and pH. Chemical reactions would increase as water flows over new rock fractures, especially after rainfall, and act to mobilize elements from carbonate rock minerals, which are common in sandstones of the area (Sherwin & Holmes, 1986).

Both mined and one non-mined creek were in drinking water catchments closed to the public with no other anthropogenic activity, and the remaining non-mined creek within national park with minimal anthropogenic activity in the catchment, that could likely contribute to such differences. Wright *et al* (2015) also observed increased electrical conductivity, sodium, chloride, iron and manganese in a small stream disturbed by subsidence from long wall mining.

pH levels between non-mined and mined streams remained similar (between 6.2 to 7.5). This may be due to an increase in carbonate minerals from fractured rock strata in mined streams helping to buffer the dissolution of pyritic material (Stout, 2004).

Of the three trace metals that had acceptable detection limits detecting increased groundwater to surface water connectivity, only lithium was significantly different between streams with and without mining. Relatively little information is available for trace metals in natural rivers (Luck and Othman, 1998). The extremely low levels of lithium (mean 0.25µg/L) in non-mined streams in this study suggest transport from underground sources to surface water is limited by the low permeability of between-lying rock strata. The increased Li concentrations at sites with mining is consistent with groundwater returning to the surface and infiltrating at much faster rates to interact with newly cracked rock. Lithium has a variety of manufacturing uses (including in heat resistant glass, air conditioners, lithium batteries and grease lubricants). However, due to the extremely limited anthropogenic activities in these catchments it is highly unlikely that lithium was the result of pollution. Lithium is therefore a useful indicator of mining subsidence, but only in streams with very little anthropogenic activity in the catchment.

Beryllium and molybdenum recoveries were within an acceptable range of 85-115% for winter but were outside the acceptable range for spring. This makes it difficult to infer differences that may exist as a result from mining induced subsidence because of possible laboratory interference or contamination. Further development of methods to detect these elements and improve recovery results would be required before their usefulness could be assessed.

Other water quality variables also contribute further to the understanding of surface water quality changes associated with subsidence from long wall coal mining. Significantly elevated bicarbonate, barium, calcium, chloride, sodium, iron and manganese concentrations at mined sites further support evidence of increased chemical reactions from water discharging from subsurface routes to streams. Krogh (2007) indicate increased sub-surface cracks and new fracture networks exposed fresh rock which rapidly reacts with oxygen and flowing groundwater to significantly enhance oxidisation of carbonate rock minerals and release of elements. Jankowski (2008) further determined increased bicarbonate concentrations were a result of increased chemical reactions involving carbonate minerals within the Hawkesbury Sandstone aquifer mix. This thesis is consistent with Jankowski (2008) that increased mobilization of iron, manganese and barium from metal carbonates significantly increased downstream of those creeks where mining subsidence had occurred. Increased availability of iron and manganese in surface waters for iron oxidizing bacteria observed in the mined streams also enable the formation of thick mats of iron/manganese-oxides/hydroxides which further act to reduce in-stream habitat and available food, clog streams and lead to potential loss of biodiversity.

Chloride was significantly elevated at mined compared to non-mined sites. The elevated levels of chloride ions in the surface waters of all streams interfered with the detection of trace levels of chromium (Wilbur *et al,* 2012; Henri Wong pers comm). Chromium is therefore not useful in detecting groundwater to surface water interactions as a result of subsidence from long wall mining because of the increased chloride produced as a result of cracking.

The greater variability of water chemistry variables at mined compared to non-mined sites and the greater distance between samples when plotted in a 2D space using the principal component analysis suggest a clear shift away from the more stable and consistent water quality results from non-mined sites.

4.3 Macroinvertebrates

Overall, EPT individuals in riffles and EPT taxa in edges and riffles, in particular Trichoptera, differed the most between sites with and without mining. The EPT fauna have been shown to be useful indicators of water quality as they are responsive to disturbance (Rosenberg & Resh, 1993). In particular, their long life cycle in the larval/nymph stage, is known to be up to or longer than nine months before emergence as adults (Wallace & Anderson, 1996). The significant reductions in EPT taxa represented by Trichoptera, at mined compared to reference sites (7 vs 19 and 8 vs 22, in edge and riffle habitat respectively) may be linked to longer development stage requirements than other EPT taxa.

Similar results were found within EPT taxa in headwater streams in West Virginia as a result of long wall mining (Stout, 2004) but was difficult to compare to this thesis due to increased occurrence of dry streams and no detailed analysis of any individual EPT order contributing to differences. This thesis was also consistent with Wright *et al* (2015) that found a reduction in number of EPT individuals, but predominantly represented by Ephemoptera, at subsidence impacted mined sites compared to upstream reference sites. Again, it was difficult to directly compare these findings to current results because of the additional influence of urban pollution degrading mined and reference sites.

Further investigation of feeding characteristics of Trichoptera reveal that genera missing from mined but present at non-mined sites were represented by all FFG (scrapers, shredders, filtering collectors, gathering collectors and predators). Schmera (2004) discovered association among Trichoptera belonging to the same FFG and positive co-existence patterns linked to the presence of microhabitats. In effect, even though no particular pattern of dominance or loss emerged within FFG between mined and reference sites within this study, the possibility of increased microhabitats favorably supporting an increased number of Trichoptera taxa within each FFG is evident. This further supports evidence that impaired microhabitat, as a result of cracked rock and loss of surface waters more rapidly at mined than reference sites, is potentially responsible for controlling Trichoptera diversity at sites impacted by mining subsidence, rather than food supply. Additionally, De Moor & Ivanov (2008) described high caddis fly endemism in mountainous regions with high rainfall conditions, similar to the area in which this study was conducted, valuing Trichopterans as extremely important functional components of aquatic ecosystems and thus worthy of environmental protection.

Humpesch (1979) recorded life cycles of particular Baetidae mayflies as short as two and a half to three months in duration and found their emergence was positively correlated with an increase in temperature in laboratory experiments. These findings support the evidence that habitats in this study are possibly retaining water at an optimal interval for development and combined with elevated temperatures may be contributing to the conflicting yet not significantly elevated Ephemoptera abundance in edges and riffles at mined sites.

The significant decrease of overall EPT abundance solely in riffle habitats at mined compared to reference sites (34 vs 86) may be attributed to habitat differences, where riffles in comparison may not retain water as deep or for as long as in edges, and are thus more sensitive to increased surface water loss potentially leading to habitat loss.

The lack of other biological indices, such as taxa richness, to detect significant differences between non-mined and mined sites, could be attributed to the replacement of sensitive taxa with those of another less sensitive or tolerant taxa. This can be common in areas with increasing anthropogenic activity, indicating a loss of sensitive taxa and increase in tolerant taxa (sometimes exceeding sensitive numbers from reference sites), at sites with increasing organic pollution (Lenat, 1983). This was, however, not generally supported by lower Signal-SG scores at mined compared to non-mined sites in this study. Difference among Signal-SG scores between creeks within the same potential impact were stronger than any overall difference between them, indicating other in-stream factors are potentially driving macroinvertebrate sensitivity.

The nMDS and SIMPER results revealed more dissimilar macroinvertebrate assemblages at both edge and riffle habitats within mined compared to reference sites. This was supported by similar results found by Wright *et al* (2015) where macroinvertebrates were modified to a greater degree in a stream impacted by mining subsidence than by mine waste discharge when compared to reference streams. SIMPER results help further understand the shift in macroinvertebrate structure by highlighting differences within the percent dominance of Trichoptera. They appear within the first five most dominant taxa at both non-mined edge and riffle habitats (5^{th} and 3^{rd} taxa respectively), but shift to the 9^{th} and 11^{th} place in mined edges and riffles respectively. No other macroinvertebrate taxa showed a strong pattern of change in dominance between mined and reference sites, highlighting the importance of understanding the physical and chemical environmental requirements of Trichoptera fauna to maintain their populations in streams.

Even though most water quality variables did not reach eco-toxic levels (ANZECC, 2000), the BEST routine attempted to find any water quality variables (collected and collated within this thesis), and physical parameters including rainfall and distance from source, best correlating thus potentially driving macroinvertebrate assemblages. The weak to moderate correlations with edge and riffle macroinvertebrates highlight the difficulty in any one particular water quality variable being associated with the presence or loss of taxa with a wide range of responses. It also indicates the potential for other unmeasured factors to be responsible for controlling assemblages. A re-run of the BEST routine including only Trichoptera fauna actually weakened the correlations for both habitats, further indicating factors other than water chemistry potentially controlling caddis fly assemblages.

Interestingly, rainfall appeared in both edge and riffle BEST routines. As rainfall is directly linked to the permanence of streams, and thus availability and longevity of microhabitats, it would further support evidence in studies by Schmera (2004) and De Moor & Ivanov (2008) that these are two important physical drivers of Trichoptera fauna.

4.4 Diatoms

Diatom assemblages indicate a significant decrease in abundance but significant increase in number of taxa (142 vs 361, and 6 vs 5.5 respectively) at mined compared to reference sites. Increased diatom diversity have been positively correlated in published studies (McCormick, 1990) with a reduced number of macroinvertebrate scrapers (grazers). This supports findings in this thesis, as significant reduction in scrapers occurred in edge habitats at mined compared to reference sites, most likely attributed to the reduction in Trichoptera fauna, largely represented by scrapers. Another possibility is that the greater abundance of a smaller number of taxa at reference sites may be so well-established, they out compete additional diatom taxa from colonizing, but no literature has suggested this in the absence of significant pollution loads favoring tolerant taxa which does not occur in these catchments.

Diatoms have been extensively reported as correlating well with water quality measures (Reid *et al,* 1995; Stevenson & Pan, 1999; Sonnerman *et al,* 2001; Walsh *et al,* 2001). Further evidence supporting this theory was indicated by BEST routine on diatom assemblages which returned the strongest correlation for any biological and physico-chemical data (0.530). Even though the correlation was only moderately strong, it indicates concentrations of bicarbonate, chloride, % dissolved oxygen, pH and turbidity may be influencing diatom communities at sites.

One cannot rule out the possible link between potential loss of surface water and increased habitat fragmentation through mining induced subsidence at mined sites allowing a greater number of taxa to inhabit rocks in relatively small numbers. Their fast recovery and response to any changes in their environment is supported by their short life cycles (Reid *et al,* 1995). Dewatering of the streams may act to clear rocks of diatoms present, increasing chances for recolonization, if an optimal time for rock re-submergence could occur, but further research would need to be conducted before this could be deduced.

4.5 Conclusion

The aim of this study was to investigate changes in macroinvertebrate, diatoms and water quality in streams which overlie long wall coal mining and thus potentially have subsidence.

The differences in water quality and changes in flows following rainfall in streams overlying underground mining and those at reference sites is consistent with greater connection between the ground and surface waters. This supports the first hypothesis that:

- there is a loss of surface water lost beneath the creek bed and/or greater movement of water between surface and groundwater
- this is potentially occurring as a result of rock fractures creating a conduit for water to travel into the groundwater

- this is supported by the increased temperature and electrical conductivity, and increased concentrations of lithium, bicarbonate, barium, calcium, sodium, chloride and iron, at mined sites compared to reference sites
- potential faster loss of surface water following periods of rain is partially supported by water level data in mined sites compared to reference sites.

The changes in the stream macroinvertebrates observed in the current study are somewhat consistent with the one previously published study on subsistence. Reduced EPT taxa richness, reduced Trichopteran richness and significantly different diatom abundance and assemblage observed at mined sites relative to reference sites supports the second hypothesis that:

- difference's in stream macroinvertebrate and diatom assemblages can be detected between streams above long wall coal mining and similar nearby streams.

And finally, water quality variables only partially explained these differences in macroinvertebrate and diatom assemblage, so the findings within this thesis only partially support the third hypothesis:

- that correlating ecological health with water quality data can assist with determining long term impacts of stream surface water loss.

While it is impossible to rule out that the streams with mining under them had greater connection with the groundwater prior to mining, the areas were specifically chosen for their similarity.

Consequently I conclude that the most likely explanation, is that underground mining has resulted in greater ground-surface water connection and this in turn has resulted in changes to the stream invertebrate and diatom assemblages.

Further investigation into more accurate flow gauging and water level changes between mined sites compared to non-mined sites would likely improve correlations with biological communities. Especially after rain, and for extended periods after no rain, as this would help accurately determine extent of habitat reduction and possible cease to flow events impacting on macroinvertebrates and diatom communities.

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APPENDICES

Appendix 1.

Rainfall base table

Average monthly rainfall in mm from 1996 to 2015

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	TOTAL
1996	109.8	91.2	64.4	42.8	232.8	103	62.6	297.8	151.6	50.4	109.8	51.4	1367.6
1997	167.2	185.2	115	5.6	106.6	143.4	55.4	40.7	120.6	81.4	40.2	40.6	1101.9
1998	121.6	58	36	135.4	259.6	142.4	100	744.2	82.2	31.2	139.4	28.2	1878.2
1999	205.6	215.4	79.8	136	49	90	326.6	51	34	334.4	51	215.4	1788.2
2000	0	45.4	360.2	53.8	47	50.2	57.8	26.8	58.8	60.4	219.8	39	1019.2
2001	141.6	243.6	216.6	64.6	123.6	24.4	157.6	70.6	21.8	49.8	79.2	23.2	1216.6
2002	82.6	432.2	245.2	74.4	77.6	34.8	52.8	23.8	10.4	14.4	25.2	97	1170.4
2003	49.6	162.6	0	176.4	417.6	66.2	57.4	49.4	5.8	68.4	111.2	51.8	1216.4
2004	49.2	155	88.2	289.6	13	11	56.6	-	54.6	276.6	85	122.6	1201.4
2005	100.6	99.4	140.6	33.8	42.2	83.6	109.8	4.4	71.2	72.8	161.6	32.8	952.8
2006	146.4	105.6	36.6	4	46	115.8	86.4	49	273.4	18.2	56.4	92.8	1030.6
2007	56	326.4	144.4	198.8	27.4	391.8	60.4	-	51.8	28.6	207.8	103.2	1596.6
2008	114.8	279.2	61.6	165	5.6	204.8	83.2	47.4	117.4	69.8	64	85.8	1298.6
2009	57.6	271.4	62.4	264	180.8	96.6	72.8	5.4	30.6	174.2	69.6	80.2	1365.6
2010	41.6	253.4	162	30.6	173.4	181.8	73.6	46.8	183.2	143.2	156.2	137.8	1583.6
2011	48.6	26.2	312.4	182	133.6	199.4	252.4	89.8	85.6	116	183.8	81.2	1711
2012	242.2	272.4	285.8	111	14.6	165.8	62.2	10.6	24.6	71.4	67.4	39.6	1367.6
2013	187	241	79.4	137.6	167.4	363.2	16	9	132.6	16.2	329.4	69	1747.8
2014	52.4	0	0	-	-	-	12.8	-	-	-	-	-	-
2015	133.2	116.4	34.8	436	122.6	72.2	58.8	95.6	51.6	33.6	110.2	70.6	1335.6
Historical Average	110.9	172.7	120.3	133.8	117.9	133.7	90.8	97.8	82.2	90.1	119.3	77.0	1365.8

- = data not available

Appendix 2.

PERMANOVA for Trace Metal Results

All TRACE PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem16
Data type: Distance
Selection: All
Normalise
Resemblance: D1 Euclidean distance

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Mined/Non-mined	Fixed	2
Creek	Random	4
Season	Fixed	2

Excluded terms
Mined/Non-minedxSeason

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Mined/Non-mined	1	40.349	40.349	9.2995	0.3372	3	0.0185
Creek(Mined/Non-mined)	2	8.6776	4.3388	2.8464	0.0211	9949	0.0273
Season	1	27.296	27.296	25.036	0.0218	1129	0.0033
Creek(Mined/Non-mined)xSeason	2	2.1805	1.0903	0.71525	0.5958	9955	0.5877
Res	41	62.497	1.5243				
Total	47	141					

Details of the expected mean squares (EMS) for the model

Source	EMS
Mined/Non-mined	1*V(Res) + 12*V(Creek(Mined/Non-mined)) + 24*S(Mined/Non-mined)
Creek(Mined/Non-mined)	1*V(Res) + 12*V(Creek(Mined/Non-mined))
Season	1*V(Res) + 6*V(Creek(Mined/Non-mined)xSeason) + 24*S(Season)
Creek(Mined/Non-mined)xSeason	1*V(Res) + 6*V(Creek(Mined/Non-mined)xSeason)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Mined/Non-mined	1*Mined/Non-mined	1*Creek(Mined/Non-mined)	1	2
Creek(Mined/Non-mined)	1*Creek(Mined/Non-mined)	1*Res	2	41
Season	1*Season	1*Creek(Mined/Non-mined)xSeason	1	2
Creek(Mined/Non-mined)xSeason	1*Creek(Mined/Non-mined)xSeason	1*Res	2	41

Estimates of components of variation

Source	Estimate	Sq.root
S(Mined/Non-mined)	1.5004	1.2249
V(Creek(Mined/Non-mined))	0.23454	0.48429
S(Season)	1.0919	1.0449
V(Creek(Mined/Non-mined)xSeason)	-7.2341E-2	-0.26896
V(Res)	1.5243	1.2346

Li PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Distance
Selection: All
Normalise
Resemblance: D1 Euclidean distance

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Mined/Non-mined	Fixed	2
Creek	Random	4
Season	Fixed	2

Excluded terms
Mined/Non-minedxSeason

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Mined/Non-mined	1	29.152	29.152	39.81	0.3362	3	0.0246
Creek(Mined/Non-mined)	2	1.4645	0.73227	1.9548	0.1497	9957	0.1601
Season	1	0.47933	0.47933	1.7552	0.3134	1124	0.3142
Creek(Mined/Non-mined)xSeason	2	0.54619	0.2731	0.72905	0.4856	9949	0.4887
Res	41	15.358	0.37459				
Total	47	47					

Details of the expected mean squares (EMS) for the model

Source	EMS
Mined/Non-mined	1*V(Res) + 12*V(Creek(Mined/Non-mined)) + 24*S(Mined/Non-mined)
Creek(Mined/Non-mined)	1*V(Res) + 12*V(Creek(Mined/Non-mined))
Season	1*V(Res) + 6*V(Creek(Mined/Non-mined)xSeason) + 24*S(Season)
Creek(Mined/Non-mined)xSeason	1*V(Res) + 6*V(Creek(Mined/Non-mined)xSeason)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Mined/Non-mined	1*Mined/Non-mined	1*Creek(Mined/Non-mined)	1	2
Creek(Mined/Non-mined)	1*Creek(Mined/Non-mined)	1*Res	2	41
Season	1*Season	1*Creek(Mined/Non-mined)xSeason	1	2
Creek(Mined/Non-mined)xSeason	1*Creek(Mined/Non-			

mined)xSeason	1*Res
2	41

Estimates of components of variation

Source	Estimate	Sq.root
S(Mined/Non-mined)	1.1841	1.0882
V(Creek(Mined/Non-mined))	2.9806E-2	0.17265
S(Season)	8.5929E-3	9.2698E-2
V(Creek(Mined/Non-mined)xSeason)	-1.6916E-2	-0.13006
V(Res)	0.37459	0.61204

Appendix 3.

RAW Water Quality - Laboratory

				WR1	WR1	WR2	WR2	WR3
				S1	S2	S1	S2	S1
Alkalinity	(Bicarbonate)	mg	CaCO3/L	19	36	24	9	21
Alkalinity	(Carbonate)	mg	CaCO3/L	2.5	<5	2.5	<5	2.5
Alkalinity	(Hydroxide)	mg	CaCO3/L	2.5	<5	2.5	<5	2.5
Alkalinity	(Total)	mg	CaCO3/L	19	36	24	9	21
Total	Barium	mg/L		0.065	0.072	0.078	0.035	0.063
Total	Calcium	mg/L		5.1	5.34	6.65	2.93	5.71
Total	Sodium	mg/L		16.1	18.9	16.3	14.4	15.8
Total	Aluminium	mg/L		0.09	0.09	0.08	0.98	0.09
Total	Iron	mg/L		0.872	0.717	0.509	1.47	0.471
Total	Manganese	mg/L		0.063	0.045	0.031	0.062	0.021
Chloride		mg/L		30	34	31	24	30
Sulphate		mg/L		7.1	11	7.9	5.7	7.5

				WR3	WR4	WR4	WR5	WR5
				S2	S1	S2	S1	S2
Alkalinity	(Bicarbonate)	mg	CaCO3/L	18	21	19	30	10
Alkalinity	(Carbonate)	mg	CaCO3/L	<5	2.5	<5	2.5	<5
Alkalinity	(Hydroxide)	mg	CaCO3/L	<5	2.5	<5	2.5	<5
Alkalinity	(Total)	mg	CaCO3/L	18	21	19	30	10
Total	Barium	mg/L		0.032	0.066	0.024	0.083	0.034
Total	Calcium	mg/L		2.88	6.28	2.63	8.27	3.12
Total	Sodium	mg/L		14.1	15.9	14	17.4	14
Total	Aluminium	mg/L		0.92	0.06	0.43	0.04	0.43
Total	Iron	mg/L		1.54	1.16	1.16	0.763	1.43
Total	Manganese	mg/L		0.057	0.121	0.063	0.094	0.08
Chloride		mg/L		25	30	26	31	26
Sulphate		mg/L		5.6	6.5	5.5	6.8	5.4

				WR6	WR6	OH1	OH1	OH2
				S1	S2	S1	S2	S1
Alkalinity	(Bicarbonate)	mg	CaCO3/L	32	34	2.5	<5	5
Alkalinity	(Carbonate)	mg	CaCO3/L	2.5	<5	2.5	<5	2.5
Alkalinity	(Hydroxide)	mg	CaCO3/L	2.5	<5	2.5	<5	2.5
Alkalinity	(Total)	mg	CaCO3/L	32	34	2.5	<5	5
Total	Barium	mg/L		0.087	0.099	0.002	<0.005	0.01
Total	Calcium	mg/L		9.12	11.3	1.74	1.73	1.44
Total	Sodium	mg/L		17.4	24.2	13.7	13.7	12.7
Total	Aluminium	mg/L		0.04	0.07	0.19	0.29	0.12
Total	Iron	mg/L		0.709	1.1	0.569	0.82	0.466
Total	Manganese	mg/L		0.109	0.06	0.041	0.041	0.028
Chloride		mg/L		30	31	25	25	23
Sulphate		mg/L		7.3	7.5	5.7	5.7	4.3

				OH2	OH3	OH3	LR1	LR1
				S2	S1	S2	S1	S2
Alkalinity	(Bicarbonate)	mg	CaCO3/L	<5	7	6	2.5	<5
Alkalinity	(Carbonate)	mg	CaCO3/L	<5	2.5	<5	2.5	<5
Alkalinity	(Hydroxide)	mg	CaCO3/L	<5	2.5	<5	2.5	<5
Alkalinity	(Total)	mg	CaCO3/L	<5	7	6	2.5	<5
Total	Barium	mg/L		0.009	0.009	0.011	0.002	<0.005
Total	Calcium	mg/L		1.48	1.68	1.77	1.26	1.53
Total	Sodium	mg/L		13.2	13.5	13	11.5	13.2
Total	Aluminium	mg/L		0.24	0.12	0.29	0.21	0.34
Total	Iron	mg/L		0.594	0.425	0.619	0.467	0.689
Total	Manganese	mg/L		0.029	0.012	0.02	0.016	0.018
Chloride		mg/L		23	25	22	22	24
Sulphate		mg/L		3.9	4.5	3.9	3.2	3.1

				LR2	LR2	LR3	LR3
				S1	S2	S1	S2
Alkalinity	(Bicarbonate)	mg	CaCO3/L	2.5	<5	2.5	<5
Alkalinity	(Carbonate)	mg	CaCO3/L	2.5	<5	2.5	<5
Alkalinity	(Hydroxide)	mg	CaCO3/L	2.5	<5	2.5	<5
Alkalinity	(Total)	mg	CaCO3/L	2.5	<5	2.5	<5
Total	Barium	mg/L		0.002	<0.005	0.002	<0.005
Total	Calcium	mg/L		1.37	1.62	1.26	1.24
Total	Sodium	mg/L		11.3	13.5	11.4	11.7
Total	Aluminium	mg/L		0.21	0.35	0.2	0.3
Total	Iron	mg/L		0.416	0.661	0.36	0.559
Total	Manganese	mg/L		0.012	0.015	0.009	0.011
Chloride		mg/L		21	23	21	21
Sulphate		mg/L		3.3	3.1	3.4	3.1

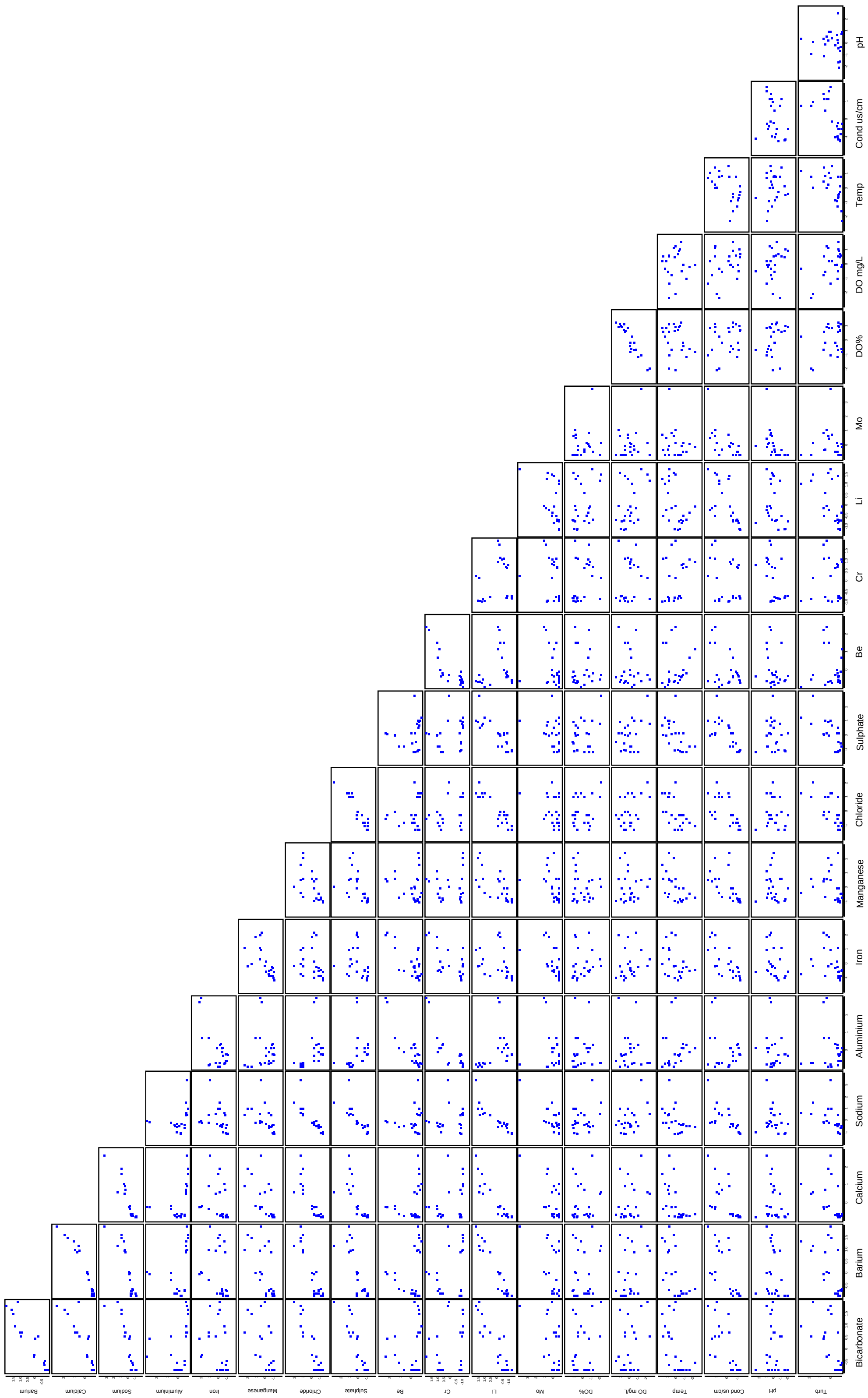
RAW Water Quality - Field

	DO%	DO mg/L	Temp	Cond us/cm	pH	Turb
LR1 Spr u/s	81.9	8.89	10	98	7.14	2.16
LR2 Spr m/s	92.3	9.86	10.7	96	6.9	2.56
LR3 Spr d/s	86.8	9.435	10.95	94	8.43	2.09
OH1 Spr u/s	89.6	9.9	10.6	116	7.4	2.29
OH2 Spr m/s	87.7	9.74	9.4	111	7.45	1.475
OH3 Spr d/s	85.5	9.855	8.3	120	7.52	1.43
LR1 Win u/s	104.3	11.025	11.35	92	6.075	2.02
LR2 Win m/s	100.75	10.44	12.35	91	6.115	1.71
LR3 Win d/s	101.45	10.665	11.7	89	6.63	1.725
OH1 Win u/s	103.45	10.925	11.5	111	5.835	1.975
OH2 Win m/s	105.35	10.56	13.5	102	6.815	1.63
OH3 Win d/s	106.7	11.575	11.05	111	6.745	2.06
WR1 Spr u/s	72.5	7.76	12.2	159	7.065	6.55
WR2 Spr m/s	103.5	11.255	12.15	163.5	7.32	4.14
WR3 Spr d/s	87.2	9.13	12.95	173.5	7.21	4.66
WR4 Spr u/s	100.04	10.5	14.6	164	6.37	4.62
WR5 Spr m/s	102.9	10.145	13.95	178	7.545	3.74
WR6 Spr d/s	83.1	8.53	13.35	185.5	7.545	3.46
WR1 Win u/s	73.65	7.48	13.5	152	6.47	6.84
WR2 Win m/s	96.66	9.625	14.2	152	7.215	8.67
WR3 Win d/s	92.25	9.38	13.6	144	6.945	4.4
WR4 Win u/s	100.04	10.5	13.5	122	7.015	2.14
WR5 Win m/s	102.9	10.145	14.75	124	7.23	3.24
WR6 Win d/s	105.7	11.125	12.55	164	7.13	3.8

Appendix 4.

PCA & PERMANOVAS for WQ variables

Untreated Draftsman Plot for all water quality variables



Draftsman plot correlation for all water quality variables

	Bicarbona	Barium	Calcium	Sodium	Aluminiur	Iron	Manganes	Chloride	Sulphate	Be	Cr	Li	Mo	DO%	DO mg/L	Temp	Cond us/c	pH	Turb
Bicarbonate																			
Barium	0.949075																		
Calcium	0.906608	0.965301																	
Sodium	0.870524	0.88361	0.913117																
Aluminiur	-0.28942	-0.3256	-0.38935	-0.30209															
Iron	0.303267	0.300182	0.24343	0.313813	0.651725														
Manganes	0.633456	0.667249	0.651731	0.524996	-0.02477	0.635004													
Chloride	0.916879	0.916366	0.849346	0.848049	-0.40145	0.232971	0.607922												
Sulphate	0.874095	0.835684	0.73722	0.785934	-0.25964	0.260952	0.52856	0.935827											
Be	-0.16512	-0.23374	-0.31459	-0.19884	0.875134	0.718217	0.137362	-0.28297	-0.1345										
Cr	-0.21181	-0.27145	-0.30831	-0.10893	0.818919	0.626711	-0.04433	-0.30403	-0.1873	0.850327									
Li	0.914277	0.963891	0.920371	0.875927	-0.35164	0.295136	0.688971	0.918344	0.845055	-0.21738	-0.229								
Mo	0.520908	0.546838	0.645648	0.750465	0.152368	0.545406	0.41653	0.360307	0.348631	0.197821	0.334045	0.511127							
DO%	-0.21864	-0.18546	-0.11363	-0.33004	0.020501	-0.08341	0.150188	-0.26495	-0.28738	0.007544	-0.3042	-0.30903	-0.19599						
DO mg/L	-0.38383	-0.37267	-0.28613	-0.4535	0.121592	-0.12538	0.027855	-0.43879	-0.42529	0.105588	-0.14755	-0.43611	-0.23092	0.934227					
Temp	0.619774	0.627269	0.566158	0.433086	-0.12107	0.353073	0.551969	0.589613	0.53514	-0.08462	-0.31596	0.466938	0.193487	0.253885	-0.06158				
Cond us/c	0.729679	0.708778	0.636817	0.69224	0.243874	0.719152	0.596255	0.654327	0.709624	0.412081	0.300585	0.65949	0.613406	-0.18922	-0.30996	0.541273			
pH	0.148068	0.216441	0.205548	0.226673	0.172332	0.272755	0.113252	0.075446	0.064209	0.219367	0.484965	0.259376	0.466657	-0.33455	-0.27939	-0.16456	0.233512		
Turb	0.652807	0.649335	0.487929	0.490325	0.007578	0.275384	0.262976	0.700228	0.740212	0.01536	-0.03873	0.592679	0.084321	-0.33345	-0.49965	0.562175	0.676845	0.033719	

PCA

Principal Component Analysis

Data worksheet
Name: Data11
Data type: Environmental
Sample selection: All
Variable selection: All

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	7.94	46.7	46.7
2	3.72	21.9	68.6
3	1.95	11.5	80.1
4	1.3	7.6	87.7
5	0.565	3.3	91.1

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
CaCO3	0.339	0.068	-0.011	0.016	-0.016
Ca	0.326	0.107	-0.049	-0.233	-0.050
Na	0.325	0.023	-0.174	-0.136	-0.327
Al	-0.070	-0.449	0.211	0.137	-0.074
Fe	0.165	-0.398	0.244	-0.052	0.001
Mn	0.252	-0.058	0.281	-0.288	0.305
Cl	0.330	0.130	-0.031	0.123	0.065
SO4	0.316	0.073	-0.016	0.238	-0.003
Be	-0.025	-0.468	0.214	0.105	0.000
Li	0.334	0.074	-0.104	-0.049	0.159
Mo	0.217	-0.222	-0.157	-0.433	-0.425
DO%	-0.090	0.113	0.529	-0.386	0.106
Temp	0.225	0.094	0.413	0.055	0.073
Cond	0.293	-0.216	0.130	0.120	-0.119
pH	0.079	-0.251	-0.375	-0.234	0.726
Turb	0.243	0.005	0.063	0.571	0.143
Rainfall	0.000	0.439	0.300	-0.052	0.050

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
LR1 Spr u/s	-2.46	-0.685	-1.68	0.33	-6.04E-2
LR2 Spr m/s	-2.56	-0.383	-0.869	0.15	-0.288
LR3 Spr d/s	-2.77	-1.03	-2.2	-0.503	1.56
OH1 Spr u/s	-1.2	-0.976	-1.11	-0.142	0.278
OH2 Spr m/s	-2.2	-1.14	-1.68	-0.424	0.205
OH3 Spr d/s	-2.24	-1.56	-1.98	-0.194	0.226
LR1 Win u/s	-3.34	1.6	0.906	-9.1E-2	-0.812
LR2 Win m/s	-3.36	1.67	0.862	-2.02E-2	-0.811
LR3 Win d/s	-3.44	1.56	0.298	-0.244	-0.208
OH1 Win u/s	-1.86	1.6	1.23	0.107	-1.11
OH2 Win m/s	-2.19	1.39	1.02	-0.477	0.244

OH3 Win d/s	-2.15	1.57	0.275	-0.268	-0.15
WR1 Spr u/s	4.34	0.416	-2.07	2.29	-0.237
WR2 Spr m/s	0.434	-4.31	1.78	-7.25E-2	-0.11
WR3 Spr d/s	1.05	-4.22	1.23	0.938	-0.294
WR4 Spr u/s	0.643	-1.64	2.26	1.05	-0.439
WR5 Spr m/s	1.02	-2.79	1.68	-0.399	0.8
WR6 Spr d/s	5.94	-0.864	-2.23	-2.23	-1.97
WR1 Win u/s	2.55	1.34	-0.106	2.19	-2.03E-2
WR2 Win m/s	2.87	2.12	0.153	1.89	0.968
WR3 Win d/s	1.6	1.97	-0.251	0.823	-1.36E-2
WR4 Win u/s	2.39	1.17	1.14	-1.57	1.04
WR5 Win m/s	3.25	1.72	0.704	-1.6	0.647
WR6 Win d/s	3.67	1.49	0.634	-1.54	0.548

Outputs
Plot: Graph2

WQ PERMANOVAS

All Other Variables PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem3
Data type: Distance
Selection: All
Normalise
Resemblance: D1 Euclidean distance

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creek	Random	4
Position	Random	3
Season	Fixed	2

Excluded terms
Position(Creek(Impact/Control))xSeason

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Impact/Control	1	107.56	107.56	15.152	0.3369	3	0.01
Season	1	15.961	15.961	6.5963	0.0868	801	0.041
Creek(Impact/Control)	2	14.198	7.0991	1.9382	0.1028	8979	0.1356
Impact/ControlxSeason	1	6.2485	6.2485	2.5824	0.1435	801	0.1706
Position(Creek(Impact/Control))	8	29.302	3.6628	1.0144	0.4918	9931	0.4863
Creek(Impact/Control)xSeason	2	4.8394	2.4197	0.67011	0.6156	9947	0.6121
Res	8	28.887	3.6109				
Total	23	207					

Details of the expected mean squares (EMS) for the model

Source	EMS
Impact/Control	1*V(Res) + 2*V(Position(Creek(Impact/Control))) + 6*V(Creek(Impact/Control)) + 12*S(Impact/Control)
Season	1*V(Res) + 3*V(Creek(Impact/Control)xSeason) +

12*S(Season)	
Creek(Impact/Control)	1*V(Res) + 2*V(Position(Creek(Impact/Control))) + 6*V(Creek(Impact/Control))
Impact/ControlxSeason	1*V(Res) + 3*V(Creek(Impact/Control)xSeason) + 6*S(Impact/ControlxSeason)
Position(Creek(Impact/Control))	1*V(Res) + 2*V(Position(Creek(Impact/Control)))
Creek(Impact/Control)xSeason	1*V(Res) + 3*V(Creek(Impact/Control)xSeason)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Impact/Control	1*Impact/Control	1*Creek(Impact/Control)	1	2
Season	1*Season	1*Creek(Impact/Control)xSeason	1	2
Creek(Impact/Control)	1*Creek(Impact/Control)	1*Position(Creek(Impact/Control))	2	8
Impact/ControlxSeason	1*Impact/ControlxSeason	1*Creek(Impact/Control)xSeason	1	2
Position(Creek(Impact/Control))	1*Position(Creek(Impact/Control))	1*Res	8	8
Creek(Impact/Control)xSeason	1*Creek(Impact/Control)xSeason	1*Res	2	8

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	8.372	2.8934
S(Season)	1.1284	1.0623
V(Creek(Impact/Control))	0.57272	0.75678
S(Impact/ControlxSeason)	0.63814	0.79884
V(Position(Creek(Impact/Control)))	2.5962E-2	0.16113
V(Creek(Impact/Control)xSeason)	-0.39707	-0.63013
V(Res)	3.6109	1.9002

Appendix 5.

RAW macroinvertebrate data

						LR1	LR1	LR1	LR1
						Winter	Winter	Winter	Winter
						14313	14314	14315	14316
						Edg	Edg	Edg	Edg
Class	Order	Family	SG	Genus	Stage	1	2	3	4
Annelida	Oligochaeta	Oligochaeta indeterminate		unassessed genus	Non-Insect	4		5	
Annelida	Oligochaeta	Opisthopora indeterminate		unassessed genus	Non-Insect				
Arthropoda	Acarina	Acarina indeterminate		indeterminate genus	Non-Insect				
Arthropoda	Acarina	Aturidae	10	Axonopsella	Non-Insect				
Arthropoda	Acarina	Hydrodromidae	7	Hydrodroma	Non-Insect				
Arthropoda	Acarina	Hygrobatidae	7	Corticacarus	Non-Insect			1	
Arthropoda	Acarina	Hygrobatidae	8	Caenobates	Non-Insect				
Arthropoda	Acarina	Hygrobatidae	8	Coaustraliobates	Non-Insect				
Arthropoda	Acarina	Hygrobatidae	9	Australiobates	Non-Insect				
Arthropoda	Acarina	Limnesiidae	7	Limnesia	Non-Insect				
Arthropoda	Acarina	Limnocharidae	9	Limnochares	Non-Insect				
Arthropoda	Acarina	Mideopsidae	7	Gretacarus	Non-Insect				
Arthropoda	Acarina	Momoniidae	9	Momoniella	Non-Insect				
Arthropoda	Acarina	Oxidae	7	Oxus	Non-Insect				
Arthropoda	Acarina	Oxidae	8	Flabellifrontipoda	Non-Insect				
Arthropoda	Acarina	Oxidae	8	Frontipoda	Non-Insect				
Arthropoda	Acarina	Oxidae		indeterminate genus	Non-Insect				
Arthropoda	Acarina	Torrenticolidae	10	Torrenticola	Non-Insect				
Arthropoda	Acarina	Unionicolidae	6	Unionicola	Non-Insect				
Arthropoda	Acarina	Unionicolidae	7	Koenikea	Non-Insect				2
Arthropoda	Acarina	Unionicolidae	7	Recifella	Non-Insect		2		4
Arthropoda	Acarina	Unionicolidae		indeterminate genus	Non-Insect				
Arthropoda	Amphipoda	Chiltoniidae	7	Austrochiltonia	Non-Insect				
Arthropoda	Amphipoda	Chiltoniidae		indeterminate genus	Non-Insect				
Arthropoda	Coleoptera	Dytiscidae	10	Barretthydrus	Larva				
Arthropoda	Coleoptera	Dytiscidae	5	Chostonectes	Adult				
Arthropoda	Coleoptera	Dytiscidae	5	Chostonectes	Larva				
Arthropoda	Coleoptera	Dytiscidae	5	Rhantus	Larva				
Arthropoda	Coleoptera	Dytiscidae	6	Antiporus	Larva				
Arthropoda	Coleoptera	Dytiscidae	6	Necterosoma	Adult				
Arthropoda	Coleoptera	Dytiscidae	6	Necterosoma	Larva				
Arthropoda	Coleoptera	Dytiscidae	8	Sternopriscus	Adult				
Arthropoda	Coleoptera	Dytiscidae	8	Sternopriscus	Larva				
Arthropoda	Coleoptera	Dytiscidae		indeterminate genus	Larva				
Arthropoda	Coleoptera	Elmidae	6	Notriolus	Adult				
Arthropoda	Coleoptera	Elmidae	6	Simsonia	Adult				
Arthropoda	Coleoptera	Elmidae	6	Simsonia	Larva				
Arthropoda	Coleoptera	Elmidae	7	Kingolus	Adult			1	
Arthropoda	Coleoptera	Elmidae	7	Kingolus	Larva				
Arthropoda	Coleoptera	Elmidae	8	Austrolimnius	Adult				
Arthropoda	Coleoptera	Elmidae	8	Austrolimnius	Larva			4	
Arthropoda	Coleoptera	Elmidae		indeterminate genus	Larva				
Arthropoda	Coleoptera	Gyrinidae	9	Macrogyrus	Adult				
Arthropoda	Coleoptera	Gyrinidae	9	Macrogyrus	Larva				
Arthropoda	Coleoptera	Hydrochidae	5	Hydrochus	Adult				
Arthropoda	Coleoptera	Hydrophilidae	5	Paracymus	Adult				
Arthropoda	Coleoptera	Hydrophilidae	7	Berosus	Adult				
Arthropoda	Coleoptera	Hydrophilidae	7	Berosus	Larva				
Arthropoda	Coleoptera	Hydrophilidae		indeterminate genus	Larva				
Arthropoda	Coleoptera	Psephenidae	7	Sclerocyphon	Larva				
Arthropoda	Coleoptera	Scirtidae		shin	Larva			1	
Arthropoda	Decapoda	Atyidae	6	Paratya	Non-Insect	7	7	3	9
Arthropoda	Diptera	Ceratopogonidae	5	Dasyhelea	Larva				
Arthropoda	Diptera	Ceratopogonidae	6	Bezzia	Larva				1
Arthropoda	Diptera	Ceratopogonidae	7	Nilobezzia	Larva				
Arthropoda	Diptera	Ceratopogonidae		indeterminate genus	Larva				
Arthropoda	Diptera	Chironomidae		indeterminate genus	Larva				
Arthropoda	Diptera	Chironomidae		S.F. Aphroteniiae	Larva	2	1	2	
Arthropoda	Diptera	Chironomidae		S.F. Chironominae	Larva	9	1	4	10
Arthropoda	Diptera	Chironomidae		S.F. Diamesinae	Larva				
Arthropoda	Diptera	Chironomidae		S.F. Orthocladiinae	Larva	2	5	2	7
Arthropoda	Diptera	Chironomidae		S.F. Podonominae	Larva				
Arthropoda	Diptera	Chironomidae		S.F. Tanypodinae	Larva	7	1	6	1
Arthropoda	Diptera	Culicidae	6	Aedes	Larva				
Arthropoda	Diptera	Culicidae		indeterminate genus	Larva				
Arthropoda	Diptera	Dixidae	9	Dixa	Larva				
Arthropoda	Diptera	Empididae		alpha	Larva				
Arthropoda	Diptera	Muscidae		alpha	Larva				
Arthropoda	Diptera	Muscidae		indeterminate genus	Larva				
Arthropoda	Diptera	Simuliidae	4	Simulium	Larva				
Arthropoda	Diptera	Simuliidae	6	Austrosimulium	Larva				
Arthropoda	Diptera	Simuliidae	6	Austrosimulium	Larva				
Arthropoda	Diptera	Simuliidae	6	Cnephia	Larva				
Arthropoda	Diptera	Simuliidae		indeterminate genus	Larva				
Arthropoda	Diptera	Thaumaleidae		alpha	Larva				
Arthropoda	Diptera	Thaumaleidae		indeterminate genus	Larva				
Arthropoda	Diptera	Tipulidae	8	Antocha	Larva				1
Arthropoda	Diptera	Tipulidae		beta	Larva				
Arthropoda	Diptera	Tipulidae		eta	Larva				
Arthropoda	Diptera	Tipulidae		indeterminate genus	Larva				

LR1	LR1	LR1	LR1	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3
Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter
169191	169195	169196	169197	14321	14322	14323	14324	169199	169203	169204	169205	14329	14330	14331
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
				8	2		2				1		3	
			3					1						
								1						
								1						
	2													
												1		
			1											
	3		2											
	1													
											1			
1		1				1	2		3					
					1			3		3	1	1		
					3	1		12	2	9	2	1		
								3		6		1		
17	55	9	58	5	18	9	5		4	14	6	3	1	1
							1	1			2			
														1
				1										
				1										
		1												
				5	2	1								1
20	1	5	2	1	2		1	5	7	6	2	12	11	4
		2	3	3	5	1	1	3	3	1	4	3	3	4
4	7	5	1	4			3	3	1	4	5	4	12	
							1							

LR3	LR3	LR3	LR3	LR3	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2
Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter
14332	169207	169211	169212	169213	14289	14290	14291	14292	169167	169171	169172	169173	14297	14298
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
9				1		37	53	4	10	22	16	16	2	
							1							
	1													
								1		1		6		
			1											
				1										
					1				1					
				2					4					
1														
1	1					1	1							
	6	2	2				1	1	7	2	21	20		
5	5	12	8	2	2	2	5		4	3	15	26		
						2	4				3	16		
								1		1		2		
												1		
											1	1		
								1		1		2	3	4
2	22	7	9	6										1
		1		1	1							1		
1	3				4	5	7	3	1	4	4	6	1	1
							1							
7	4				4			2	1				1	
8	19	25	12	31	37	8	14	45	76	37	30	85	3	5
													2	1
9	23	14	15	9	69	260	348	46	28	24	38	48	3	7
			1										1	
10	7	10	4	7	21	5	2	19	5	8	1	6	2	10
						1	3							
	2	7				45	54			2	2	27		
						2								
						1								
				2										

OH2	OH2	OH2	OH2	OH2	OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1
Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14299	14300	169175	169179	169180	169181	14305	14306	14307	14308	169183	169187	169188	169189	14241
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
3	1					5	9	3	6				1	
		1	1											
								1						
												1		
		1					1	3		1				
								1					1	
			1											3
	1				1		2			3		1		
														1
6	1	1				32	12	2	15	41	4	1	3	
		1	2											
											1			
							2							
		1			1					1				
			1								2		2	
									2					
													2	
										1	1			
										1	1		2	
1			1								1	1		
											3		3	
	1					1								
			8	4	1									
1														
					1					1				
9	1	6		2	1	6			2	6	1	4	1	1
	8	10	4		2	4		5	2	14	1	7	2	3
							1		1			1		
1			1		1		3				2		1	
												1		
3	1				2		3	13	2					
17	1	1	24	3	8	18	4	1	7	1	4	3	5	1
18	4	1	2			4			5		1		2	
				1										
20	2	2	5	7	13	9	15	9	6	5	4		4	1
													1	
	1													

WR1	WR1	WR1	WR1	WR1	WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14242	14243	14244	14530	14531	14532	14533	14249	14250	14251	14252	14538	14539	14540	14541
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
	1				1									
		1	2								1			
								1						
1				1			4	2	4	2				
			1	1										
										1				
					1									
	1													
								2						
							1				1			2
											1			2
													1	
							1							
							1	1						
1														
														3
				1										
								1				1		
	1													
							1							
1	1		1	8			1		1					
4		3	13	13	15	9	10	14	13	8	1	9	1	10
		1												1
5	1	8					1	4	2	2	1			2
3	7							3		1	15	2	3	41
1				3							2	1	2	
							1							
1	6		3	2			4	24	3	1	9	1	1	5
					1								1	
										1				
	1													
1														
1														
													1	
							1							
														1

WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14257	14258	14259	14260	14550	14551	14552	14553	14265	14266	14267	14268	14554	14555	14556
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
											1			
								1						
								2						
									2					
									1					
			1											
15	16	9	55		1	11	2			1				3
				1		1								
	1													
													1	
											1			
	1					1								
		1		3		1			1		1	1		
										1		1		
									2					
					1		1	3		10	2		5	2
3	7	4	2	21	6	4	10					3		3
					1									
									2				2	1
2									1					
14	3		2			1		4	20	17	9			
11	4	1	3	5	5	1	1	6	39	19	6	5	74	7
								1						
1	1		2			7	1	12	12	7	1			7
2								1						
5	7		3	2	1	4		5	8	16	7	3	12	3
												2		
									1					
1														

WR4	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
14557	14273	14274	14275	14276	14562	14563	14564	14565	14281	14282	14283	14284	14570	14571
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
5	2	9	1	6			2			1	1	1		2
							1							
											3			
													1	
							1							
												2		
									1				1	
												2	3	
													2	
								1						
		1				1						1		2
														1
	1									1				
						1	1						1	
								1						
						1			1					
								1						
1										1	2	1		
											2		1	
2														
					2									
1														
														2
										3	5		1	
2							7					1		11
	2						1		1	1		1		
1			1							2	1			1
				1										
										1				
2	1	3							3	8		34		
231	7	7	1	2	1	5	14		3	5	14	1	48	36
	1								1	5	1			
2	3	1			2	2	2		3	1	8		1	
		1												
40	2	1		1					4	4	2	3	3	5
					6									
						1								
	1													
							7				2			
									1					
									4					

WR6	WR6	WREF	WREF	WREF	WREF	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR2
Spring	Spring	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14572	14573	14337	14338	14339	14340	14309	14310	14311	14312	169190	169192	169193	169194	14317
Edg	Edg	Edg	Edg	Edg	Edg	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
						7	3	1			2	1		4
1							1							
										1			1	
											1			
										1				
			1		5									
10	4													
1														
						11	12	1		11	36	21	16	1
	1					1	3					2	9	5
						16	12	2	4	57	109	98	63	
						8	11			23	41	33	19	12
						2				1	12	4	6	
8	4								1					
12	55									5	4			
					1						3			
						8	12	6	3	10	17	16	8	4
								1			1		3	
						2	1							
10	8	4		5	3	33	38	17	20	31	67	51	65	100
3	6	2			6		4	15	10	7	3	8	8	41
6	5		3	2		15	18	10	27	11	19	2	4	17
1														
													1	
							4	1		4	16	5	1	
						1								
				1										
														2
								1						

LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3	LR3	LR3	LR3	LR3	LR3
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14318	14319	14320	169198	169200	169201	169202	14325	14326	14327	14328	169206	169208	169209	169210
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
2									2	1		3		
							1							
			1											
		1	19	11	11	17	2			3	25	22	5	9
4	1	6	74	32	36	43	2	5	3	2	6	17	17	19
1						1	1			2	18	16	2	4
11		1		3		4	12	8	19	20	40	36	9	11
			18	2	2	5					6	6		
			1				1		2	3	1		2	1
9					1	1			1	1				
1	1													
99	19	32	37	20	25	35	26	27	21	32	25	36	3	1
31	42	26	86	31	62	50	26	24	22	30	24	32	9	10
				2			3	1	4	10		1		1
24	1		2	2	3	3			2	9	4	9		2
			7	5	6	6	2	1	5	6	6	3	1	
		1									1			
		2	1						1		3	8	5	4
			2								1	3		
2	6	12	6	17	6	20		2	1	1				

OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2	OH2	OH2	OH2	OH2	OH2
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14285	14286	14287	14288	169166	169168	169169	169170	14293	14294	14295	14296	169174	169176	169177
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
13	45	86	59	10	13	13	19	21	35	37	45			1
					1		2							
		4	1			13	11							1
	1													
				2	3									
						1								
					1	1	3							
											1			
									1					1
		3	2	10	15	15	13			2	1	3		5
		3	2	5	1	2	5	1			1	1		
		14	7	40	62	22	27	1	1					
2	1	21	8	55	68	62	101	2	1		1			2
3		3		14	13	19	11	1						
	2													
														2
			2				1	1	1					8
1				1		1	2	1	1	3				5
2	4	11	4	4	4	9	2		5	1	3	1	1	1
				12	8				3		9			
1	1													1
34	38	31	27	34	46	56	73	80	132	96	87	8	4	32
										26	14	57	27	5
126	139	528	453	109	111	168	239	111	184	374	289	44	42	27
		4						1		28	25	92	63	7
21	14	5	4	3	2	5	4	1	1			1		2
1		3	2	6	14	6	6	1		1	1		1	2
		48	31	22	29	122	117					2		1
														1
	1	10	5					18	13	23	17		2	4
					1									

OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1	WR1	WR1	WR1	WR1	WR1
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
169178	14301	14302	14303	14304	169182	169184	169185	169186	14237	14238	14239	14240	14534	14535
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
	9	57	2	2			1		2	2	2	1		
									3	2			2	3
2														
				1	5	3	6	5						
	3	1	2	2	3	3	4	4						
4					6	6	3	1			2			1
				1	5	4	2	1	3		3			
	1					1	1	2			9	5		
14	2	11	1	2	1	1	2	1			4	2		
2		1												
									1	1				
					1		1		12	8	1	1		
5	1	2	1								2	3		
								1						
47	6	21	26	26	9	10	38	62	16	19	13	16	1	
40	26	55	36	53	4	6	6	18	161	167	51	60		1
5	1	2	3	5										
6		3			2	3								
			1				1	2		4	1	1		
4		2		3	12	6		1	8	10	11	6		
		1					1	4	2				12	16
5			3	5	18	22	14	15	1	1				

WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR3	WR3	WR3	WR3	WR3
Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring
14536	14537	14245	14246	14247	14248	14542	14543	14544	14545	14253	14254	14255	14256	14546
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
	3						1			1				
							1						1
			1		1						1		2	
		1	1										1	
	3	2	3	3		2	10	5	9	2	1	3	5	6
1		25	47	16	18	15	18	34	52	1	2	8	6	6
			4		1	8	15	3	4	2			3	8
						54	52	6	4	3	2			35
			7		5									3
1														
	1					7	6	5	2		2			21
						11	5	2						1
		5	11	2	4	12	12	5	9	4	3	43	34	1
	4	1	4	1	1	61	48	13	26	18	15			86
		6	6	7	9			2		3	4	2	6	
		2	1		1	1	1	1		2	3		2	1
1	1													
						1	1	1						1
			1	2	8							3	3	
		2	4	3	4						1	3	7	
3	18													
		9	17	4	2	12	9	15	8		1	10	14	20

WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR5	WR5	WR5	WR5
Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter
14547	14548	14549	14261	14262	14263	14264	14558	14559	14560	14561	14269	14270	14271	14272
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
			2						7	4	3		8	9
2														
	1						1	1	3	2				
	1													
									1					
1	10	11						1	3	1				
10	23	14												
6	1		1											
51														
1														
												1	
	1	1												
17	4	2									10	9	84	37
4							1		4	3			1	1
													17	14
												1		
7	24	12	15	14	9	11	11	7	41	27	39	23	174	95
			12	13	5	5					15	19	8	5
129	19	16	68	77	47	40	10	5	34	34	87	73	222	138
	1		3	5					2	1	1	1	1	1
1									2					
1									14	11	1		8	1
									1					
					1	1				1	2			
											5			
1					1					1		4	4	5
							2	1	1	3			1	1
16	18	13	11	10	2	4	10	1	13	14	1			2

WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14566	14567	14568	14569	14277	14278	14279	14280	14574	14575	14576	14577
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4
		3	2							1	
							1				1
								2	1	11	4
										2	5
										1	
							1	1		2	6
					1	4	11	10	4	5	3
					2		4	18	10	59	39
				4	5		3	6	8	30	21
						2	3			1	
								1			
								3	4	1	3
	1	1	1								2
		2	2					3	3		1
							2				
7	6	20	20			11	15	41	83	293	267
				8	19	4	5				
2	4	7	8	1		5	7	4	6	14	9
	1	2	1	1	5		1	2	3		
	1		1			1	1	1	4		
				6	6	1	5				
5	8	4	11			2	4				
					1						
1		2	1						2		
					1	10	13	11	6	25	19

						LR1	LR1	LR1	LR1
						Winter	Winter	Winter	Winter
						14313	14314	14315	14316
						Edg	Edg	Edg	Edg
Class	Order	Family	SG	Genus	Stage	1	2	3	4
Arthropoda	Diptera	Tipulidae		nu	Larva				
Arthropoda	Ephemeroptera	Baetidae	6	Cloeon	Nymph				
Arthropoda	Ephemeroptera	Baetidae	7	Offadens	Nymph				
Arthropoda	Ephemeroptera	Baetidae	9	Bungona	Nymph				
Arthropoda	Ephemeroptera	Baetidae	9	Centroptilum	Nymph	1			
Arthropoda	Ephemeroptera	Baetidae		indeterminate genus	Nymph				
Arthropoda	Ephemeroptera	Caenidae	6	Tasmanocoenis	Nymph				
Arthropoda	Ephemeroptera	Caenidae		indeterminate genus	Nymph				
Arthropoda	Ephemeroptera	Leptophlebiidae	10	Koorrnonga	Nymph	19	8	2	2
Arthropoda	Ephemeroptera	Leptophlebiidae	10	Nousia	Nymph				
Arthropoda	Ephemeroptera	Leptophlebiidae	10	Ulmerophlebia	Nymph				
Arthropoda	Ephemeroptera	Leptophlebiidae	8	Atalophlebia	Nymph		1		
Arthropoda	Ephemeroptera	Leptophlebiidae		indeterminate genus	Nymph	2	2	1	2
Arthropoda	Hemiptera	Corixidae	4	Sigara	Adult				
Arthropoda	Hemiptera	Corixidae		indeterminate genus	Nymph				
Arthropoda	Hemiptera	Gelastocoridae	5	Nerthra	Nymph				
Arthropoda	Hemiptera	Gerridae	7	Tenagogerris	Adult				
Arthropoda	Hemiptera	Gerridae	7	Tenagogerris	Nymph				
Arthropoda	Hemiptera	Gerridae		indeterminate genus	Nymph				
Arthropoda	Hemiptera	Hemiptera indeterminate		indeterminate genus	Nymph				
Arthropoda	Hemiptera	Hydrometridae	5	Hydrometra	Adult				
Arthropoda	Hemiptera	Hydrometridae	5	Hydrometra	Nymph				
Arthropoda	Hemiptera	Micronectidae	6	Micronecta	Adult				
Arthropoda	Hemiptera	Nepidae	6	Ranatra	Adult				
Arthropoda	Hemiptera	Notonectidae	6	Enithares	Adult				
Arthropoda	Hemiptera	Notonectidae	6	Enithares	Nymph				
Arthropoda	Hemiptera	Notonectidae	7	Anisops	Adult				
Arthropoda	Hemiptera	Notonectidae	7	Anisops	Nymph				
Arthropoda	Hemiptera	Notonectidae	9	Paranisops	Adult				
Arthropoda	Hemiptera	Notonectidae	9	Paranisops	Nymph				
Arthropoda	Hemiptera	Notonectidae		indeterminate genus	Nymph				
Arthropoda	Hemiptera	Pleidae	4	Paraplea	Adult				
Arthropoda	Hemiptera	Pleidae		indeterminate genus	Nymph				
Arthropoda	Hemiptera	Veliidae	7	Microvelia	Adult				
Arthropoda	Hemiptera	Veliidae		Drepanovelia	Adult				
Arthropoda	Hemiptera	Veliidae		indeterminate genus	Nymph				
Arthropoda	Lepidoptera	Crambidae		indeterminate genus	Larva				
Arthropoda	Megaloptera	Corydalidae	7	Archichauliodes	Larva				
Arthropoda	Odonata	Aeshnidae	6	Adversaeschna	Nymph				
Arthropoda	Odonata	Aeshnidae	7	Austroaeschna	Nymph				
Arthropoda	Odonata	Argiolestidae	5	Austroargiolestes	Nymph		1		
Arthropoda	Odonata	Austrocorduliidae	9	Austrocordulia	Nymph				
Arthropoda	Odonata	Cordulephyidae	9	Cordulephya	Nymph				
Arthropoda	Odonata	Corduliidae	5	Hemicordulia	Nymph				
Arthropoda	Odonata	Corduliidae		indeterminate genus	Nymph				
Arthropoda	Odonata	Diphlebiidae	8	Diphlebia	Nymph				
Arthropoda	Odonata	Epiproctophora indetermin		indeterminate genus	Nymph				
Arthropoda	Odonata	Gomphidae	6	Austrogomphus	Nymph				
Arthropoda	Odonata	Gomphidae	8	Hemigomphus	Nymph				
Arthropoda	Odonata	Gomphidae		indeterminate genus	Nymph				
Arthropoda	Odonata	Isostictidae	5	Rhadinosticta	Nymph				
Arthropoda	Odonata	Lestidae	6	Austrolestes	Nymph				
Arthropoda	Odonata	Synlestidae	7	Synlestes	Nymph	1			1
Arthropoda	Odonata	Synlestidae		indeterminate genus	Nymph				
Arthropoda	Odonata	Synthemistidae	7	Eusynthemis	Nymph				
Arthropoda	Odonata	Telephlebiidae		indeterminate genus	Nymph				
Arthropoda	Odonata	Zygoptera indeterminate		indeterminate genus	Nymph				
Arthropoda	Plecoptera	Gripopterygidae	7	Dinotoperla	Nymph				
Arthropoda	Plecoptera	Gripopterygidae	8	Leptoperla	Nymph	3	2	5	1
Arthropoda	Plecoptera	Gripopterygidae	8	Newmanoperla	Nymph				
Arthropoda	Plecoptera	Gripopterygidae	9	Illiesoperla	Nymph				
Arthropoda	Plecoptera	Gripopterygidae		indeterminate genus	Nymph				
Arthropoda	Plecoptera	Plecoptera indeterminate		indeterminate genus	Nymph				
Arthropoda	Trichoptera	Atriplectididae	8	Atriplectides	Larva				
Arthropoda	Trichoptera	Calamoceratidae	8	Anisocentropus	Larva				
Arthropoda	Trichoptera	Calocidae	9	Caenota	Larva				
Arthropoda	Trichoptera	Calocidae/Helicophidae		Genus H	Larva				
Arthropoda	Trichoptera	Conoesucidae	8	Coenoria	Larva				
Arthropoda	Trichoptera	Conoesucidae		Hampa	Larva				
Arthropoda	Trichoptera	Conoesucidae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Ecnomidae	6	Ecnomus	Larva				
Arthropoda	Trichoptera	Ecnomidae	9	Ecnomina	Larva		1		
Arthropoda	Trichoptera	Ecnomidae		Daternomina	Larva				
Arthropoda	Trichoptera	Helicophidae	8	Alloecella	Larva				
Arthropoda	Trichoptera	Helicopsychidae	10	Helicopsyche	Larva				
Arthropoda	Trichoptera	Hydrobiosidae	6	Ulmerochorema	Larva				
Arthropoda	Trichoptera	Hydrobiosidae	8	Taschorema	Larva	1			
Arthropoda	Trichoptera	Hydrobiosidae	9	Apsilochorema	Larva				
Arthropoda	Trichoptera	Hydrobiosidae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Hydropsychidae	8	Asmicridea	Larva				

LR1	LR1	LR1	LR1	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3
Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter
169191	169195	169196	169197	14321	14322	14323	14324	169199	169203	169204	169205	14329	14330	14331
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
			1											
				4		4	6	1	1	1		2	5	2
				3			3					1		
				3			1	1		2		1	10	
									1					
6	3	6			5								1	
				3			1				2	2		
													1	
4					1				1				1	
	1													
		2												
										1	1			
			1											
				1										
1													1	
				1										
1	1													
						1						1		
5	1	2	4	3							2	4		1
											1			
													1	
													2	
				1										1
					1									
												1		

LR3	LR3	LR3	LR3	LR3	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2
Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter
14332	169207	169211	169212	169213	14289	14290	14291	14292	169167	169171	169172	169173	14297	14298
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
	2													
11	1		2	3	7							2	1	30
	4	7	1		3			2						2
1	6	4	1	1									4	2
1														
		1			1			1		1		1	4	
2	1	2	1	1	1							1		
					2									
3		1		1				2				2		2
									2	1				
				1				1						
			2	1								1		
										2		2		
														1
					6			1					1	1
									3	1				
									1					
													4	
										1	2			
										2				
										1				
										2				
								2	1					
	1										1			
			1									1		
									3					
	1				1			6	1	1		1		
								1	1		1			
						4	1							
2		7												
														3
													1	
													1	
						6	8							
						1	3							
2	1	2				1	1	1	3	1	2	4		
					2									
					1		1	1	1		8	7		
						19	28	1			1			
														2
		2						1						
						1	1	4						

OH2	OH2	OH2	OH2	OH2	OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1
Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14299	14300	169175	169179	169180	169181	14305	14306	14307	14308	169183	169187	169188	169189	14241
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
								11	6	11		4	1	
8	23	4		2		4		4		1				
3		2					1				2		1	
18	11			7	1	1	1	2	2		1			1
											1			
3	8	1	7		2	26	12	26	7	20	2			3
4			4	3	7		3	2						
	1						1	2		1				1
2	3	2			3	6	2	17	3	1				2
									1					
		2			29					51			1	
		7		1	4							1		
2						1		1	3			1		
					1									1
	2									1		1		
		2	1		1					13	2			
							1					2	1	
		1								1				
		13	10		17							11	3	
										1				
				1										
		1								2			1	
						1								
3			2		2		1							
	2													
											1			
2		1		1										
					1			3						
												1		
1					1	1	2			1				
		1	2	2	1					3	1	1		1
1								2						
			3		4	2		1		3		1	2	
						1								
1			1	1		1								
				2										
	1		1			1		7	5		1			
												1		

WR1	WR1	WR1	WR1	WR1	WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14242	14243	14244	14530	14531	14532	14533	14249	14250	14251	14252	14538	14539	14540	14541
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
							1							
											1		4	
1											3			4
1	2			1			6			6				
							2	5						
1		1						2		1				
2	4	2	3	13	2		1	1	1		7	2	6	2
								3	1		2			4
								1			3			1
4	5	1	1	1	1		1	12	1	2	1	1		1
				1										
									1					
													2	
			2								1			
				1										
							1		3				1	2
											1	2		2
										1				
			19	8	1	6					9	7	2	1
	1			1										
				4									2	
	1													
							3	1					1	
									1					
								3						
							5			3				
							3			3				
			1											
	1	1											1	
						1							4	
												1		
				3										

WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14257	14258	14259	14260	14550	14551	14552	14553	14265	14266	14267	14268	14554	14555	14556
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
1														
								54	205	53	44	74	29	2
11	3		1	2			3	68	62	20	55	35	13	1
2	2							7	6	8			2	
									13					
1	2		4	3	12	32	37	2		2	1	3		8
				2			1	10	9	3	3		1	
2	1							1	1			1		3
12	9	1	7	2				5	15	11	3	1	1	
														1
							1	1				1		2
												5		1
														1
								1		2				
						1								
	1					2	1			7		4		2
				1	2		2					8	1	
1														
					5	15						9		
										1	1			
					4							6	7	57
														1
												1		
													1	
										1				
2														
6	2	1	1	5									1	6
1									4	1	2			
			1											
			1						1					
	1					6	10	1					2	
1			1						1					
2				1										

WR4	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
14557	14273	14274	14275	14276	14562	14563	14564	14565	14281	14282	14283	14284	14570	14571
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
									1					
							1		1		1	1		
						1			3					
18	1	16					1			29	4			24
5	2	25	1	11			3		7	6	28	2		7
				1					1	5	4		3	
											1		4	
2									5			1		1
2														1
												2		1
	1	1		3					4	1		12	2	
													2	
													1	
						1								
														1
2				1		2								
					1									
			1				1			1		1		
												1	1	1
													1	1
									1					
														1
18					1	15	3	2					11	17
			1											
			1			1								
						3							1	
								1						
									1			2		
												4		
												5		
											2		2	1
										1				
												1		
													1	
										1				
											1			

WR6	WR6	WREF	WREF	WREF	WREF	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR2
Spring	Spring	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14572	14573	14337	14338	14339	14340	14309	14310	14311	14312	169190	169192	169193	169194	14317
Edg	Edg	Edg	Edg	Edg	Edg	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
							1		1					
3	4													
								1	1					
4														
										2	2		2	
												2		
				2	1									
2	1	1				2	1	2	3	2				
					6									
1	4	10												
												1		
												1		
		1												
1														
12	3													
			1											
28	10													
1	2													
													1	
	1													
	1												1	
													1	
1														
											1			
	2													
														13
1	2					10	6	3	8	3	6	3	2	
						5	1		3		1	1	2	2
											1			
					1									
											1			
						1	2					1	1	2
												1		
										1	3	2		
										1				
						1	1	1						
						1	2			1	1	7	8	23

LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3	LR3	LR3	LR3	LR3	LR3
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14318	14319	14320	169198	169200	169201	169202	14325	14326	14327	14328	169206	169208	169209	169210
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
											6	1		
1														
1														
9	8	11	1	2	2	5	22	29	17	24	6	8	6	4
2							2							
				1					1					
1	2	1	2	10	4	7	1				1	6	3	
		1	1	1		6			1	2		1		1
1														
		1	7	1		2		2	5	5	3			
42	180	190	105	188	68	229	56	39	16	28	51	51	20	19

OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2	OH2	OH2	OH2	OH2	OH2
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14285	14286	14287	14288	169166	169168	169169	169170	14293	14294	14295	14296	169174	169176	169177
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
								3	4	3		8	16	17
55	9	1	2											4
	1												1	
1														
														7
	1													
	1													
														1
			2			1		1						1
	1													
	8													
		10	11					14	14	11	17	1		
1	1													
										1	1			
														1
													1	
		7	2		2	3	5	1	4	2				
5		3	2	6	6	11	8							
	3													
			2	3	3	3	3							4
		14	13	6	6	12	26		1					
									2					1
								2	4	5	3	1	2	2
	1	3		4	11	10	6	1						1
		2	1	3	1		1	5	5		8	1	1	
		1						10	7	6	3	8	1	5

OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1	WR1	WR1	WR1	WR1	WR1
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
169178	14301	14302	14303	14304	169182	169184	169185	169186	14237	14238	14239	14240	14534	14535
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
19	12	44	27	36	75	39	25	38		1	1	2		
	3	8		2			2	4						
						1								
													1	
7							1							
5		2					1							
								1						
1														
	1	1	2	1			1	1	1	5		4		
1														
	1	2					1			1				
	2													
	3	5	18	22	42	49	6	21						
											1			
	1			1				2						
2	4	11	2	10	1	3	1	1						
		1	1	1	1	2		1						
							2							
		4		2				4	1					
3	1	2	10	8	198	200	129	177						

WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR3	WR3	WR3	WR3	WR3
Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring
14536	14537	14245	14246	14247	14248	14542	14543	14544	14545	14253	14254	14255	14256	14546
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
		93	84	42	48	19	20	30	36	41	42	54	66	10
	2	3	14	6	2					4	2		2	18
														1
1														
1	1	2	3	6	9					5	9	13	17	
		1	2	3	7						1		1	
1														
						2	2							2
			1					1				1		
										1		2	1	
		3	3	1	11	20	19	9	9			26	29	

WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR5	WR5	WR5	WR5
Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter
14547	14548	14549	14261	14262	14263	14264	14558	14559	14560	14561	14269	14270	14271	14272
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
14	9	7	18	18	7	9		1	1		2	3	4	5
								1						
9	3	2	1			2	2	2	7	6			2	
			3		32	22						1		
			2		7	4						3	2	1
1														
	21		3	3									1	
													1	
	2										1			
1	1	2	1	1								1	2	1

WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14566	14567	14568	14569	14277	14278	14279	14280	14574	14575	14576	14577
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4
4		4	2	30	37	43	60	1		9	2
							2		1		
			1			1				
								1		
							2	1		2
			1				3			1	
							3	5	7	10	3

Class	Order	Family	SG	Genus	Stage	LR1	LR1	LR1	LR1
						Winter	Winter	Winter	Winter
						14313	14314	14315	14316
						Edg	Edg	Edg	Edg
						1	2	3	4
Arthropoda	Trichoptera	Hydropsychidae	8	Diplectrona	Larva				
Arthropoda	Trichoptera	Hydropsychidae		Austropsyche	Larva				
Arthropoda	Trichoptera	Hydropsychidae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Hydroptilidae	4	Hydroptila	Larva				
Arthropoda	Trichoptera	Hydroptilidae	4	Orphninotrichia	Larva				
Arthropoda	Trichoptera	Hydroptilidae	6	Hellyethira	Larva	11	8	1	3
Arthropoda	Trichoptera	Hydroptilidae	8	Oxyethira	Larva				
Arthropoda	Trichoptera	Hydroptilidae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Leptoceridae	6	Notalina	Larva	6	18	4	18
Arthropoda	Trichoptera	Leptoceridae	7	Oecetis	Larva				
Arthropoda	Trichoptera	Leptoceridae	8	Triplectides	Larva			4	
Arthropoda	Trichoptera	Leptoceridae	9	Lectrides	Larva				
Arthropoda	Trichoptera	Leptoceridae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Philorheithridae	7	Kosrheithrus	Larva				
Arthropoda	Trichoptera	Philorheithridae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Tasimiidae		indeterminate genus	Larva				
Arthropoda	Trichoptera	Trichoptera indeterminate		indeterminate genus	Larva	4	8		
Arthropoda	Trombidioidea	Johnstonianidae		alpha	Non-Insect				
Mollusca	Hygrophila	Planorbidae		indeterminate genus	Non-Insect				
Mollusca	Veneroida	Sphaeriidae	5	Musculium	Non-Insect				
Mollusca	Veneroida	Sphaeriidae		indeterminate genus	Non-Insect				
Nematoda	Indeterminate	Nematoda indeterminate		unassessed genus	Non-Insect				
Nemertea	Indeterminate	Nemertea indeterminate		alpha	Non-Insect				
Platyhelminthes	Tricladidia	Dugesiidae	4	Cura	Non-Insect				
Porifera	Indeterminate	Spongillidae		alpha	Non-Insect				

Family	Genus	LR1	LR1	LR1	LR1	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3
		Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter
		169191	169195	169196	169197	14321	14322	14323	14324	169199	169203	169204	169205	14329	14330	14331
		Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Hydropsychidae	Diplectrona															
Hydropsychidae	Austropsyche															
Hydropsychidae	indeterminate genus															
Hydroptilidae	Hydroptila															
Hydroptilidae	Orphninotrichia								1							
Hydroptilidae	Hellyethira			2		1		1	5	2	1		1	2		1
Hydroptilidae	Oxyethira															
Hydroptilidae	indeterminate genus															
Leptoceridae	Notalina	6	5		2	4	4	15	19	6				2		
Leptoceridae	Oecetis															
Leptoceridae	Triplectides	1	3	4												
Leptoceridae	Lectrides															
Leptoceridae	indeterminate genus															
Philorheithridae	Kosrheithrus															
Philorheithridae	indeterminate genus															
Tasimiidae	indeterminate genus															
Trichoptera indeterminate	indeterminate genus												1			
Johnstonianidae	alpha															
Planorbidae	indeterminate genus															
Sphaeriidae	Musculium															
Sphaeriidae	indeterminate genus															
Nematoda indeterminate	unassessed genus															
Nemertea indeterminate	alpha															
Dugesiidae	Cura															
Spongillidae	alpha															

Family	Genus	LR3	LR3	LR3	LR3	LR3	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2
		Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter
		14332	169207	169211	169212	169213	14289	14290	14291	14292	169167	169171	169172	169173	14297	14298
		Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
		4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Hydropsychidae	Diplectrona															
Hydropsychidae	Austropsyche															
Hydropsychidae	indeterminate genus															
Hydroptilidae	Hydroptila															
Hydroptilidae	Orphninotrichia															
Hydroptilidae	Hellyethira	1				1										
Hydroptilidae	Oxyethira		11	94	3	4										
Hydroptilidae	indeterminate genus															
Leptoceridae	Notalina			1	1						1					
Leptoceridae	Oecetis															
Leptoceridae	Triplectides	1								4		8		4	2	5
Leptoceridae	Lectrides															
Leptoceridae	indeterminate genus															
Philorheithridae	Kosrheithrus															1
Philorheithridae	indeterminate genus											1	1			
Tasimiidae	indeterminate genus															
Trichoptera indeterminate	indeterminate genus				1	1					2		2	19		
Johnstonianidae	alpha															
Planorbidae	indeterminate genus															
Sphaeriidae	Musculium															
Sphaeriidae	indeterminate genus															
Nematoda indeterminate	unassessed genus							1	2					1		
Nemertea indeterminate	alpha															
Dugesiidae	Cura															
Spongillidae	alpha															

OH2	OH2	OH2	OH2	OH2	OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1
Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14299	14300	169175	169179	169180	169181	14305	14306	14307	14308	169183	169187	169188	169189	14241
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
		3		3	1	1		2	2	2	1		5	
						1			1		9			
3			1			5		1	1	4	1		2	
		1											1	
9	4	49	10	3	16	10	15	3	10	10	31	34	7	3
								1						
								1						
		2	3	2		1				1			5	
						1								
							1							
							3	1						

WR1	WR1	WR1	WR1	WR1	WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14242	14243	14244	14530	14531	14532	14533	14249	14250	14251	14252	14538	14539	14540	14541
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1														
											1	1	3	1
											1			1
									2			2	1	
7	1		2			3	2			1	3	4	2	
							1	1	1					
											1			
			1	1			1				2	3	4	3
				2										

WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14257	14258	14259	14260	14550	14551	14552	14553	14265	14266	14267	14268	14554	14555	14556
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
	1													
	2				2	1		2					1	
										1				
2			11			2				1				
1	1		2		2	4	6	2		4			15	3
	1													
				5	1		66						20	1
										4	5			
			1											
							1							
											1			

WR4	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
14557	14273	14274	14275	14276	14562	14563	14564	14565	14281	14282	14283	14284	14570	14571
Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg	Edg
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
1										1	1		2	2
							1				1			
2												2	8	
1	1						1						10	2
1		2									3			
		1		2										

WR6	WR6	WREF	WREF	WREF	WREF	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR1	LR2
Spring	Spring	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter
14572	14573	14337	14338	14339	14340	14309	14310	14311	14312	169190	169192	169193	169194	14317
Edg	Edg	Edg	Edg	Edg	Edg	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
4				1										
									2	3	4		2	13
											1			
5					1					1				
				1										
4	1					3	5					1		3
							1							

LR2	LR2	LR2	LR2	LR2	LR2	LR2	LR3	LR3	LR3	LR3	LR3	LR3	LR3	LR3
Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14318	14319	14320	169198	169200	169201	169202	14325	14326	14327	14328	169206	169208	169209	169210
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
														2
	19	25	2	2	3	9	1				14	12		2
9							1			1	14	16		
1														
							1							

OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH1	OH2	OH2	OH2	OH2	OH2	OH2	OH2
Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring
14285	14286	14287	14288	169166	169168	169169	169170	14293	14294	14295	14296	169174	169176	169177
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
				3		1	1							
		1	5											
						1		2	1		1			27
									1					
											1			2
												1		2
					1									
		1	1	4	10	15	11			1		24	11	19
		3	1											

OH2	OH3	OH3	OH3	OH3	OH3	OH3	OH3	OH3	WR1	WR1	WR1	WR1	WR1	WR1
Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring
169178	14301	14302	14303	14304	169182	169184	169185	169186	14237	14238	14239	14240	14534	14535
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
									1		1	5		
31														
	1													
			1		1		1							
	1				1	1	4	2						
23					20	21	106	102						

WR1	WR1	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR2	WR3	WR3	WR3	WR3	WR3
Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring
14536	14537	14245	14246	14247	14248	14542	14543	14544	14545	14253	14254	14255	14256	14546
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
			4		5							32	24	1
						1								
		2	1					1	1		1			
														1
1	1					3	2	2	1	1		5	1	

WR3	WR3	WR3	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR4	WR5	WR5	WR5	WR5
Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter
14547	14548	14549	14261	14262	14263	14264	14558	14559	14560	14561	14269	14270	14271	14272
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
													4	4
1									1	1				
	2	2								2	1	2		
						1					1	2	1	1

WR5	WR5	WR5	WR5	WR6	WR6	WR6	WR6	WR6	WR6	WR6	WR6
Spring	Spring	Spring	Spring	Winter	Winter	Winter	Winter	Spring	Spring	Spring	Spring
14566	14567	14568	14569	14277	14278	14279	14280	14574	14575	14576	14577
Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff	Riff
1	2	3	4	1	2	3	4	1	2	3	4
						2	2				
											4
		3	1					15	24	43	30

Appendix 6.

Macroinvertebrate PERMANOVAS

Edge Taxa Richness PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Impact/Control	1	1318.4	1318.4	1.6186	0.6732	3	0.323
Season	1	83.384	83.384	3.6882	0.1854	801	0.1742
Creeks(Impact/Control)	2	1629.1	814.53	1.9222	0.2074	8963	0.1979
Impact/ControlxSeason	1	19.894	19.894	0.87995	0.4463	799	0.4413
Position(Creeks(Impact/Control))	8	3390	423.75	7.697	0.0001	9936	0.0001
Creeks(Impact/Control)xSeason	2	45.217	22.608	0.43174	0.6959	9953	0.6868
Position(Creeks(Impact/Control))xSeason	8	418.93	52.366	0.95118	0.4919	9944	0.4786
Res	72	3963.9	55.054				
Total	95	10869					

Details of the expected mean squares (EMS) for the model

Source	EMS
Impact/Control	1*V(Res) + 8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season	1*V(Res) + 4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control)	1*V(Res) + 8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason	1*V(Res) + 4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control))	1*V(Res) + 8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason	1*V(Res) + 4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason	1*V(Res) + 4*V(Position(Creeks(Impact/Control))xSeason)
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator

	Num.df Den.df
Impact/Control	1*Impact/Control 1*Creeks(Impact/Control)
1	2
Season	1*Season 1*Creeks(Impact/Control)xSeason
1	2
Creeks(Impact/Control)	1*Creeks(Impact/Control) 1*Position(Creeks(Impact/Control))
2	8
Impact/ControlxSeason	1*Impact/ControlxSeason 1*Creeks(Impact/Control)xSeason
1	2
Position(Creeks(Impact/Control))	1*Position(Creeks(Impact/Control)) 1*Res
8	72
Creeks(Impact/Control)xSeason	1*Creeks(Impact/Control)xSeason 1*Position(Creeks(Impact/Control))xSeason
2	8
Position(Creeks(Impact/Control))xSeason	1*Position(Creeks(Impact/Control))xSeason 1*Res
8	72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	10.498	3.24
S(Season)	1.2662	1.1252
V(Creeks(Impact/Control))	16.283	4.0352
S(Impact/ControlxSeason)	-0.11308	-0.33628
V(Position(Creeks(Impact/Control)))	46.087	6.7887
V(Creeks(Impact/Control)xSeason)	-2.4798	-1.5747
V(Position(Creeks(Impact/Control))xSeason)	-0.672	-0.81976
V(Res)	55.054	7.4199

Edge EPT Individual PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem3
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Impact/Control	1	1452.3	1452.3	0.4565	0.6603	3	0.7358
Season	1	1003.8	1003.8	1.3326	0.3571	799	0.3393
Creeks(Impact/Control)	2	6362.6	3181.3	1.4942			

0.2433	8947		0.2262	
Impact/ControlxSeason	1	679.14	679.14	0.90155
0.4672	800		0.4953	
Position(Creeks(Impact/Control))	8	17033	2129.1	4.3956
0.0001	9896		0.0001	
Creeks(Impact/Control)xSeason	2	1506.6	753.31	0.93703
0.4857	9948		0.4868	
Position(Creeks(Impact/Control))xSeason	8	6431.4	803.93	1.6597
0.0252	9883		0.0372	
Res	72	34875	484.37	
Total	95	69344		

Details of the expected mean squares (EMS) for the model

Source EMS
Impact/Control 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control) 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) +
24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control)) 1*V(Res) +
8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason)
Res 1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source Numerator
Denominator
Num.df
Den.df
Impact/Control 1*Impact/Control
1*Creeks(Impact/Control)

1 2
Season 1*Season
1*Creeks(Impact/Control)xSeason

1 2
Creeks(Impact/Control) 1*Creeks(Impact/Control)
1*Position(Creeks(Impact/Control))

2 8
Impact/ControlxSeason 1*Impact/ControlxSeason
1*Creeks(Impact/Control)xSeason

1 2
Position(Creeks(Impact/Control)) 1*Position(Creeks(Impact/Control))
1*Res

8 72
Creeks(Impact/Control)xSeason 1*Creeks(Impact/Control)xSeason
1*Position(Creeks(Impact/Control))xSeason

2 8
Position(Creeks(Impact/Control))xSeason 1*Position(Creeks(Impact/Control))xSeason
1*Res

8 72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	-36.022	-6.0018
S(Season)	5.2191	2.2845
V(Creeks(Impact/Control))	43.841	6.6213
S(Impact/ControlxSeason)	-3.0903	-1.7579
V(Position(Creeks(Impact/Control)))	205.59	14.339
V(Creeks(Impact/Control)xSeason)	-4.2188	-2.054

V(Position(Creeks(Impact/Control))xSeason)	79.889	8.9381
V(Res)	484.37	22.009

Edge EPT Taxa PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem4
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

Source	Unique df	SS	MS	Pseudo-F
	P(perm)		perms	P(MC)
Impact/Control	1	4123.8	4123.8	6.3174
0.3312	3	0.0154		
Season	1	524.6	524.6	1.2915
0.3572	801		0.3445	
Creeks(Impact/Control)	2	1305.6	652.78	0.45714
0.8845	8948		0.8644	
Impact/ControlxSeason	1	493.97	493.97	1.2161
0.3636	800		0.3742	
Position(Creeks(Impact/Control))	8	11424	1427.9	3.0867
0.0001	9860		0.0001	
Creeks(Impact/Control)xSeason	2	812.39	406.2	0.72671
0.6281	9948		0.6592	
Position(Creeks(Impact/Control))xSeason	8	4471.6	558.95	1.2082
0.1691	9861		0.2136	
Res	72	33308	462.61	
Total	95	56464		

Details of the expected mean squares (EMS) for the model

Source EMS
Impact/Control 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control) 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) +
24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control)) 1*V(Res) +
8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason)
Res 1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source Numerator
Denominator
Num.df
Den.df
Impact/Control 1*Impact/Control

1*Creeks(Impact/Control)

1 | 2
Season | 1*Season
1*Creeks(Impact/Control)xSeason

1 | 2
Creeks(Impact/Control) | 1*Creeks(Impact/Control)
1*Position(Creeks(Impact/Control))

2 | 8
Impact/ControlxSeason | 1*Impact/ControlxSeason
1*Creeks(Impact/Control)xSeason

1 | 2
Position(Creeks(Impact/Control)) | 1*Position(Creeks(Impact/Control))
1*Res

8 | 72
Creeks(Impact/Control)xSeason | 1*Creeks(Impact/Control)xSeason
1*Position(Creeks(Impact/Control))xSeason

2 | 8
Position(Creeks(Impact/Control))xSeason | 1*Position(Creeks(Impact/Control))xSeason
1*Res

8 | 72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	72.314	8.5038
S(Season)	2.4668	1.5706
V(Creeks(Impact/Control))	-32.299	-5.6832
S(Impact/ControlxSeason)	3.6573	1.9124
V(Position(Creeks(Impact/Control)))	120.67	10.985
V(Creeks(Impact/Control)xSeason)	-12.729	-3.5678
V(Position(Creeks(Impact/Control))xSeason)	24.084	4.9075
V(Res)	462.61	21.508

Riffle Taxa Richness PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem1
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

Unique
Source | df SS MS Pseudo-F
P(perm) perms P(MC)
Impact/Control | 1 2087.4 2087.4 8.3133
0.3337 | 3 0.0864
Season | 1 37.946 37.946 0.73748
0.4964 | 801 0.4893
Creeks(Impact/Control) | 2 502.17 251.09 1.7549

0.2244 8987 0.2265
Impact/ControlxSeason 1 315.46 315.46 6.1308
0.1296 801 0.1011
Position(Creeks(Impact/Control)) 8 1144.6 143.08 5.3704
0.0001 9938 0.0001
Creeks(Impact/Control)xSeason 2 102.91 51.454 0.30341
0.7542 9945 0.7789
Position(Creeks(Impact/Control))xSeason 8 1356.7 169.59 6.3654
0.0001 9932 0.0001
Res 72 1918.2 26.642

Total 95 7465.4

Details of the expected mean squares (EMS) for the model
Source EMS
Impact/Control 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control) 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) +
24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control)) 1*V(Res) +
8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason)
Res 1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares
Source Numerator
Denominator
Num.df
Den.df
Impact/Control 1*Impact/Control
1*Creeks(Impact/Control)

1 2
Season 1*Season
1*Creeks(Impact/Control)xSeason

1 2
Creeks(Impact/Control) 1*Creeks(Impact/Control)
1*Position(Creeks(Impact/Control))

2 8
Impact/ControlxSeason 1*Impact/ControlxSeason
1*Creeks(Impact/Control)xSeason

1 2
Position(Creeks(Impact/Control)) 1*Position(Creeks(Impact/Control))
1*Res

8 72
Creeks(Impact/Control)xSeason 1*Creeks(Impact/Control)xSeason
1*Position(Creeks(Impact/Control))xSeason

2 8
Position(Creeks(Impact/Control))xSeason 1*Position(Creeks(Impact/Control))xSeason
1*Res

8 72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	38.256	6.1851
S(Season)	-0.28141	-0.53048
V(Creeks(Impact/Control))	4.5003	2.1214
S(Impact/ControlxSeason)	11	3.3166
V(Position(Creeks(Impact/Control)))	14.555	3.815
V(Creeks(Impact/Control)xSeason)	-9.8445	-3.1376

V(Position(Creeks(Impact/Control))xSeason)	35.736	5.978
V(Res)	26.642	5.1616

Riffle EPT Individual PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem5
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

	Unique			
Source	df	SS	MS	Pseudo-F
	P(perm)		perms	P(MC)
Impact/Control	1	9474.3	9474.3	10.593
0.3373	3	0.0061		
Season	1	1271.8	1271.8	1.6277
0.2715	798		0.2661	
Creeks(Impact/Control)	2	1788.8	894.42	0.2122
0.9275	8880		0.9705	
Impact/ControlxSeason	1	2708.1	2708.1	3.4658
0.122	800		0.0768	
Position(Creeks(Impact/Control))	8	33720	4215.1	12.342
0.0001	9905		0.0001	
Creeks(Impact/Control)xSeason	2	1562.8	781.38	0.93645
0.472	9950		0.4794	
Position(Creeks(Impact/Control))xSeason	8	6675.3	834.41	2.4432
0.0001	9885		0.0007	
Res	72	24589	341.52	
Total	95	81791		

Details of the expected mean squares (EMS) for the model

Source | EMS
Impact/Control | 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season | 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control) | 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason | 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) +
24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control)) | 1*V(Res) +
8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason | 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason | 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason)
Res | 1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator
	Denominator
	Num.df
	Den.df
Impact/Control	1*Impact/Control
	1*Creeks(Impact/Control)

1	2
Season	1*Season 1*Creeks(Impact/Control)xSeason
1	2
Creeks(Impact/Control)	1*Creeks(Impact/Control) 1*Position(Creeks(Impact/Control))
2	8
Impact/ControlxSeason	1*Impact/ControlxSeason 1*Creeks(Impact/Control)xSeason
1	2
Position(Creeks(Impact/Control))	1*Position(Creeks(Impact/Control)) 1*Res
8	72
Creeks(Impact/Control)xSeason	1*Creeks(Impact/Control)xSeason 1*Position(Creeks(Impact/Control))xSeason
2	8
Position(Creeks(Impact/Control))xSeason	1*Position(Creeks(Impact/Control))xSeason 1*Res
8	72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	178.75	13.37
S(Season)	10.217	3.1965
V(Creeks(Impact/Control))	-138.36	-11.763
S(Impact/ControlxSeason)	80.28	8.9599
V(Position(Creeks(Impact/Control)))	484.19	22.004
V(Creeks(Impact/Control)xSeason)	-4.4191	-2.1022
V(Position(Creeks(Impact/Control))xSeason)	123.22	11.101
V(Res)	341.52	18.48

Riffle EPT Taxa PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem6
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact/Control	Fixed	2
Creeks	Random	4
Position	Random	3
Season	Fixed	2

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F
	Unique			
	P(perm)		perms	P(MC)
Impact/Control	1	8559.5	8559.5	5.9512
0.3227	3	0.0241		
Season	1	753.41	753.41	2.2068
0.1944	797		0.1871	
Creeks(Impact/Control)	2	2876.6	1438.3	3.3143
0.0228	8901		0.0147	
Impact/ControlxSeason	1	880.67	880.67	2.5796
0.1487	800		0.1371	
Position(Creeks(Impact/Control))	8	3471.7	433.96	1.1691

0.2114 9885 0.2655
Creeks(Impact/Control)xSeason 2 682.8 341.4 0.59424
0.7243 9943 0.7397
Position(Creeks(Impact/Control))xSeason 8 4596.1 574.51 1.5478
0.0233 9884 0.055
Res 72 26725 371.18

Total 95 48546

Details of the expected mean squares (EMS) for the model
Source EMS
Impact/Control 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control)) + 48*S(Impact/Control)
Season 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) + 48*S(Season)
Creeks(Impact/Control) 1*V(Res) +
8*V(Position(Creeks(Impact/Control))) + 24*V(Creeks(Impact/Control))
Impact/ControlxSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason) +
24*S(Impact/ControlxSeason)
Position(Creeks(Impact/Control)) 1*V(Res) +
8*V(Position(Creeks(Impact/Control)))
Creeks(Impact/Control)xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason) + 12*V(Creeks(Impact/Control)xSeason)
Position(Creeks(Impact/Control))xSeason 1*V(Res) +
4*V(Position(Creeks(Impact/Control))xSeason)
Res 1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares
Source Numerator
Denominator
Num.df
Den.df
Impact/Control 1*Impact/Control
1*Creeks(Impact/Control)

1 2
Season 1*Season
1*Creeks(Impact/Control)xSeason

1 2
Creeks(Impact/Control) 1*Creeks(Impact/Control)
1*Position(Creeks(Impact/Control))

2 8
Impact/ControlxSeason 1*Impact/ControlxSeason
1*Creeks(Impact/Control)xSeason

1 2
Position(Creeks(Impact/Control)) 1*Position(Creeks(Impact/Control))
1*Res

8 72
Creeks(Impact/Control)xSeason 1*Creeks(Impact/Control)xSeason
1*Position(Creeks(Impact/Control))xSeason

2 8
Position(Creeks(Impact/Control))xSeason 1*Position(Creeks(Impact/Control))xSeason
1*Res

8 72

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact/Control)	148.36	12.18
S(Season)	8.5835	2.9298
V(Creeks(Impact/Control))	41.847	6.4689
S(Impact/ControlxSeason)	22.47	4.7402
V(Position(Creeks(Impact/Control)))	7.848	2.8014
V(Creeks(Impact/Control)xSeason)	-19.426	-4.4075
V(Position(Creeks(Impact/Control))xSeason)	50.834	7.1298
V(Res)	371.18	19.266

Appendix 7.

Edge SIMPER
Similarity Percentages - species contributions

Two-Way Analysis

Data worksheet
Name: Edge SqRt
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90.00%

Factor Groups

Sample	Impact	Creek
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR2	Mined	Eastern Trib

WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet

Examines Impact groups
(across all Creek groups)
Group Non-mined
Average similarity: 37.44

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Chironominae L	3.12	5.99	1.72	15.99	15.99
Diptera Chironomidae S.F. Tanypodinae L	2.20	4.52	1.65	12.07	28.06
Diptera Chironomidae S.F. Orthocladiinae L	3.01	4.36	1.18	11.64	39.71
Decapoda Atyidae Paratya X	1.74	3.88	0.88	10.36	50.06
Trichoptera Leptoceridae Triplectides L	1.45	1.97	0.67	5.26	55.32
Ephemeroptera Baetidae Centroptilum N	1.08	1.36	0.56	3.63	58.95
Trichoptera Leptoceridae Notalina L	1.00	1.33	0.42	3.55	62.50
Oligochaeta Oligochaeta indeterminate unassessed genus X	1.36	1.26	0.56	3.36	65.85
Ephemeroptera Leptophlebiidae Koorrnonga N	1.24	1.25	0.55	3.34	69.19
Coleoptera Elmidae Austrolimnius L	1.06	1.22	0.51	3.27	72.46
Trichoptera Hydroptilidae Hellyethira L	0.77	1.20	0.58	3.20	75.65
Ephemeroptera Leptophlebiidae indeterminate genus N	0.77	0.84	0.53	2.23	77.89
Plecoptera Gripopterygidae Leptoperla N	0.66	0.80	0.43	2.14	80.03
Ephemeroptera Caenidae Tasmanocoenis N	0.81	0.79	0.48	2.10	82.13
Coleoptera Scirtidae shin L	0.59	0.73	0.51	1.96	84.09
Diptera Ceratopogonidae Bezzia L	0.65	0.70	0.55	1.87	85.96
Diptera Chironomidae S.F. Aphroteniiae L	0.66	0.60	0.41	1.61	87.57
Ephemeroptera Leptophlebiidae Ulmerophlebia N	0.54	0.43	0.36	1.15	88.72
Coleoptera Elmidae Austrolimnius A	0.66	0.42	0.34	1.13	89.85
Amphipoda Chiltoniidae Austrochiltonia X	0.65	0.41	0.31	1.09	90.94

Group Mined
Average similarity: 30.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decapoda Atyidae Paratya X	1.74	4.49	0.80	14.49	14.49
Diptera Chironomidae S.F. Chironominae L	2.55	4.33	1.25	13.97	28.46
Diptera Chironomidae S.F. Tanypodinae L	1.66	2.93	1.17	9.45	37.91
Ephemeroptera Baetidae indeterminate genus N	1.85	2.55	0.71	8.24	46.15

Ephemeroptera Leptophlebiidae Koorrnonga N	1.28	2.46	0.79	7.96	54.11
Ephemeroptera Leptophlebiidae indeterminate genus N	1.21	2.23	0.88	7.19	61.29
Hemiptera Notonectidae indeterminate genus N	1.28	1.36	0.43	4.40	65.69
Diptera Chironomidae S.F. Orthocladiinae L	0.96	1.33	0.63	4.30	70.00
Trichoptera Leptoceridae Triplectides L	0.88	1.33	0.55	4.30	74.30
Ephemeroptera Baetidae Centroptilum N	1.63	1.30	0.38	4.21	78.51
Diptera Chironomidae S.F. Aphroteniiae L	1.05	1.07	0.49	3.45	81.96
Coleoptera Scirtidae shin L	0.64	0.59	0.40	1.89	83.85
Trichoptera Trichoptera indeterminate indeterminate genus L	0.78	0.56	0.39	1.82	85.67
Amphipoda Chiltoniidae Austrochiltonia X	0.73	0.45	0.24	1.44	87.11
Oligochaeta Oligochaeta indeterminate unassessed genus X	0.37	0.39	0.27	1.27	88.39
Ephemeroptera Caenidae Tasmanocoenis N	0.52	0.31	0.29	1.02	89.40
Trichoptera Hydroptilidae Hellyethira L	0.39	0.27	0.30	0.87	90.27

Groups Non-mined & Mined
No pairs of groups with samples

Examines Creek groups
(across all Impact groups)
Group Loddon
Average similarity: 42.79

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decapoda Atyidae Paratya X	2.50	7.45	1.91	17.41	17.41
Diptera Chironomidae S.F. Chironominae L	2.64	7.11	1.84	16.61	34.03
Diptera Chironomidae S.F. Orthocladiinae L	2.07	5.79	2.19	13.54	47.57
Diptera Chironomidae S.F. Tanypodinae L	1.87	4.83	1.45	11.28	58.85
Trichoptera Leptoceridae Notalina L	1.52	2.54	0.60	5.93	64.78
Trichoptera Hydroptilidae Hellyethira L	1.02	2.19	0.86	5.11	69.89
Ephemeroptera Baetidae Centroptilum N	1.04	2.06	0.73	4.81	74.70
Coleoptera Elmidae Austrolimnius L	1.24	2.04	0.66	4.77	79.47
Plecoptera Gripopterygidae Leptoperla N	0.92	1.51	0.61	3.53	83.00
Ephemeroptera Leptophlebiidae indeterminate genus N	0.64	0.96	0.54	2.24	85.24
Ephemeroptera Caenidae Tasmanocoenis N	0.76	0.92	0.53	2.15	87.39
Ephemeroptera Leptophlebiidae Koorrnonga N	0.87	0.92	0.38	2.15	89.54
Oligochaeta Oligochaeta indeterminate unassessed genus X	0.76	0.82	0.41	1.92	91.47

Group O'Hares
Average similarity: 32.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Chironominae L	3.55	5.05	1.78	15.32	15.32
Diptera Chironomidae S.F. Tanypodinae L	2.50	4.26	2.03	12.93	28.25
Trichoptera Leptoceridae Triplectides L	2.52	3.52	1.10	10.67	38.92
Diptera Chironomidae S.F. Orthocladiinae L	3.87	3.16	0.78	9.58	48.50
Oligochaeta Oligochaeta indeterminate unassessed genus X	1.91	1.62	0.69	4.91	53.41
Ephemeroptera Leptophlebiidae Koorrnonga N	1.58	1.53	0.71	4.63	58.04
Coleoptera Scirtidae shin L	1.10	1.35	0.79	4.08	62.13
Diptera Ceratopogonidae Bezzia L	1.05	1.21	0.82	3.67	65.79
Decapoda Atyidae Paratya X	1.04	0.89	0.52	2.69	68.48
Ephemeroptera Baetidae Centroptilum N	1.11	0.77	0.43	2.34	70.82
Amphipoda Chiltoniidae Austrochiltonia X	1.25	0.75	0.43	2.27	73.09
Ephemeroptera Leptophlebiidae indeterminate genus N	0.89	0.73	0.54	2.22	75.31
Ephemeroptera Caenidae Tasmanocoenis N	0.85	0.68	0.44	2.05	77.36
Odonata Synlestidae Synlestes N	0.63	0.58	0.54	1.75	79.11
Coleoptera Elmidae Austrolimnius L	0.91	0.54	0.47	1.63	80.74
Diptera Chironomidae S.F. Aphroteniiae L	0.68	0.49	0.43	1.48	82.22
Trichoptera Trichoptera indeterminate indeterminate genus L	0.67	0.37	0.37	1.14	83.36
Trichoptera Hydroptilidae Hellyethira L	0.54	0.37	0.37	1.12	84.47
Hemiptera Notonectidae indeterminate genus N	0.76	0.35	0.25	1.07	85.55
Hemiptera Notonectidae Enithares A	0.48	0.34	0.38	1.04	86.59
Coleoptera Elmidae Austrolimnius A	0.77	0.34	0.34	1.02	87.61
Trichoptera Leptoceridae Notalina L	0.52	0.32	0.38	0.96	88.57
Ephemeroptera Leptophlebiidae Ulmerophlebia N	0.56	0.32	0.31	0.96	89.53
Ephemeroptera Baetidae indeterminate genus N	0.46	0.31	0.33	0.93	90.46

Group Eastern Trib
Average similarity: 33.51

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Decapoda Atyidae Paratya X	2.54	8.52	1.60	25.41	25.41
Ephemeroptera Leptophlebiidae Koorrnonga N	1.90	4.44	1.37	13.24	38.65
Ephemeroptera Leptophlebiidae indeterminate genus N	1.29	3.12	1.12	9.31	47.96
Diptera Chironomidae S.F. Tanypodinae L	1.48	3.11	1.16	9.29	57.25
Diptera Chironomidae S.F. Chironominae L	1.50	2.66	0.89	7.94	65.19

Trichoptera Leptoceridae Triplectides L	1.06	2.29	0.78	6.85	72.03
Diptera Chironomidae S.F. Aphroteniiae L	0.92	1.34	0.56	4.01	76.04
Hemiptera Notonectidae indeterminate genus N	0.86	1.00	0.34	3.00	79.03
Ephemeroptera Baetidae indeterminate genus N	0.73	0.75	0.42	2.23	81.27
Amphipoda Chiltoniidae Austrochiltonia X	1.04	0.74	0.29	2.20	83.47
Trichoptera Trichoptera indeterminate indeterminate genus L	0.88	0.72	0.42	2.16	85.63
Diptera Chironomidae S.F. Orthocladiinae L	0.57	0.58	0.43	1.75	87.38
Coleoptera Scirtidae shin L	0.45	0.55	0.38	1.65	89.03
Odonata Epiproctophora indetermin indeterminate genus N	0.49	0.41	0.32	1.23	90.26

Group Waratah Rivulet
Average similarity: 28.43

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Chironominae L	3.60	5.99	1.94	21.08	21.08
Ephemeroptera Baetidae indeterminate genus N	2.98	4.35	1.09	15.31	36.39
Diptera Chironomidae S.F. Tanypodinae L	1.84	2.74	1.20	9.64	46.03
Ephemeroptera Baetidae Centroptilum N	3.06	2.56	0.57	9.02	55.04
Diptera Chironomidae S.F. Orthocladiinae L	1.35	2.08	0.86	7.32	62.37
Hemiptera Notonectidae indeterminate genus N	1.70	1.72	0.52	6.06	68.42
Ephemeroptera Leptophlebiidae indeterminate genus N	1.13	1.33	0.71	4.69	73.11
Diptera Chironomidae S.F. Aphroteniiae L	1.17	0.79	0.41	2.79	75.90
Oligochaeta Oligochaeta indeterminate unassessed genus X	0.66	0.77	0.39	2.69	78.59
Coleoptera Scirtidae shin L	0.82	0.62	0.42	2.17	80.77
Ephemeroptera Leptophlebiidae Koorrnonga N	0.67	0.49	0.42	1.74	82.51
Ephemeroptera Caenidae Tasmanocoenis N	0.72	0.48	0.37	1.70	84.21
Decapoda Atyidae Paratya X	0.95	0.46	0.30	1.63	85.83
Trichoptera Trichoptera indeterminate indeterminate genus L	0.67	0.40	0.37	1.41	87.25
Trichoptera Leptoceridae Triplectides L	0.70	0.37	0.33	1.30	88.55
Diptera Ceratopogonidae Bezzia L	0.39	0.29	0.32	1.00	89.55
Hemiptera Notonectidae Enithares A	0.42	0.26	0.27	0.92	90.47

Groups Loddon & O'Hares
Average dissimilarity = 70.25

Edge BEST
Biota and/or Environment matching

Data worksheet
Name: Data12
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BVSTEP
Termination criteria:
rho > 0.95
delta rho < 0.001
Use fixed starting variables
Starting selection:
Resemblance:
Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 DFS
2 Bicarbonate
3 Log Ca
4 Log Na
5 Log Al
6 Iron
7 Manganese
8 Chloride
9 Sulphate
10 Log Be
11 Li
12 Log Mo

13 DO%
14 DO mg/L
15 Temp
16 Cond us/cm
17 pH
18 Turb
19 Rainfall

Steps for global test:

No.Vars	Corr.	Selections
1	0.246	7
2	0.268	7,18
3	0.285	7,18,19

Global Test
Sample statistic (Rho): 0.285
Significance level of sample statistic: 1%
Number of permutations: 99 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

Best results

Multiple	No.Vars	Corr.	Selections
1	3	0.285	7,18,19

Outputs
Plot: Graph8

Riffle SIMPER
Similarity Percentages - species contributions

Two-Way Analysis

Data worksheet
Name: Riffle SqRt
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90.00%

Factor Groups

Sample	Impact	Creek
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR1	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR2	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
LR3	Non-mined	Loddon
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares
OH1	Non-mined	O'Hares

OH1	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH2	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
OH3	Non-mined	O'Hares
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR1	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR2	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR3	Mined	Eastern Trib
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR4	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR5	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet
WR6	Mined	Waratah Rivulet

Examines Impact groups
(across all Creek groups)
Group Non-mined
Average similarity: 45.79

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Orthocladiinae L	7.30	8.86	1.81	19.34	19.34
Diptera Chironomidae S.F. Chironominae L	5.87	8.37	2.74	18.29	37.63
Trichoptera Hydropsychidae Asmicridea L	4.56	4.13	0.78	9.02	46.65

Coleoptera Elmidae Austrolimnius L	2.83	2.68	0.95	5.85	52.49
Diptera Chironomidae S.F. Tanypodinae L	1.84	1.99	0.87	4.35	56.85
Coleoptera Elmidae Kingolus A	1.98	1.87	0.78	4.08	60.92
Coleoptera Elmidae Kingolus L	1.76	1.70	0.72	3.71	64.63
Oligochaeta Oligochaeta indeterminate unassessed genus X	2.04	1.57	0.61	3.42	68.06
Plecoptera Gripopterygidae Dinotoperla N	1.53	1.28	0.59	2.80	70.85
Diptera Ceratopogonidae Bezzia L	1.37	1.25	0.75	2.72	73.57
Ephemeroptera Baetidae Offadens N	1.52	1.23	0.45	2.69	76.26
Coleoptera Elmidae Austrolimnius A	2.10	1.21	0.51	2.65	78.91
Diptera Tipulidae Antocha L	1.60	1.20	0.63	2.63	81.54
Diptera Simuliidae Austrosimulium L	1.77	0.97	0.58	2.13	83.67
Trichoptera Trichoptera indeterminate indeterminate genus L	1.49	0.83	0.42	1.81	85.48
Trichoptera Conoesucidae Hampa L	1.01	0.69	0.45	1.52	86.99
Diptera Empididae alpha L	0.97	0.67	0.58	1.46	88.45
Trichoptera Helicophidae Alloecella L	1.04	0.66	0.58	1.45	89.90
Trichoptera Hydrobiosidae indeterminate genus L	0.80	0.55	0.54	1.20	91.10

Group Mined
Average similarity: 38.20

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Orthocladiinae L	4.72	7.51	1.17	19.67	19.67
Diptera Chironomidae S.F. Chironominae L	4.21	7.40	1.37	19.38	39.05
Ephemeroptera Baetidae Offadens N	3.27	4.91	0.90	12.86	51.91
Diptera Tipulidae Antocha L	2.01	2.75	0.82	7.20	59.11
Coleoptera Elmidae Kingolus L	1.85	2.15	0.64	5.61	64.73
Coleoptera Elmidae Kingolus A	1.33	1.43	0.66	3.74	68.47
Diptera Simuliidae Austrosimulium L	0.99	1.12	0.44	2.94	71.41
Diptera Chironomidae S.F. Podonominae L	0.87	1.12	0.60	2.93	74.34
Diptera Chironomidae S.F. Diamesinae L	0.76	0.94	0.34	2.47	76.81
Diptera Ceratopogonidae Dasyhelea L	1.20	0.90	0.48	2.36	79.17
Trichoptera Hydropsychidae Asmicridea L	1.11	0.82	0.46	2.15	81.32
Ephemeroptera Baetidae indeterminate genus N	0.84	0.79	0.45	2.06	83.38
Plecoptera Gripopterygidae Dinotoperla N	0.87	0.76	0.38	1.98	85.36
Diptera Simuliidae indeterminate genus L	0.56	0.69	0.20	1.80	87.16
Trichoptera Trichoptera indeterminate indeterminate genus L	0.87	0.61	0.40	1.61	88.77
Coleoptera Elmidae Austrolimnius A	0.69	0.58	0.39	1.53	90.30

Groups Non-mined & Mined
No pairs of groups with samples

Examines Creek groups
(across all Impact groups)
Group Loddon
Average similarity: 48.91

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Chironominae L	5.66	9.47	2.98	19.36	19.36
Diptera Chironomidae S.F. Orthocladiinae L	4.53	7.12	1.97	14.57	33.93
Trichoptera Hydropsychidae Asmicridea L	5.84	6.57	1.08	13.42	47.35
Coleoptera Elmidae Austrolimnius L	3.01	3.63	1.05	7.42	54.77
Diptera Chironomidae S.F. Tanypodinae L	2.38	3.11	1.19	6.36	61.14
Coleoptera Elmidae Kingolus L	2.70	2.95	1.05	6.03	67.17
Coleoptera Elmidae Kingolus A	2.58	2.94	1.03	6.01	73.18
Coleoptera Elmidae Austrolimnius A	2.69	1.95	0.64	3.99	77.17
Plecoptera Gripopterygidae Dinotoperla N	1.87	1.93	0.72	3.95	81.12
Diptera Ceratopogonidae Bezzia L	1.46	1.34	0.64	2.74	83.86
Trichoptera Helicophidae Alloecella L	1.03	0.99	0.78	2.03	85.89
Diptera Simuliidae Austrosimulium L	1.06	0.91	0.61	1.86	87.76
Diptera Tipulidae Antocha L	1.12	0.73	0.48	1.49	89.24
Diptera Empididae alpha L	0.94	0.69	0.49	1.40	90.65

Group O'Hares
Average similarity: 42.92

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Orthocladiinae L	9.95	10.44	1.95	24.33	24.33
Diptera Chironomidae S.F. Chironominae L	6.07	7.37	2.87	17.16	41.50
Oligochaeta Oligochaeta indeterminate unassessed genus X	3.36	2.59	0.84	6.03	47.53
Ephemeroptera Baetidae Offadens N	2.84	2.35	0.68	5.48	53.00
Trichoptera Hydropsychidae Asmicridea L	3.34	1.89	0.60	4.41	57.42
Coleoptera Elmidae Austrolimnius L	2.65	1.80	1.09	4.20	61.62
Diptera Tipulidae Antocha L	2.06	1.64	0.78	3.83	65.44
Trichoptera Trichoptera indeterminate indeterminate genus L	2.59	1.49	0.60	3.48	68.93
Trichoptera Conoesucidae Hampa L	1.97	1.33	0.69	3.10	72.03

Diptera Ceratopogonidae Bezzia L	1.28	1.16	1.03	2.70	74.73
Diptera Simuliidae Austrosimulium L	2.45	1.03	0.56	2.40	77.13
Diptera Chironomidae S.F. Tanypodinae L	1.32	0.96	0.78	2.25	79.37
Coleoptera Elmidae Kingolus A	1.40	0.88	0.72	2.06	81.43
Diptera Chironomidae S.F. Podonominae L	1.75	0.86	0.43	2.01	83.44
Plecoptera Gripopterygidae Dinotoperla N	1.20	0.68	0.53	1.59	85.03
Diptera Empididae alpha L	1.00	0.65	0.75	1.52	86.55
Trichoptera Hydrobiosidae Ulmerochorema L	0.73	0.56	0.61	1.30	87.86
Coleoptera Elmidae Kingolus L	0.86	0.55	0.67	1.29	89.15
Trichoptera Hydrobiosidae indeterminate genus L	0.87	0.55	0.58	1.27	90.42

Group Eastern Trib
Average similarity: 37.74

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Orthocladiinae L	4.54	6.06	0.92	16.06	16.06
Ephemeroptera Baetidae Offadens N	4.04	5.45	0.92	14.44	30.49
Diptera Chironomidae S.F. Chironominae L	2.76	4.61	1.36	12.21	42.71
Coleoptera Elmidae Kingolus L	2.82	3.86	1.01	10.23	52.93
Diptera Tipulidae Antocha L	2.08	2.59	0.83	6.87	59.80
Coleoptera Elmidae Kingolus A	1.46	2.29	0.98	6.07	65.88
Plecoptera Gripopterygidae Dinotoperla N	1.20	1.37	0.58	3.64	69.52
Diptera Ceratopogonidae Dasyhelea L	1.32	1.36	0.65	3.61	73.13
Trichoptera Hydropsychidae Asmicridea L	1.52	1.20	0.53	3.18	76.31
Coleoptera Elmidae Austrolimnius A	1.17	1.11	0.58	2.94	79.26
Ephemeroptera Baetidae indeterminate genus N	1.08	1.05	0.54	2.77	82.03
Diptera Simuliidae Austrosimulium L	1.05	1.04	0.51	2.75	84.78
Coleoptera Elmidae Austrolimnius L	1.61	0.92	0.38	2.43	87.21
Diptera Simuliidae indeterminate genus L	0.62	0.72	0.16	1.90	89.10
Diptera Chironomidae S.F. Podonominae L	0.86	0.69	0.41	1.84	90.94

Group Waratah Rivulet
Average similarity: 38.66

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Diptera Chironomidae S.F. Chironominae L	5.65	10.20	1.82	26.38	26.38
Diptera Chironomidae S.F. Orthocladiinae L	4.91	8.97	1.52	23.19	49.57
Ephemeroptera Baetidae Offadens N	2.51	4.38	0.91	11.32	60.89
Diptera Tipulidae Antocha L	1.95	2.91	0.81	7.53	68.42
Diptera Chironomidae S.F. Diamesinae L	1.51	1.88	0.52	4.87	73.29
Diptera Chironomidae S.F. Podonominae L	0.88	1.55	0.78	4.00	77.29
Diptera Simuliidae Austrosimulium L	0.92	1.21	0.40	3.13	80.42
Diptera Simuliidae indeterminate genus L	0.50	0.66	0.39	1.71	82.14
Diptera Empididae alpha L	0.79	0.65	0.45	1.69	83.82
Trichoptera Trichoptera indeterminate indeterminate genus L	1.14	0.58	0.34	1.49	85.32
Coleoptera Elmidae Kingolus A	1.19	0.57	0.35	1.47	86.78
Diptera Ceratopogonidae Bezzia L	0.58	0.55	0.40	1.43	88.21
Oligochaeta Oligochaeta indeterminate unassessed genus X	0.74	0.54	0.36	1.39	89.60
Ephemeroptera Baetidae indeterminate genus N	0.59	0.53	0.35	1.36	90.96

Riffle BEST
Biota and/or Environment matching

Data worksheet
Name: Data12
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: Resem3
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BVSTEP
Termination criteria:
rho > 0.95
delta rho < 0.001
Use fixed starting variables
Starting selection:
Resemblance:

Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 DFS
2 Bicarbonate
3 Log Ca
4 Log Na
5 Log Al
6 Iron
7 Manganese
8 Chloride
9 Sulphate
10 Log Be
11 Li
12 Log Mo
13 DO%
14 DO mg/L
15 Temp
16 Cond us/cm
17 pH
18 Turb
19 Rainfall

Steps for global test:

No.Vars	Corr.	Selections
1	0.361	2
2	0.395	2,9
3	0.403	2,9,19
4	0.417	2,9,15,19

Global Test
Sample statistic (Rho): 0.417
Significance level of sample statistic: 1%
Number of permutations: 99 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

Best results

Multiple	No.Vars	Corr.	Selections
1	4	0.417	2,9,15,19

Outputs
Plot: Graph9

Riffle Trichoptera BEST
Biota and/or Environment matching

Data worksheet
Name: Data12
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: Trichoptera for BEST
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BVSTEP
Termination criteria:
rho > 0.95
delta rho < 0.001
Use fixed starting variables
Starting selection:
Resemblance:
Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 DFS
2 Bicarbonate
3 Log Ca

4 Log Na
5 Log Al
6 Iron
7 Manganese
8 Chloride
9 Sulphate
10 Log Be
11 Li
12 Log Mo
13 DO%
14 DO mg/L
15 Temp
16 Cond us/cm
17 pH
18 Turb
19 Rainfall

Steps for global test:

No.Vars	Corr.	Selections
1	0.288	7
2	0.320	7,14

Global Test
Sample statistic (Rho): 0.32
Significance level of sample statistic: 1%
Number of permutations: 99 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

Best results

Multiple	No.Vars	Corr.	Selections
1	2	0.320	7,14

Outputs
Plot: Graph8

Appendix 8.

RAW Diatom data

Client Sample Id	GOMPHONE_CCNT	ENCYONEM_CCNT	DIATOMELLA_CCNT	NAVICULOID_CCNT	EUNOTIA_CCNT	SYNEDRA_CCNT	DIATOMA_CCNT	TABELLAR_CCNT	NITZSCHI_CCNT	ACHNANTM_CCNT	NAVICULA_CCNT	COCCONEI_CCNT	PINNULAR_CCNT	SURIRELL_CCNT	AMPHORA_CCNT
WR1-R1	741	148	519	519											
WR1-R2	2000		2852	2445											
WR1-R3	356		71	214	71	35									
WR2-1	3992	1426	214	143			285	35							
WR2-2	5779	20862	148	741	148		148		148						
WR2-3	998	4490				71	71			71	214				
WR3-1	751		888				68			751		68			
WR3-2	2404	1502	2322	12155		656	2131			819			546	35	
WR3-3	1015	68	203	406		17				338					
WR4-1	424			212		71			71	565					
WR4-2	478	410		410						683	137			17	
WR4-3	2352	2922			35	71			71						
WR5-1	762	423		7078					8636	339					
WR5-2	68	271		204	136	68		68		136			204		
WR5-3		70		210		280	335	70		210					
WRr-1	296			222	74										
WRr-2				489											
WRr-3	71														
WR6-1	136	672		1194		68		68		821					68
WR6-2	1141	296	74	667		74				570					
WR6-3	978	445		815	148	222	18	445		74					
L1-1	165511	7828	373	22739				2609						36	
L1-2	3630			2593	74										
L1-3	14061	148		20447	1778	296								18	
L2-1	10490			14965	2223					445				36	
L2-2	3596			25287	3260										
L2-3	4741			21336	790										
L3-1	18906	198		25485	198				18						
L3-2	4736	271		16778											
L3-3	10283	541		8840											
OH1-1	13434			177208	2845	198		4267		395					
OH1-2	19361	395		171874	3260			5532							
OH1-3	8175	372	372	224063	2973			5797		372					
OH2-1	2979	71		3564	1140			998		71					
OH2-2	4205	855		3421	356	356			143	2274				18	
OH2-3	7841	927	214	1996	214			71		1639					
OH3-1	7451	85	9567		508					1185					
OH3-2	2771	3704	3260	4149	652	1830		985	667	6668				73	
OH3-3	279		348	2299	488	2020		634		418					
HSref-1	136			522	136										
HSref-2	148					18									
HSref-3	74			55										18	

Appendix 9.

PEMANOVA, SIMPER and BEST Diatom data

Diatom PERMANOVA
Permutational MANOVA

Resemblance worksheet
Name: Resem2
Data type: Similarity
Selection: All
Transform: Square root
Resemblance: S17 Bray Curtis similarity

Sums of squares type: Type III (partial)
Fixed effects sum to zero for mixed terms
Permutation method: Permutation of residuals under a reduced model
Number of permutations: 9999

Factors

Name	Type	Levels
Impact	Fixed	2
Creek	Random	4
Position'	Random	3

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
Impact	1	4095.2	4095.2	32.75	0.3299	3	0.0168
Creek(Impact)	2	250.09	125.05	0.51749	0.7051	8883	0.6527
Position'(Creek(Impact))	8	1933.1	241.64	1.9525	0.0716	9925	0.0806
Res	24	2970.2	123.76				
Total	35	9248.6					

Details of the expected mean squares (EMS) for the model

Source	EMS
Impact	1*V(Res) + 3*V(Position'(Creek(Impact))) + 9*V(Creek(Impact)) + 18*S(Impact)
Creek(Impact)	1*V(Res) + 3*V(Position'(Creek(Impact))) + 9*V(Creek(Impact))
Position'(Creek(Impact))	1*V(Res) + 3*V(Position'(Creek(Impact)))
Res	1*V(Res)

Construction of Pseudo-F ratio(s) from mean squares

Source	Numerator	Denominator	Num.df	Den.df
Impact	1*Impact	1*Creek(Impact)	1	2
Creek(Impact)	1*Creek(Impact)	1*Position'(Creek(Impact))	2	8
Position'(Creek(Impact))	1*Position'(Creek(Impact))	1*Res	8	24

Estimates of components of variation

Source	Estimate	Sq.root
S(Impact)	220.57	14.851
V(Creek(Impact))	-12.955	-3.5992
V(Position'(Creek(Impact)))	39.292	6.2684
V(Res)	123.76	11.125

Diatom SIMPER
Similarity Percentages - species contributions

Two-Way Analysis

Data worksheet
Name: Data1
Data type: Abundance
Sample selection: All
Variable selection: All

Parameters
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 100.00%

Factor Groups

Sample	Impact	Creek
WR1-R1	Mined	Eastern Trib
WR1-R2	Mined	Eastern Trib
WR1-R3	Mined	Eastern Trib
WR2-1	Mined	Eastern Trib
WR2-2	Mined	Eastern Trib
WR2-3	Mined	Eastern Trib
WR3-1	Mined	Eastern Trib
WR3-2	Mined	Eastern Trib
WR3-3	Mined	Eastern Trib
WR4-1	Mined	Waratah Riv
WR4-2	Mined	Waratah Riv
WR4-3	Mined	Waratah Riv
WR5-1	Mined	Waratah Riv
WR5-2	Mined	Waratah Riv
WR5-3	Mined	Waratah Riv
WR6-1	Mined	Waratah Riv
WR6-2	Mined	Waratah Riv
WR6-3	Mined	Waratah Riv
L1-1	Non-mined	Loddon
L1-2	Non-mined	Loddon
L1-3	Non-mined	Loddon
L2-1	Non-mined	Loddon
L2-2	Non-mined	Loddon
L2-3	Non-mined	Loddon
L3-1	Non-mined	Loddon
L3-2	Non-mined	Loddon
L3-3	Non-mined	Loddon
OH1-1	Non-mined	O'Hares
OH1-2	Non-mined	O'Hares
OH1-3	Non-mined	O'Hares
OH2-1	Non-mined	O'Hares
OH2-2	Non-mined	O'Hares
OH2-3	Non-mined	O'Hares
OH3-1	Non-mined	O'Hares
OH3-2	Non-mined	O'Hares
OH3-3	Non-mined	O'Hares

Examines Impact groups
(across all Creek groups)
Group Mined
Average similarity: 47.22

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
GOMPHONE_CCNT	31.86	15.67	1.83	33.19	33.19
NAVICULOID_CCNT	27.39	9.43	1.26	19.96	53.15
ENCYONEM_CCNT	27.35	7.44	1.00	15.75	68.90
ACHNANTM_CCNT	13.25	5.87	0.78	12.44	81.34
DIATOMELLA_CCNT	11.79	4.16	0.66	8.81	90.14
SYNEDRA_CCNT	6.54	2.68	0.71	5.68	95.83
DIATOMA_CCNT	6.36	0.74	0.40	1.57	97.40
TABELLAR_CCNT	2.88	0.64	0.30	1.34	98.74
EUNOTIA_CCNT	2.80	0.34	0.23	0.72	99.46
NITZSCHI_CCNT	6.77	0.25	0.20	0.54	100.00

Group Non-mined
Average similarity: 58.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%

NAVICULOID_CCNT	152.19	25.85	1.50	44.27	44.27
GOMPHONE_CCNT	101.87	20.45	2.21	35.02	79.28
EUNOTIA_CCNT	27.75	4.61	1.19	7.90	87.18
ACHNANTM_CCNT	16.30	2.46	0.61	4.21	91.39
ENCYONEM_CCNT	18.43	1.80	0.71	3.08	94.47
TABELLAR_CCNT	20.19	1.78	0.55	3.04	97.51
DIATOMELLA_CCNT	12.60	0.85	0.33	1.46	98.97
SYNEDRA_CCNT	7.66	0.49	0.25	0.85	99.81
SURIRELL_CCNT	1.61	0.06	0.24	0.11	99.92
NITZSCHI_CCNT	2.33	0.05	0.12	0.08	100.00

Groups Mined & Non-mined
No pairs of groups with samples

Examines Creek groups
(across all Impact groups)
Group Eastern Trib
Average similarity: 44.48

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
GOMPHONE_CCNT	41.10	20.41	3.37	45.88	45.88
DIATOMELLA_CCNT	22.63	8.32	1.24	18.71	64.58
NAVICULOID_CCNT	28.49	7.13	0.98	16.03	80.61
ENCYONEM_CCNT	34.26	4.95	0.64	11.12	91.74
ACHNANTM_CCNT	9.20	1.54	0.38	3.45	95.19
DIATOMA_CCNT	10.21	1.38	0.58	3.09	98.28
SYNEDRA_CCNT	4.90	0.63	0.40	1.42	99.70
EUNOTIA_CCNT	2.29	0.13	0.17	0.30	100.00
TABELLAR_CCNT	0.66	0.00	#######	0.00	100.00
NITZSCHI_CCNT	1.35	0.00	#######	0.00	100.00
NAVICULA_CCNT	1.63	0.00	#######	0.00	100.00
COCCONEI_CCNT	0.92	0.00	#######	0.00	100.00
PINNULAR_CCNT	2.60	0.00	#######	0.00	100.00
SURIRELL_CCNT	0.66	0.00	#######	0.00	100.00
AMPHORA_CCNT	0.00	0.00	#######	0.00	100.00

Group Waratah Riv
Average similarity: 49.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
NAVICULOID_CCNT	26.29	11.73	1.67	23.47	23.47
GOMPHONE_CCNT	22.61	10.94	1.34	21.89	45.36
ACHNANTM_CCNT	17.29	10.21	1.31	20.43	65.79
ENCYONEM_CCNT	20.44	9.92	1.57	19.86	85.65
SYNEDRA_CCNT	8.18	4.74	1.11	9.48	95.13
TABELLAR_CCNT	5.11	1.27	0.44	2.54	97.68
EUNOTIA_CCNT	3.30	0.55	0.28	1.10	98.78
NITZSCHI_CCNT	12.20	0.51	0.29	1.01	99.79
DIATOMA_CCNT	2.51	0.11	0.17	0.21	100.00

Group Loddon
Average similarity: 67.63

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
NAVICULOID_CCNT	128.37	36.81	3.24	54.42	54.42
GOMPHONE_CCNT	124.96	26.37	3.78	38.99	93.41
EUNOTIA_CCNT	21.91	3.15	0.67	4.65	98.07
ENCYONEM_CCNT	17.16	1.22	0.57	1.80	99.86
SURIRELL_CCNT	1.80	0.09	0.29	0.14	100.00

Group O'Hares
Average similarity: 49.17

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
NAVICULOID_CCNT	176.01	14.90	0.99	30.30	30.30
GOMPHONE_CCNT	78.79	14.53	2.01	29.55	59.85
EUNOTIA_CCNT	33.60	6.08	2.92	12.36	72.21
ACHNANTM_CCNT	30.25	4.92	1.08	10.00	82.21
TABELLAR_CCNT	34.71	3.55	0.93	7.23	89.43
ENCYONEM_CCNT	19.71	2.38	0.85	4.84	94.27
DIATOMELLA_CCNT	23.05	1.70	0.50	3.46	97.73
SYNEDRA_CCNT	13.41	0.99	0.36	2.01	99.74
NITZSCHI_CCNT	4.20	0.09	0.17	0.19	99.93
SURIRELL_CCNT	1.42	0.03	0.17	0.07	100.00

BEST
Biota and/or Environment matching

Data worksheet
Name: Data15
Data type: Environmental
Sample selection: All
Variable selection: All

Resemblance worksheet
Name: Resem5
Data type: Similarity
Selection: All

Parameters
Rank correlation method: Spearman
Method: BVSTEP
Termination criteria:
rho > 0.95
delta rho < 0.001
Use fixed starting variables
Starting selection:
Resemblance:
Analyse between: Samples
Resemblance measure: D1 Euclidean distance

Variables
1 Bicarbonate
2 Barium
3 Log Ca
4 Log Na
5 Log Al
6 Iron
7 Manganese
8 Chloride
9 Sulphate
10 Log Be
11 Li
12 Log Mo
13 DO%
14 DO mg/L
15 Temp
16 Cond us/cm
17 pH
18 Turb
19 Rainfall

Steps for global test:

No.Vars	Corr.	Selections
1	0.406	1
2	0.456	1,13
3	0.497	1,13,17
4	0.518	1,13,17,18
5	0.522	1,8,13,17,18
4	0.530	8,13,17,18

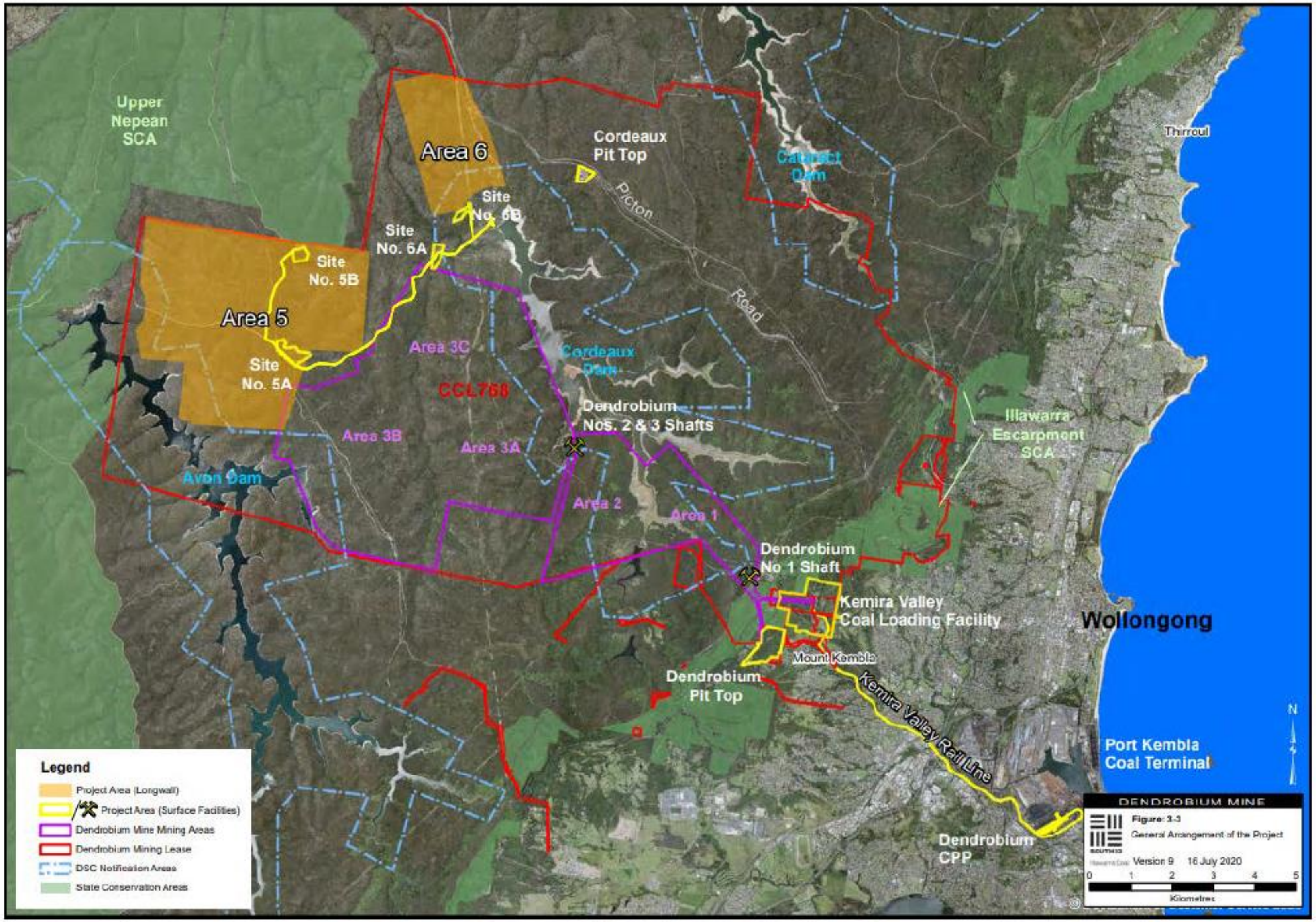
Global Test
Sample statistic (Rho): 0.53
Significance level of sample statistic: 1%
Number of permutations: 99 (Random sample)
Number of permuted statistics greater than or equal to Rho: 0

Best results

Multiple	No.Vars	Corr.	Selections
1	4	0.530	8,13,17,18

Outputs
Plot: Graph7

Figure 2 - Local Context & General Arrangement (Source: Amendment Report)



This map shows the spatial extent (Areas 5 & 6) of the Applicant's previous Significant State Development (**SSD**) application (Dendrobium Extension Project, SSD 8194), refused by the Independent Planning Commission.