Newcrest Mining Limited

Cadia Valley Operations - AEMP
Annual Report 2019-2020

August 2020

Executive summary

The Newcrest Cadia Valley Operations (CVO) environmental monitoring program includes an Aquatic Ecosystem Monitoring Project (AEMP) implemented biannually since spring 2006. This AEMP focusses on the assessment of macroinvertebrates, fish, and aquatic habitat condition potentially impacted by mine operations, within and surrounding the CVO mine lease area (MLA). This report presents the monitoring data collected during the spring 2019 and autumn 2020 monitoring periods. Major findings and recommendations in this report are:

- There was high rainfall variation with spring below and autumn above the long-term average. Downstream of Cadiangullong Dam flow generally remained low from June to late September, then increased and remained relatively constant between 2.1 and 5.6 ML/day due to a combination of releases and natural flow events until mid-February.
- Disturbances to riparian zone vegetation and broader catchment scale land-use are likely to be impacting on aquatic ecosystem health regardless of mining activities.
- There was no evidence to suggest mining activities have impacted on water quality of Cadiangullong Creek or Rodd's Creek.
- As found in previous monitoring periods, there was evidence of increased copper in the sediments of Cadiangullong Creek downstream of the mine at CC2 and CC3 where concentrations exceeded the upper ANZG (2018) guideline. Due to the geomorphology of CC2, the pool at this site appears to act as sink for copper.
  - Sediment transport from CC2 and CC3 with copper bound to it may occur during higher flow events and appears to be dependent on a) the connectivity between CC2 and downstream reaches, b) the frequency and size of the high flow events, and c) the size of the sediment particles.
  - Despite elevated concentrations at CC2 and CC3, copper was found to dissipate further downstream at CC4 and during the 2019-20 monitoring period, concentrations at CC4 were lower than 2018-19.
  - Although copper concentrations at CC4 were higher than upstream of the mine, the dissipation downstream reduces potential ecological risks with conditions no longer exceeding the upper ANZG (2018) guideline.
- Macroinvertebrate communities of all waterways are potentially impacted by multiple disturbances irrespective of mine operations including high salinity or nutrient levels, agricultural pollution, or the downstream impacts of dams.
- There was some evidence sites CC2 and CC3 were less healthy than other sites on Cadiangullong Creek or reference sites. It is likely habitat conditions are more influential on macroinvertebrate community health than water or sediment quality.
- Sediment analytes were not found to be a major contributor the macroinvertebrate health. This includes the relatively high copper concentrations at CC2 and CC3.
- A relatively healthy community fish dominated by the native Mountain Galaxias (*Galaxias olidus*) remains distributed throughout Cadiangullong Creek, along with Flyers Creek and Swallow Creek. Spring recruitment of juveniles indicates a self-sustaining population with adequate recruitment.

Recommendations

- The AEMP should be maintained (and perhaps enhanced) during future non-release periods to provide information on how the aquatic ecosystem is performing and coping with river flows not supplemented with releases.
- Determine the contribution of groundwater to base flow in Cadiangullong Creek to support future cease to release applications for CVO.
- Continue monitoring sediment as a means to investigate the role of metals in waterway health and undertake a long-term analyses of correlations between sediment analytes and macroinvertebrates.
- Examine source of contaminants such as copper using 2D sediment modelling or the tracking of sediments through the use of stable isotopes.
- Consider use of environmental DNA (eDNA) to assess the distribution of fish populations as an ethical cost effective method.

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1. Introduction

1.1 Background

Cadia Valley Operations (CVO) is the largest gold and copper producer in New South Wales (NSW) and is one of Australia's largest gold mining operations. It is located approximately 25 km from the city of Orange in central west NSW and is 250 km west of Sydney. CVO is 100% owned by Newcrest Pty Ltd (Newcrest).

The CVO mine lease area (MLA) and associated land holdings cover over 9000 ha and current operations include the underground mining of copper and gold at 'Cadia East' and an ore processing facility. The Cadia Hill open pit mine ceased operation and has been in a state of care and maintenance since July 2012.

The key activities, both currently and historically, carried out at CVO include:

- Underground block and panel caving mining of copper and gold currently at Cadia East and historically at Ridgeway
- Open pit mining of copper and gold at Cadia Hill – ceased in 2012 now in care and maintenance phase
- Processing of ores
- Waste rock storage
- Tailing storage
- Water storage in Cadiangullong Dam and Rodd's Creek Dam

As part of the Newcrest CVO environmental monitoring program, an Aquatic Ecosystem Monitoring Project (AEMP) is implemented on a biannual basis (autumn and spring). Commencing in spring 2006, this AEMP has focused on the assessment of macroinvertebrate and fish populations, and aquatic habitat condition of streams potentially impacted by mine operations within and surrounding the CVO MLA. GHD Pty Ltd (GHD) was commissioned to conduct the most recent monitoring events for the AEMP from 21 to 24 October 2019 (spring) and 9 to 12 April 2020 (autumn).

1.2 Scope and limitations

This report details the AEMP and documents the field sampling conducted by GHD in spring 2019 and autumn 2020. It describes the methodology, results for the various components of the monitoring program, and discusses these in relation to various assessment criteria (where applicable) and in the context of the mining operation.

This report has been prepared by GHD for Newcrest Pty Ltd and may only be used and relied on by Newcrest Pty Ltd for the purpose agreed between GHD and Newcrest Pty Ltd. GHD otherwise disclaims responsibility to any person other than Newcrest Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible. The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points, and on conditions encountered and information reviewed at the date of preparation of the report. Site conditions at other parts of the mine may be different from the site conditions found at the specific sample points. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared. Investigations undertaken in respect of this report are constrained by the particular site conditions. As a result, not all relevant site features and conditions may have been identified in this report. Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

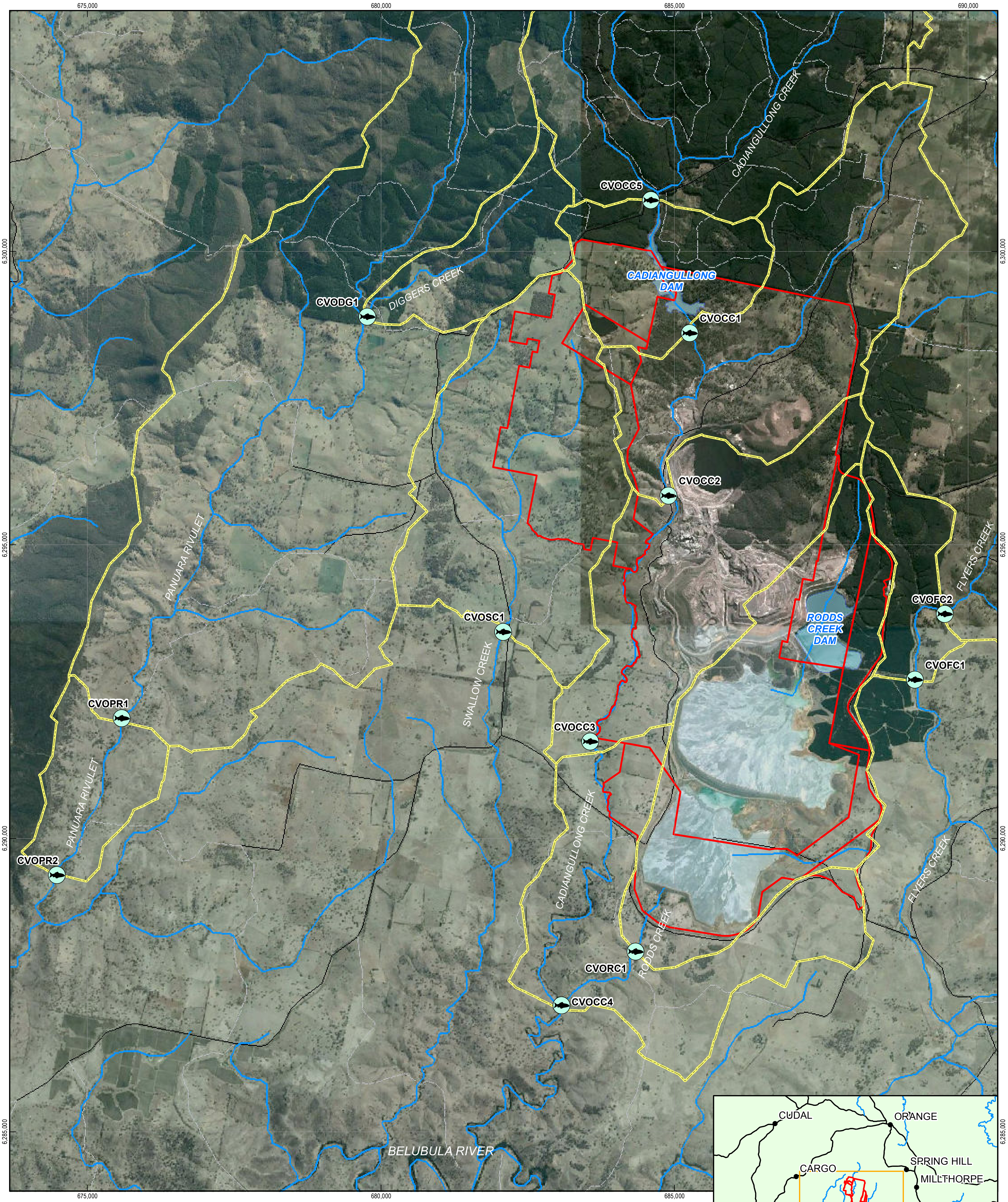
1.3 Rationale for using biological indicators

Aquatic macroinvertebrates are widely accepted and used for biological assessment of rivers and streams. The use of macroinvertebrates in ecosystem disturbance studies stems from their high abundance and diversity, sensitivity to changes in water quality, flow regime and habitat conditions, ease of sampling, a good understanding of their taxonomy and ecological requirements, and an ability to detect long-term impacts (DNR, 2001). The successful application of macroinvertebrates for biological assessment in the mining industry has been demonstrated both within Australia and overseas (Brycroft *et al.*, 1982; Dudka & Adriano, 1997; Norris *et al.*, 1982; Faith *et al.*, 1995; Humphrey *et al.*, 1995). Traditionally, biological indices such as diversity and pollution indices have been used to determine the level of impact (Garcia-Criado *et al.*, 1999).

Fish have been widely used as indicators of water quality throughout the world and were the basis for the North American Index of Biological Integrity (IBI) that has been modified for use in temporary streams and Australian inland rivers. The quantitative monitoring of fish has been applied successfully to the assessment of water quality impacts in temporary waters in Australia. Previous studies of fish populations within streams in the CVO area (Bauer, 1995; Goldney, 2000; Ecowise Environmental, 2007, 2008; ALS, 2010, 2011; GHD, 2012 to 2018) have identified the occurrence of five species; only one of which, *Galaxias olidus* (Mountain Galaxias), is native to the region. The other four exotic species recorded in past studies include Redfin Perch (*Perca fluviatilis),* Eastern Gambusia (*Gambusia holbrooki*), Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*).

1.4 Study area

Cadiangullong Creek is the main focus of the AEMP as it runs in a southerly direction directly through the mine, and is therefore susceptible to impacts from mining operations (Figure 1). Cadiangullong Dam, a key water supply for mining facilities and environmental flow releases, is located upstream of the main CVO mining facilities. A 2.4 km diversion, excavated from igneous rock, was created around open cut mining operations to allow for continuation of water supply to downstream reaches of Cadiangullong Creek. Cadiangullong Creek flows south into the Belubula River, approximately 14 km downstream of the CVO southern lease boundary. Flyers Creek, Swallow Creek, Digger’s Creek, Panuara Rivulet and Rodd’s Creek are monitored in the AEMP and also flow into the Belubula River.



LEGEND

- Aquatic Ecosystem Monitoring Site
- Sub-Catchment Boundary
- Cadia Valley Operations MLA
- River/Creek
- Water Storage/Reservoir
- Road
- Track

Paper Size A3

0 0.5 1 1.5 2 2.5

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Newcrest Pty Ltd
Cadia Valley Operations

Job Number 23-15367
Revision A
Date 12 Jun 2015

Aquatic Ecosystem Monitoring Project Sampling Locations

Figure 1

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Smith Street Parramatta NSW Australia **T** 61 2 8898 8800 **F** 61 2 8898 8810 **E** parmail@ghd.com **W** www.ghd.com

Data source: GHD, CVOAquatic Ecosystem Monitoring Sites/CVOAESITES, May2015, CVO Mine Lease Boundary/CVOMLA, NewcrestPtyLtd/ Cadia Water Storages, Geoscience Australia/Australia 250K/WATERCOURSELINES. Created by:atdickson

1.5 Monitoring locations

Twelve sites were monitored in the AEMP during spring 2019 and autumn 2020 with site locations enabling comparisons of different treatments (Table 1). Five sites were located on Cadiangullong Creek (CC1 to CC5), the main waterway flowing through the CVO MLA (Plate 1). One site was located on Swallow Creek (SC1) and two sites on Panuara Rivulet (PR1 and PR2) to the west of the MLA (Plate 2). One site was also located on Rodd's Creek (RC1) and Diggers Creek (DG1) (Plate 2). Two sites were located on Flyers Creek (FC1 and FC2) to the east of CVO (Plate 3).

Table 1 Monitoring sites and their purpose in the monitoring design

Waterway	Site Code	Site treatment
Cadiangullong Creek	CC5	Upstream
	CC1	Upstream
	CC2	On-site
	CC3	Downstream
	CC4	Downstream
Flyers Creek	FC2	Reference
	FC1	Reference
Panuara Rivulet	PR1	Reference
	PR2	Reference
Swallow Creek	SC1	Reference
Rodd's Creek	RC1	On-site (downstream tailings dam)
Diggers Creek	DG1	Upstream

Plate 1 Site photographs representative of habitat condition in Cadiangullong Creek in spring 2019 (left) and autumn 2020 (right)

Plate 2 Site photographs representative of habitat condition in reference and off-site locations in spring 2019 (left) and autumn 2020 (right)

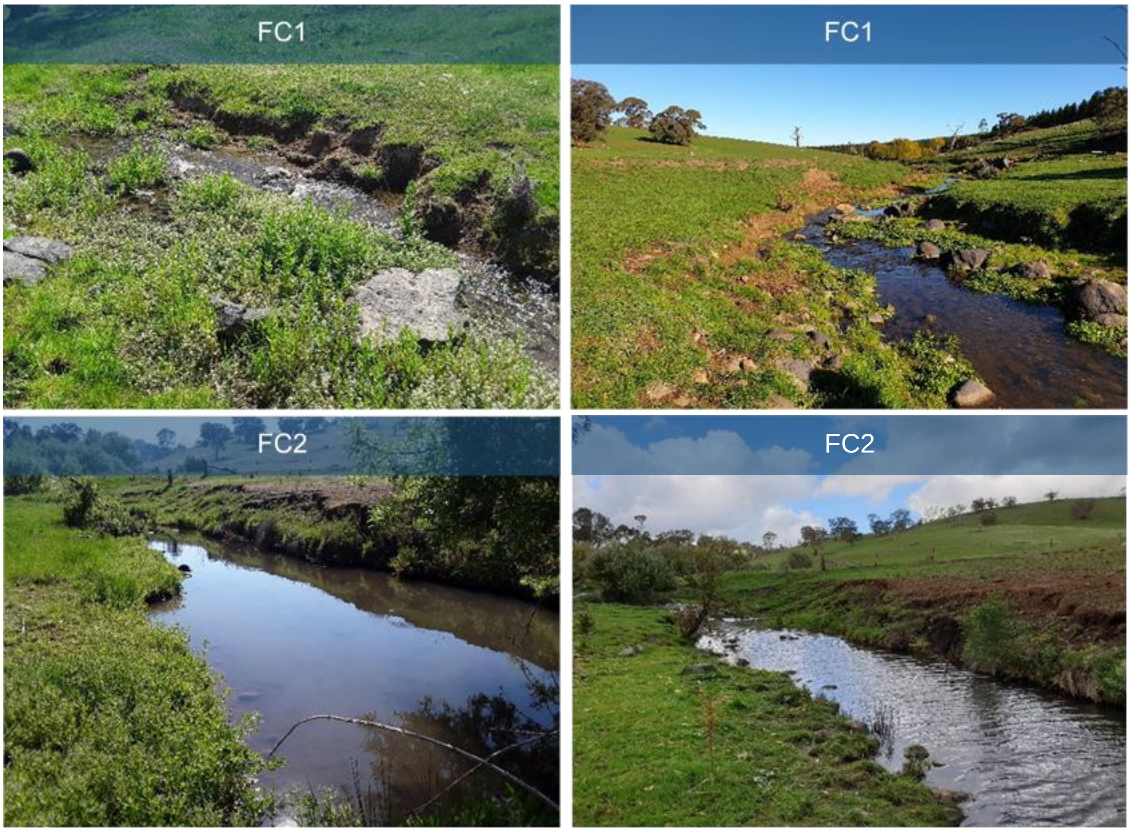

Plate 3 Site photographs representative of habitat conditions in Flyers Creek in spring 2019 (left) and autumn 2020 (right)

2. Methodology

2.1 Permits and licences

GHD has current NSW Fisheries permits and licenses to conduct macroinvertebrate and fish monitoring in NSW rivers and streams and staff operate under a NSW Department of Primary Industries (DPI) Fisheries permit, issued under section 37 of the *Fisheries Management Act 1994* (Permit No: P07/0142-4.0 & OUT13/22250).

2.2 Aquatic habitat

The aquatic habitat assessment was undertaken following methods described in the NSW AUSRIVAS Manual (Turak *et al*., 2004) that include a range of physical habitat measurements and the Visual Assessment of Disturbance Related to Human Activities (VisAssess).

This visual assessment method is an evidence-based approach of grading the degree of anthropogenic impacts at a monitoring site based on four assessment categories:

- Water Quality: odour, water clarity, disruption of the natural hydrology, presence of foam from detergents, oil
- Instream: change in substrate (e.g. rock piles or sedimentation from road construction or other development pipes), rubbish, filamentous algae, alien fish species, invasion by exotic aquatic plants
- Riparian Zone: de-vegetation, exotic plant invasion, bank degradation, point sources
- Catchment: mine, sewage treatment plant, landfill, dam, industry, logging, agriculture, clearing, salinity, grazing, urban development

A ranking of 0 to 4 and an associated description is assigned for each category with a higher score indicating a higher level of anthropogenic impact (Table 2). The Total Visual Assessment Score is the sum of these rankings for each site, which provides an overall assessment of anthropogenic impacts ranging from 0 to 16.

Table 2 NSW AUSRIVAS VisAssess ranking categories, descriptions and total scores

Ranking	Description	Total Visual Assessment Score
0	No evidence of disturbance	0-2
1	Little disturbance	3-5
2	Moderate disturbance	6-8
3	High disturbance	9-12
4	Extreme disturbance	13-16

2.3 Water quality

In situ water quality measurements were made from the surface at each site for the following physico-chemical parameters:

- Temperature (°C)
- pH (pH units)
- Electrical Conductivity (µS/cm)
- Dissolved Oxygen (% saturation and mg/L)
- Turbidity (NTU)
- Alkalinity (mg/L $CaCO_3$)

Temperature, pH, electrical conductivity and dissolved oxygen were measured at each site using a YSI 556 multi-parameter water quality meter. This meter was calibrated in accordance with QS/QA (Quality System/Quality Assurance) requirements and the manufacturer's specifications. Alkalinity was measured using a Hach Digital Alkalinity Titration kit. Turbidity was measured using a Hach 2100Q portable turbidimeter. The water quality results were compared to ANZG (2018) default guideline values for slightly disturbed upland rivers of south eastern Australia (previously known as ANZECC, 2000).

2.4 Sediment quality

2.4.1 Sampling

Sediment quality has been included in the monitoring program since autumn 2018 to fill a knowledge gap identified following a review of the water quality, environmental and biological data for CVO (GHD, 2018).

One of the key recommendations from the review was to include sediment monitoring with a view to assess its relationship with benthic macroinvertebrate communities. There was some evidence of a relationship between macroinvertebrate communities and sediment in autumn 2018, so monitoring continued in spring 2019 and autumn 2020 to determine whether there was evidence of seasonal variation in sediment quality.

From a minimum of five locations at each site, sediment was collected and consolidated into a single composite sample. Sediment from multiple locations encapsulates variation associated with different habitats and hydrological units and allows for a more standardised procedure for comparing sediments amongst sites. The sediment samples were analysed for a suite of total metals (Table 3).

Table 3 Analytical Schedule – Sediment Samples

Lab Analysis	Analytes
Total Metals	Aluminum (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Selenium (Se), Silver (Ag), Zinc (Zn),

2.4.2 Data analysis

In previous seasons, sediment concentrations were compared to ANZECC (2000) interim sediment quality guidelines (ISQG) for 95% level of protection for slightly to moderately disturbed ecosystems. These guidelines have now been reviewed and updated and in this report, sediments concentrations are compared to default guideline values (DGVs) published in ANZG (2018). The sediment DGVs indicate concentrations below which there is a low risk of unacceptable effects occurring in aquatic ecosystems (ANZG, 2018). Upper guideline values are also published to provide an indication of concentrations at which toxicity-related adverse effects may be expected (ANZG, 2018). The sediment concentrations in this report have compared to both the DGVs and upper DGVs.

Note that the major toxic effect of metals on the macroinvertebrate communities is due to the dissolved form of metals in an ecosystem (ANZG, 2018). As such, the total metal concentrations assessed in this monitoring program overestimate the fraction that is bioavailable (ANZG, 2018).

Relationships in sediment quality amongst sites were examined using a Principal Components Analysis (PCA) that reduces a large set of variables into a small set that retains most information associated with the large set. In this case, the suite of metals listed in Table 3 were reduced to two principal components (PC1 and PC2). These principal components were used as axes in PCA ordinations to graphically represent sites in ordinal space. Principal component scores explain the percentage of variation in the sediment quality contributed by each axis and linear coefficients define the contribution of each analyte to each axis. Vectors plotted on the PCA ordination superimpose environmental gradients. Prior to performing the PCA, the data were normalised to ensure scale independence. PCA analyses were conducted using PRIMER Version 7 (Clarke & Warwick, 2001). Note that where sediment results were presented as below laboratory limits of resolution (LOR), these values were halved (i.e. <0.5/ 2 = 0.25 and <1 / 2 = 0.5 respectively) and retained in the analysis. Antimony and silver were removed from analyses as all values were below laboratory detection limits and provided no information about variation.

2.5 Macroinvertebrates

2.5.1 Sampling

Macroinvertebrates were sampled in accordance with the NSW AUSRIVAS Sampling and Processing Manual (Turak *et al.*, 2004). At each site, the littoral or edge habitat was sampled by sweeping the collecting net along the edge of the stream in areas of little or no current. Where present, riffles were sampled using a kick sampling method.

For each sample, the collected material was placed into a sorting tray and macroinvertebrates ‘live picked’ for a minimum of 40 minutes. Live picked macroinvertebrates were preserved in 70% ethanol and labelled with information including site code, site location, habitat, sampling method, date, sampler and picker.

2.5.2 Laboratory processing and identification

Macroinvertebrates were processed in GHD’s laboratory in Abbotsford, Victoria. Samples were examined using Leica M80 or S6 series stereo-dissection microscopes with a minimum of 6.3:1 zoom and a standard magnification of 7.5-60x.

Freshwater macroinvertebrates were identified using published taxonomic keys (Hawking, 2000), unpublished working keys and an extensive specimen reference collection maintained by GHD. Based on standard conventions for NSW AUSRIVAS models (Turak *et al*., 2004) macroinvertebrates were identified to family-level with the following exceptions:

- Chironomidae (Diptera) were identified to Sub-family (e.g. Orthocladiinae, Chironominae, and Tanypodinae)
- Groups such as Nematoda, Oligochaeta and Acarina were identified to Class or Order
- Microcrustacea, Ostracoda, Copepoda and Cladocera were identified to the Order

Upon the completion of identifications, all samples were returned to 100% ethanol for long-term archiving. This process allows samples to be re-examined at a later date if required. This may be important, particularly if taxonomy changes significantly in the future under a long-term monitoring program or for QA/QC purposes. GHD will ensure archived samples are retained for the life of the AEMP. Reference specimens will remain the property of GHD.

2.5.3 Data analysis

The data analyses in this AEMP is designed to achieve the key objective of developing an understanding of macroinvertebrate communities as an indicator of aquatic ecosystem health.

Univariate analyses - Biological indices

The biological indices calculated from the macroinvertebrate data include:

- Taxa Richness
- EPT Taxa Richness
- SIGNAL-2
- NSW AUSRIVAS models: spring, autumn, and combined season edge and riffle where applicable

Taxa Richness

Taxa Richness refers to the number of different taxa (identified to family level) contained in a sample. Taxa Richness can reasonably indicate ecological health with healthy waterways generally having more families.

EPT Taxa Richness

The EPT taxa index refers to the number of key macroinvertebrate taxa (identified to family level) belonging to the Orders Ephemeroptera, Plecoptera and Trichoptera. These Orders are generally considered to contain pollution–sensitive insects and a loss of families usually indicates some level of disturbance (Plafkin *et al.,* 1989).

SIGNAL-2

SIGNAL-2 (Stream Invertebrate Grade Number Average Level) is a simple scoring system for macroinvertebrates in Australian rivers (see Chessman, 2003). SIGNAL-2 is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate taxa at the Order and Family levels. These grades have been derived from published and unpublished information on taxa tolerance to pollutants such as sewage and nitrification (Chessman, 1995). Each taxon is assigned a grade from 1 (tolerant) to 10 (sensitive) based on eco-toxicity assessment data.

Not all macroinvertebrate families have been assigned a SIGNAL-2 grade and those without are removed from SIGNAL-2 calculations which is the average of the grades within a sample. SIGNAL-2 scores only use the presence of taxa and are not weighted with regard to abundance. For easier interpretation, SIGNAL-2 scores and the number of macroinvertebrate taxa are graphed using a bi-plot. The resulting bi-plot is placed into context using a quadrant diagram that divides the results into four general realms, with each indicating various factors of site condition that may explain the macroinvertebrate community SIGNAL-2 score (Figure 2).

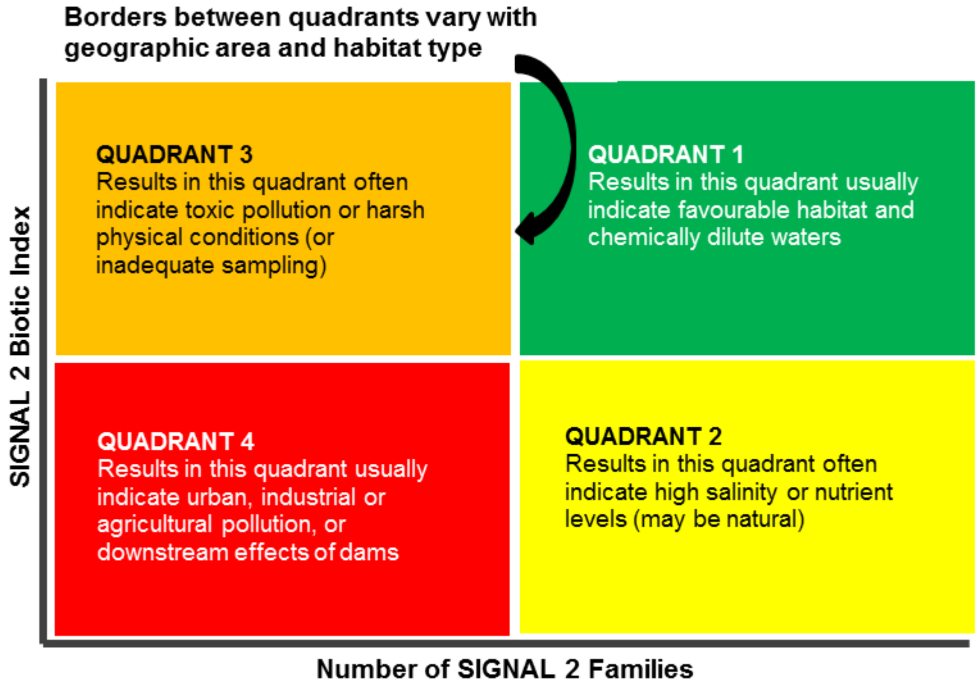

Figure 2 SIGNAL-2 bi-plot displaying the four quadrants and explanations of what each indicates

The SIGNAL-2 quadrant boundaries have been set according to the NSW interim boundaries suggested for sites within the Murray Darling basin above 400 m elevation (Chessman 2001). These are a SIGNAL-2 score of 5 and 19 for number of families in edge habitats, and SIGNAL-2 score of 6 and 17 families for riffle habitats.

NSW AUSRIVAS Model

All macroinvertebrate data, water quality parameters and habitat variables required by the AUSRIVAS models were collected according to the NSW AUSRIVAS manual (Turak *et al*, 2004) and ANZG (2018) Water Quality Guidelines for aquatic ecosystems in south eastern Australia. NSW AUSRIVAS models and accompanying scores and bandings have been used to detect changes in observed and expected macroinvertebrate communities within the CVO MLA. The AUSRIVAS models run for analysis of macroinvertebrate data for this AEMP include:

- NSW - Spring Riffle
- NSW - Spring Edge
- NSW - Autumn Riffle
- NSW - Autumn Edge
- NSW - Autumn + Spring (combined season) Riffle
- NSW - Autumn + Spring (combined season) Edge

AUSRIVAS generates site-specific predictions of the macroinvertebrate fauna expected to be present in the absence of environmental stress. The expected fauna from reference sites with a similar set of physical and chemical characteristics are compared to the observed fauna, and the ratio derived is used to indicate the extent of the impact. This ratio can range from zero (0), when none of the expected taxa are found at a site, to approximately one (1), when all of the expected taxa are present. The value can also be greater than one (1) when more families are found at a site than predicted by the model. The ratio scores are placed in bands which indicate whether the site is richer than reference, reference quality, significantly impaired, severely impaired or extremely impaired. An example of outputs from the AUSRIVAS models (i.e. O/E 50 upper limits and band descriptions) are demonstrated for the combined season edge and riffle models in Table 4.

Table 4 AUSRIVAS bands, O/E 50 upper limits, and band names and descriptions for the NSW combined season models

Band Label	O/E 50 Upper Limit Edge	O/E 50 Upper Limit Riffle	Band Name	Band Description
Band X	>1.17	>1.14	More biologically diverse than reference sites.	More taxa found than expected. Potential biodiversity hot spot. Possible mild organic enrichment.
Band A	1.17	1.14	Reference condition	Most/all of the expected families found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity.
Band B	0.82	0.85	Significantly impaired	Fewer families than expected. Potential impact, either on water quality or habitat quality or both, resulting in loss of taxa.
Band C	0.48	0.57	Severely impaired	Many fewer families than expected. Loss of macroinvertebrate biodiversity due to substantial impacts on water and/or habitat quality.
Band D	0.14	0.29	Extremely impaired	Few of the expected families remain. Extremely poor water and/or habitat quality. Highly degraded.

Multivariate Analysis

Multivariate analyses were performed on the macroinvertebrate data for both spring and autumn separately as strong seasonal differences in the macroinvertebrate communities have previously been identified by the AEMP. Edge and riffle habitats were also analysed separately due to differences in the communities associated with these habitats. The multivariate analyses were utilised to determine if significant differences in the macroinvertebrate community existed spatially. That is, are there significant differences between sites associated with each treatment type (i.e. upstream, on-site, downstream and reference). All multivariate analyses were performed using the PRIMER V7 software package (Clarke and Gorley, 2015).

Initially, the macroinvertebrate data was transformed to presence/absence data as the RBA sampling protocol is a semi-quantitative technique. Furthermore, transformation of the macroinvertebrate data increases the influence of rare species and decreases potential sample variability based on the inherent variation associated with different sample collectors.

A similarity matrix was subsequently calculated between all samples based on the Bray-Curtis similarity measure. Non-metric multidimensional scaling (nMDS) was then used to produce an ordination plot as a graphical representation of key spatial and temporal trends in the macroinvertebrate assemblages. The stress value associated with the nMDS ordination was examined to identify the accuracy of the ordination. A stress value <0.2 indicates a potential useful 2-dimensional ordination (Clarke and Warwick 2001).

To test if there were statistically significant differences in the macroinvertebrate communities between each treatment type, permutation based analyses of variance (ANOSIMs) were used using 999 permutations. Details of treatment assigned to each of site are provided in Table 1. If significant differences were detected, taxa analysis was conducted using the similarity percentages (SIMPER) routine to identify the taxa that best discriminate between the treatments. SIMPER quantifies the contribution of each taxon to the average dissimilarity between the two groups of samples, and to the average similarity within a group (Clarke and Warwick 2001).

Sediment / macroinvertebrate relationships

A key focus of the sediment monitoring was to assess if there was an association between sediment quality and macroinvertebrate communities. To investigate this, the RELATE, BEST and DISTLM procedures in the PRIMER V7 software package were used (see Clarke and Gorley, 2015). Initially, the RELATE procedure was used to test if there was a correlation between sediment quality and macroinvertebrate communities. That is, to explore if the patterns on the sediment PCA show some correlation to the macroinvertebrate nMDS. Using 999 permutations, RELATE calculates the rank correlation (q) and if the null hypothesis was accepted (significance level $P > 0.05$) no relationship between two data sets is assumed.

The sediment analytes that best explained relationships were identified using the BEST procedure. BEST identifies which analytes most strongly correlated with the macroinvertebrate communities for and was carried out by generating a resemblance matrix (based on Euclidean distance) of normalised sediment analytes and matching it, using a Spearman rank correlation, to the macroinvertebrate data.

The limitation of the BEST procedure is it gives an indication of correlation between sediment analytes and macroinvertebrate communities, but does not identify how much of the variation in macroinvertebrates communities explained by each analyte. This was determined using the distanced based linear modelling (DISTLM) procedure to test if there was a significant correlation, using 999 permutations, between each sediment analyte and the macroinvertebrate communities. DISTLM then identifies the percentage variation in the macroinvertebrates community explained by the analytes.

Note that where sediment results were presented as below laboratory limits of resolution (LOR), these values were halved (i.e. <0.5/ 2 = 0.25 and <1 / 2 = 0.5 respectively) and retained in the analysis. Antimony and silver were removed from analyses as all values were below laboratory detection limits and provided no information about variation.

2.6 Fish

2.6.1 Sampling

Electrofishing was conducted in accordance with the Australian Code of Electrofishing Practice (1997) and GHD's Fauna Survey Standard Operating Procedure to ensure all safety requirements were met prior to commencing work. At each site, the total reach surveyed was defined as 10 x bank full width. Electrofishing was undertaken using an E-fish 500 W Backpack System in areas where the depth, instream habitat, and water quality was suitable for safe operation.

Due to stream depth, elevated conductivity or turbidity electrofishing could not be conducted at CC5 and SC1. At these sites eight baitfish traps (250 mm x 250 mm x 450 mm; 5 mm mesh) were set using a stratified approach in an attempt to cover all habitat types within the reach. Traps were baited with dry cat biscuits and left overnight for approximately 12 hours. Fish surveys are not conducted at Rodd's Creek (RC1) or Diggers Creek (DG1).

2.6.2 Identification and processing

At each site, fish collected were identified to species (see Allen *et al.,* 2002; Lintermans, 2007) and their total length (TL) to the nearest millimetre (mm) recorded. Native species were returned unharmed to the stream. Non-native species were euthanized and disposed of in accordance with ethics permit requirements. All by-catch fauna (e.g. yabbies) were noted and immediately returned to the stream.

3. Results

3.1 Rainfall and hydrology

Over the five months prior to the spring 2019 sampling during October, total monthly rainfall in the surrounding catchments of the CVO was consistently below the long-term average (Table 5). Rainfall remained below the long-term average from November to February. However, from March to May rainfall above the long-term average. Prior to the autumn monitoring in April, rainfall during March was 189% higher than the long-term average. During April it was 335% higher although this monthly total would not have greatly influenced the monitoring that was carried out early in the month from 9 to 12 April.

The hydrograph for Cadiangullong Creek upstream of the dam (CC5) reflected the pattern in rainfall with an increase in mean daily flow following increased spring rainfall from August to September and autumnal rainfall from March to May (Figure 3). Lower flows occurred at CC5 throughout the summer/autumn period from November to April. Downstream of Cadiangullong Dam at CC1, flow generally remained low from June to late September, after which flow increased and remained relatively constant between 2.1 and 5.6 ML/day due to a combination of releases and natural flow events until mid-February. This was followed by another low flow period until increased rainfall from late March to the end of May contributed to increased flow events. The flow pattern at CC1 was also observed further downstream in Cadiangullong Creek. The hydrographs for Swallow Creek (SC1) illustrates the relatively low flow conditions throughout the 12-month period although there were high flow events associated with increased rainfall from mid-February to late May. Flyers Creek (FC1) showed a noticeable downward trend in flow from June to March when increased rainfall also contributed to high flow events.

Table 5 Monthly rainfall and temperature recorded at Orange Airport (63303) from June 2019 to May 2020

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total rainfall (mm)	47.2	25.0	34.2	58.8	20.2	23.8	15.0	58.2	60.0	131.2	145.2	69.2
Long-term rainfall mean (mm)	77.3	72.0	80.6	78.3	70.3	79.3	87.0	63.5	75.6	69.3	43.4	50.2
Mean maximum temperature (°C)	11.2	11.1	11.8	15.9	21.1	24.3	29.6	31.0	24.9	20.8	16.6	

Source: http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=136&p_display_type=dailyDataFile&p_startYear=&p_c=&p_stn_num=063303

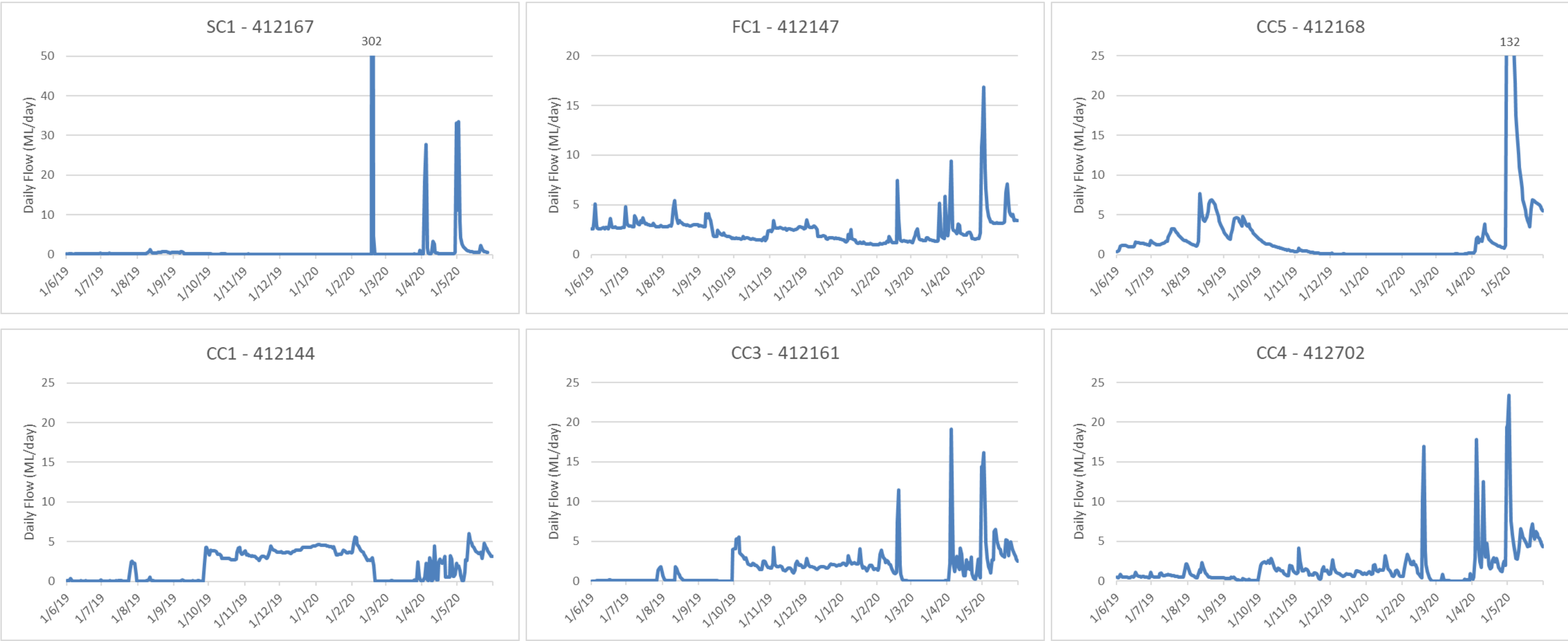

Figure 3 Hydrographs from Swallow Creek, Flyers Creek and Cadiangullong Creek for the period 1 June 2019 to 31 May 2020

3.2 Aquatic habitat

Following the NSW AUSRIVAS Visual Assessment of Disturbance Related to Human Activities the majority of sites were assessed as 'high disturbance' (Table 6). As in previous years, CC2 was assessed as 'extreme disturbance' during spring with water quality being the only disturbance assessment criteria that did not score the maximum value.

Panuara Rivulet and Diggers Creek also recorded levels of 'extreme disturbance' although this was limited to a single season. Rodd's Creek recorded levels of 'extreme disturbance' in both seasons. These results were primarily due to the conditions of the riparian zone although catchment condition also impacted Rodd's Creek. In general, sites were scored high due to the disturbances to riparian zone vegetation and broader catchment scale land-use which, aside from mining and associated operations, is heavily influenced by grazing in the mid to lower catchment areas, and pine plantations in the upper catchments.

Table 6 Results of the NSW AUSRIVAS visual assessment of disturbance

Site	Season	Water Quality	Instream	Riparian Zone	Catchment	Total Score	Rank
CC5	Spring	2	2	3	2	9	High disturbance
	Autumn	2	2	3	2	9	High disturbance
CC1	Spring	2	1	2	2	7	Moderate disturbance
	Autumn	3	2	2	2	9	High disturbance
CC2	Spring	2	4	3	4	13	Extreme disturbance
	Autumn	2	3	4	4	13	Extreme disturbance
CC3	Spring	2	3	3	3	11	High disturbance
	Autumn	2	2	3	3	10	High disturbance
CC4	Spring	2	3	3	3	11	High disturbance
	Autumn	2	3	3	3	10	High disturbance
FC1	Spring	2	2	4	3	11	High disturbance
	Autumn	2	3	4	3	12	High disturbance
FC2	Spring	2	2	3	3	10	High disturbance
	Autumn	2	3	3	3	11	High disturbance
PR1	Spring	3	4	4	3	14	Extreme disturbance
	Autumn	3	3	4	3	13	Extreme disturbance
PR2	Spring	2	2	3	3	10	High disturbance
	Autumn	2	2	3	2	9	High disturbance
SC1	Spring	2	3	4	2	11	High disturbance
	Autumn	2	3	4	2	11	High disturbance
RC1	Spring	2	2	4	4	12	High disturbance
	Autumn	2	3	4	4	13	Extreme disturbance
DG1	Spring	2	2	4	3	11	High disturbance
	Autumn	2	2	4	3	11	High disturbance

3.3 Water quality

Results for the *in situ* water quality variables collected in spring 2019 and autumn 2020 are presented in Table 7 and compared to the relevant ANZG (2018) default guideline values. The following sections discuss each variable further.

Table 7 Results of *in-situ* water quality for the CVO aquatic ecosystems sites sampled in spring 2019 and autumn 2020. Red values exceed the ANZG (2018) default guideline value

Site code	Season	Temp. (°C)	EC (µS/cm)	pH	DO (mg/L)	DO (%Sat.)	Turb. (NTU)	Alk. (mg/L)
ANZG (2018) DGVs[1]		NA	350	6.5-8.0	NA	90-110	25	NA
CC5	Autumn	12.7	57	6.9	7.4	69.8	25	30
	Spring	14.1	83	8.1	8.4	80.3	12	45
CC1	Autumn	14.3	208	7.5	5.8	56.7	8	100
	Spring	9.7	83	8.2	8.2	72.6	22	35
CC2	Autumn	14.2	279	6.9	7.0	68.3	4	100
	Spring	16.0	151	8.2	7.4	80.7	15	65
CC3	Autumn	14.8	584	7.1	8.7	86.1	7	80
	Spring	16.9	312	8.4	8.3	87.2	6	70
CC4	Autumn	16.2	911	7.5	8.2	83.7	7	160
	Spring	18.6	782	8.4	8.2	87.8	1	95
DG1	Autumn	15.1	948	7.5	8.1	80.8	12	180
	Spring	15.0	1529	7.8	5.0	57.0	3	110
FC1	Autumn	14.7	460	7.8	8.9	87.8	7	280
	Spring	16.6	433	8.7	7.5	87.5	6	90
FC2	Autumn	15.6	460	7.9	8.1	81.5	8	260
	Spring	14.6	498	8.5	7.4	74.2	7	60
PR1	Autumn	12.0	618	7.9	10.0	93.0	17	180
	Spring	18.1	1141	8.1	3.2	33.7	10	100
PR2	Autumn	17.6	718	7.7	8.3	87.2	14	160
	Spring	21.3	1388	8.2	6.2	69.9	6	110
RC1	Autumn	18.4	1700	7.8	7.2	77.2	6	440
	Spring	21.3	1807	8.3	5.4	60.7	5	100
SC1	Autumn	15.1	1584	7.2	6.8	68.0	8	120
	Spring	18.8	1953	7.8	5.6	63.9	3	110

[1] ANZG (2018) default guideline values (DGVs) are for upland rivers in south eastern Australia

3.3.1 Electrical conductivity

Electrical conductivity (EC) was above the ANZG (2018) guideline value of 350 µS/cm at the majority of monitoring sites in both seasons (Table 7, Figure 4). The exceptions were upstream of Cadiangullong Dam at CC5 and downstream at CC1 and CC2 in both seasons, and CC3 during spring. There was also a large degree of seasonal variation in EC downstream of Cadiangullong Dam with higher levels during autumn. The opposite pattern occurred upstream of the dam at CC5 and most other sites with higher levels during spring. In Cadiangullong Creek, there is a consistent salinity gradient with EC increasing moving downstream. This was also observed in Panuara Rivulet based on the two sites monitored. Generally, high EC occurs in Diggers Creek, Rodd's Creek and Swallow Creek compared to the other waterways.

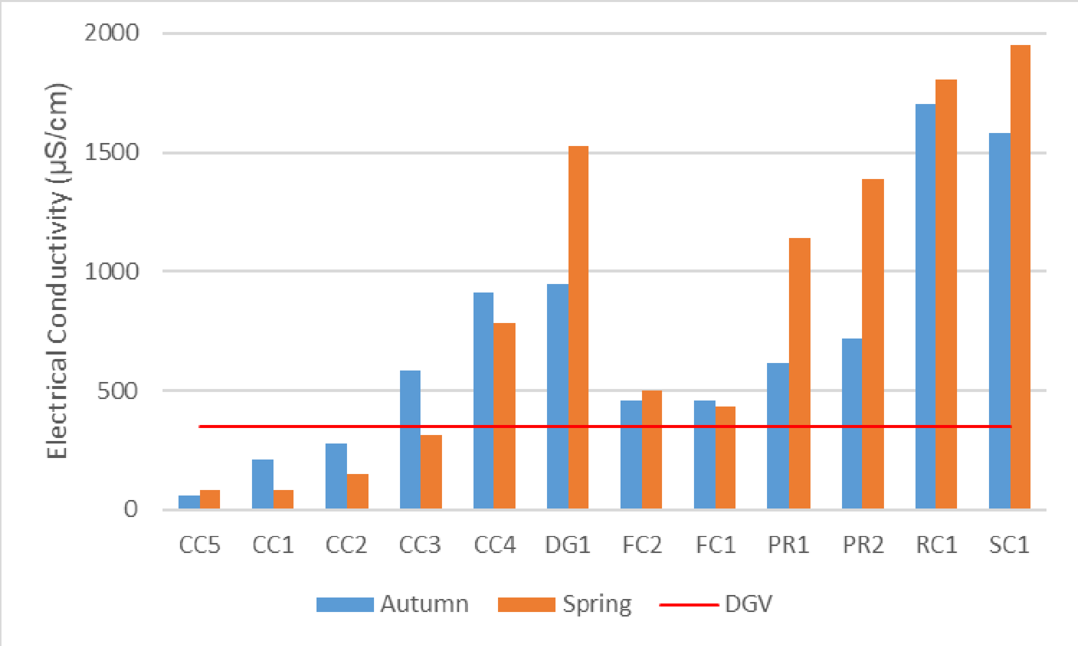

Figure 4 Electrical Conductivity for CVO sites monitored spring 2019 and autumn 2020. Red line is ANZG (2018) default guideline value

3.3.2 pH

The pH of all sites were within the ANZG (2018) default guideline value range during autumn (Table 7, Figure 5). However, higher pH was observed in spring and exceeded the upper guideline value, with the exception of Diggers Creek (DG1) and Swallow Creek (SC1).

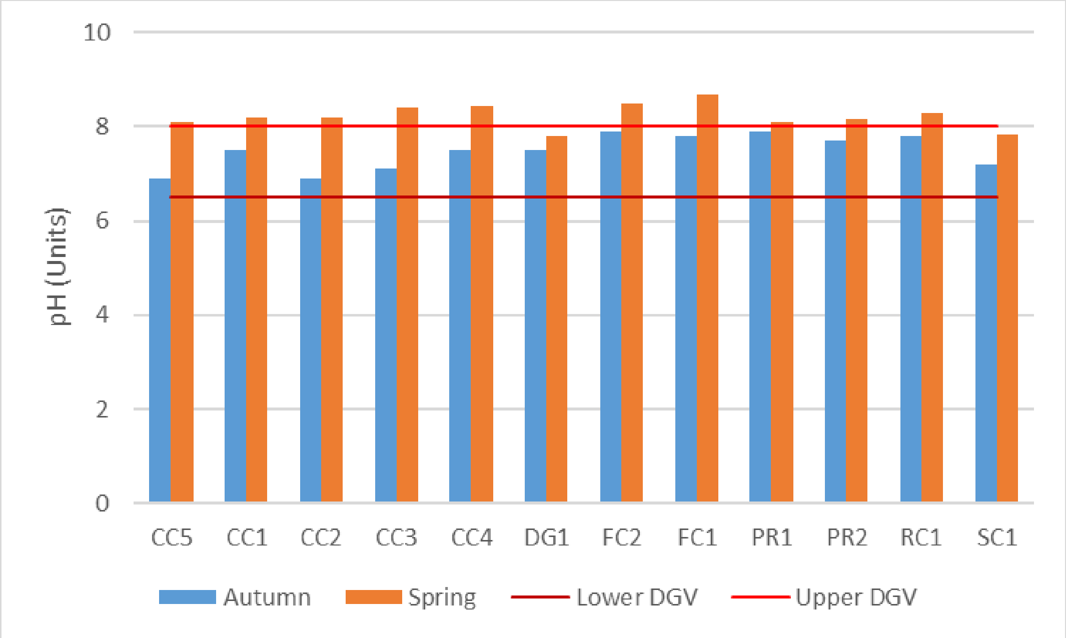

Figure 5 pH for CVO sites monitored spring 2019 and autumn 2020. Red lines are ANZG (2018) default guideline value range

3.3.3 Dissolved oxygen

With the exception of PR1 on Panuara Rivulet, dissolved oxygen (DO) was below the ANZG (2018) guideline value range at all sites in both seasons (Table 7, Figure 6). In Cadiangullong Creek, DO was higher in spring. However, the opposite was observed in the other waterways. Of note is the noticeably lower DO at PR1 during spring compared to autumn.

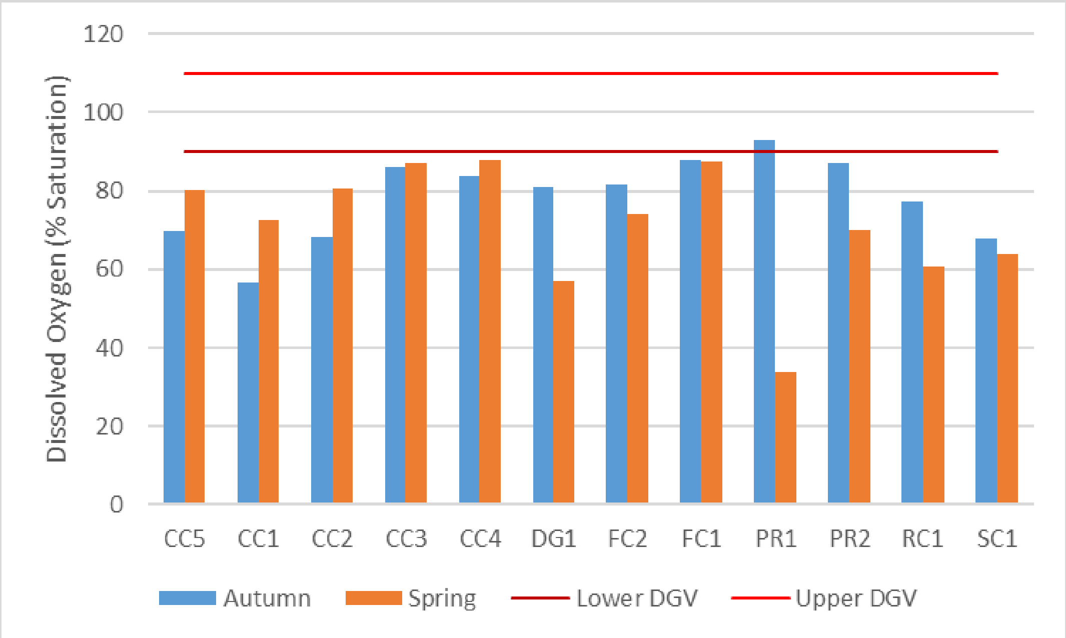

Figure 6 Dissolved Oxygen for CVO sites monitored spring 2019 and autumn 2020. Red lines are ANZG (2018) default guideline value range

3.3.4 Turbidity

Turbidity was below the ANZG (2018) guideline value of 25 NTU at all of sites in both seasons and all values represent reasonably clear water (Table 7, Figure 7).

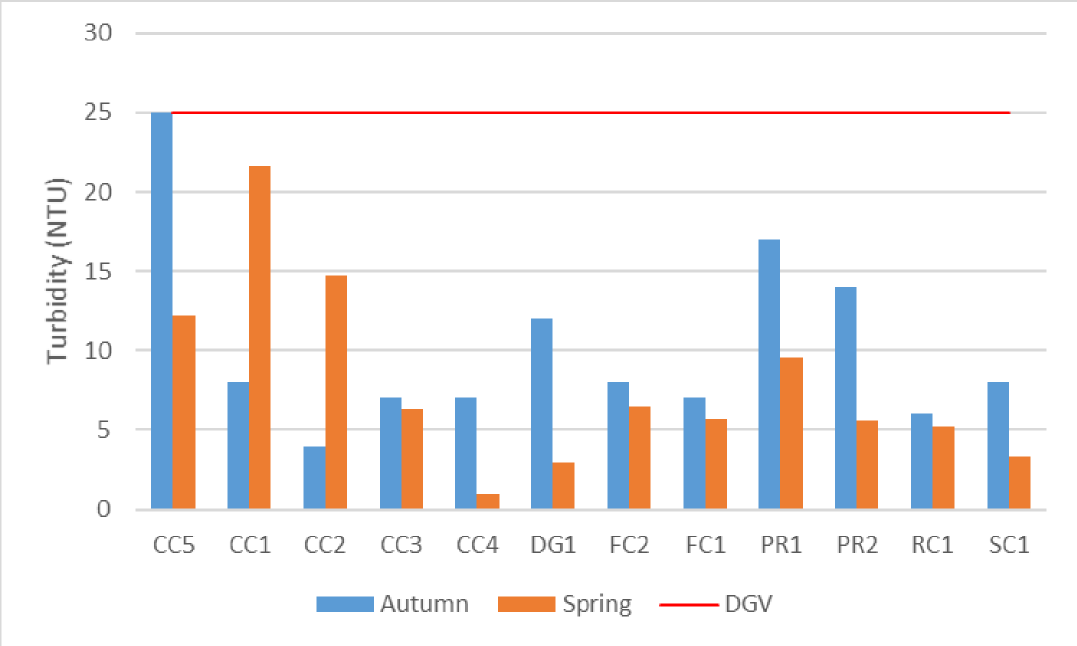

Figure 7 Turbidity for CVO sites monitored spring 2019 and autumn 2020. Red line is ANZG (2018) default guideline value

3.3.5 Temperature

Generally, there was a consistent seasonal pattern in temperature with the majority of sites having high values during spring compared to autumn (Table 7, Figure 8). The variation in temperature is related to differences in air temperature between the seasons with higher average maximums during spring 2019 (Table 5). There is no ANZG (2018) default guideline value for temperature.

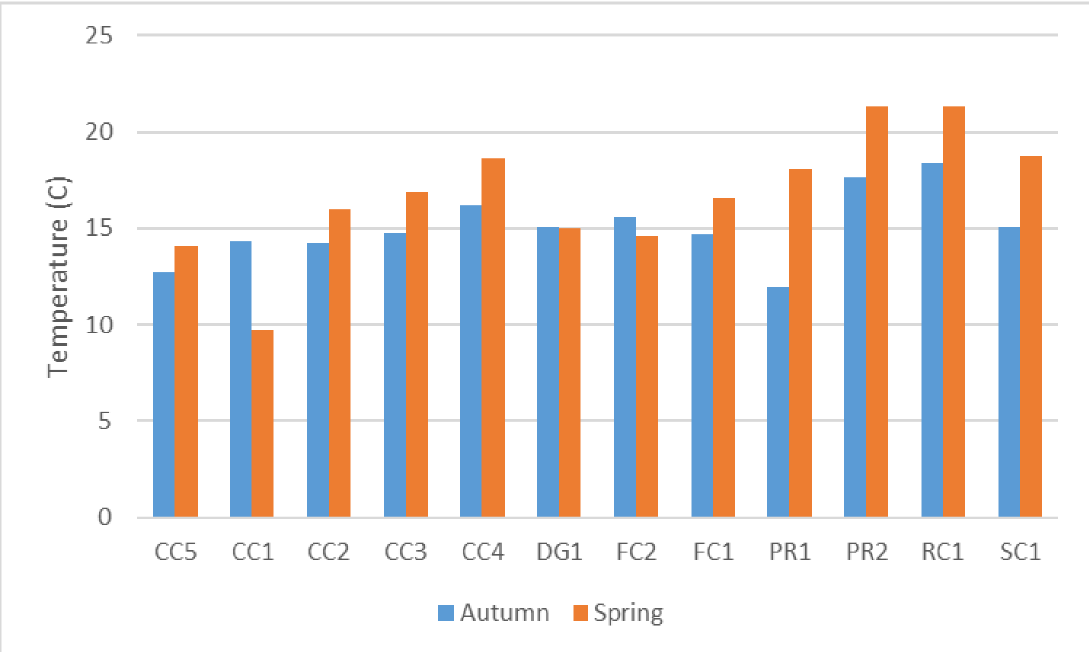

Figure 8 Temperature for CVO sites monitored spring 2019 and autumn 2020

3.4 Sediment quality

Comparisons of total metals concentrations in sediments against the ANZG (2018) default guideline values (DGVs) are included in Table 8. Antimony and silver were below laboratory limits of resolution (LOR) at all sites in both seasons. Of the metals that have DGVs published, only arsenic, chromium, copper, lead and nickel were exceeded. Of these, only arsenic and copper exceeded the upper DGV. Arsenic was exceeded in Diggers Creek (DG1) and copper in Cadiangullong Creek (CC2 and CC3) in both seasons.

Principal component analyses (PCAs) based on the sediment quality used two approaches, 1) all monitoring sites and 2) Cadiangullong Creek only. The former was undertaken in an attempt to identify major differences in sediment quality between the different waterways while the latter was to identify site differences within Cadiangullong Creek.

For the PCA ordination of all monitoring sites, the two principal components accounted for almost 46% of the variation in sediment metal concentrations (Figure 9). Diggers Creek (DG1) was clearly separated from all other sites in both seasons to the right hand side of PC1. The vectors on the PCA ordination and the metals with the highest loadings on PC1 (see Table 9) suggest this is due to a combination of relatively higher concentrations of arsenic, lead and zinc and mercury in Diggers Creek. For the other sites, there was some seasonal separation vertically along PC2 with spring samples towards the top of the PCA ordination. The vectors on the PCA ordination and the metals with the highest loadings on PC2 suggest this was predominately due to higher concentrations of mercury during spring, and higher beryllium and aluminium during autumn. Within both seasons, there was some degree of separation of Cadiangullong Creek sites CC2 and CC3 from other sites towards the left hand side of PC1 due to relatively higher concentrations of copper.

For the PCA ordination of Cadiangullong Creek sites, the two principal components accounted for over 61% of the variation in sediment metal concentrations (Figure 10). There was no obvious patterns in seasonal variation, with some degree of overlap of both spring 2019 and autumn 2020. However, within each season sites CC2 and CC3 were separated from other sites to the right hand side of PC1. The vectors on the PCA ordination and the metals with the highest loadings on PC1 (see Table 9) suggest this is due to relatively higher concentrations of copper at CC2 and CC3. Alternatively, the other Cadiangullong sites had relatively higher concentrations of aluminium (particularly in spring), zinc and beryllium. Furthermore, duplicate samples were taken from CC2 during spring 2019 from both a riffle and pool habitat. There was noticeable vertical separation along PC2 of these two habitats with relatively higher concentration of cobalt, nick and molybdenum in the riffle and higher zinc and mercury in the pool.

Table 8 Comparisons of total metals (mg/kg) against the ANZG (2018) default guideline values (DGVs) for sediment. Underlined values exceeded the DGV and red values exceeded both the DGV and Upper DGV

Site	Season	Aluminium	Antimony[2]	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Zinc
DGVs			2	20	NA	NA	1.5	80	NA	65	NA	50	NA	0.15	NA	21	NA	1	200
Upper DGVs		NA	25	70	NA	NA	10.0	370	NA	270	NA	220	NA	1.00	NA	52	NA	4	410
CC5	Spring	12100	<5	11	86	3.3	<0.1	52	19	25	67900	10.2	602	<0.10	1.6	14	1	<1	107
	Autumn	18000	<5	5	170	<5	<0.2	30	16	25	43000	12.0	1200	<0.05	<5.0	15	4	<1	180
CC1	Spring	12600	<5	8	131	1.1	<0.1	46	21	50	38200	8.0	1040	<0.10	<1.0	14	<1	<1	71
	Autumn	15000	<5	6	88	<5	<0.2	43	25	45	46000	6.0	1500	<0.05	<5.0	15	<3	<1	63
CC2[3]	Spring	8590	<5	**23**	40	0.7	0.1	35	20	**291**	37800	7.2	531	<0.10	3.1	14	<1	<1	50
	Autumn	11000	<5	13	54	<5	0.2	34	32	**330**	31000	7.0	540	<0.05	<5.0	20	<3	<1	47
CC3	Spring	8830	<5	18	59	1.3	<0.1	47	21	**280**	49000	12.1	444	<0.10	2.3	15	1	<1	86
	Autumn	16000	<5	6	110	<5	<0.2	21	21	**320**	25000	10.0	960	0.07	<5.0	12	<3	<1	70
CC4	Spring	15200	<5	7	112	0.9	<0.1	34	23	**116**	37500	8.2	438	<0.10	<1.0	17	<1	<1	73
	Autumn	23000	<5	12	130	<5	<0.2	33	27	**82**	50000	8.0	570	<0.05	<5.0	**23**	<3	<1	78
DG1	Spring	12200	<5	**178**	128	0.9	0.6	21	17	54	62100	31.1	424	0.10	1.1	18	1	<1	166
	Autumn	11000	<5	**91**	180	<5	0.6	21	17	45	43000	**55.0**	1800	0.09	<5.0	15	<3	<1	180
FC1	Spring	11800	<5	**31**	65	2.2	<0.1	**93**	23	52	67500	13.7	584	<0.10	<1.0	**29**	<1	<1	85
	Autumn	15000	<5	**39**	130	<5	<0.2	**91**	26	55	67000	21.0	1400	0.05	<5.0	**29**	<3	<1	85
FC2	Spring	12700	<5	8	67	0.6	<0.1	38	21	57	28300	14.8	683	0.10	<1.0	19	<1	<1	104
	Autumn	13000	<5	14	110	<5	<0.2	46	16	54	30000	14.0	1200	0.09	<5.0	16	<3	<1	76
PR1	Spring	11900	<5	12	177	0.8	<0.1	24	14	28	31900	13.3	924	<0.10	<1.0	15	<1	<1	72
	Autumn	14000	<5	10	130	<5	<0.2	27	13	26	34000	16.0	640	<0.05	<5.0	16	<3	<1	62
PR2	Spring	8900	<5	8	98	0.7	<0.1	21	10	22	23600	13.6	442	<0.10	<1.0	13	<1	<1	51
	Autumn	8800	<5	8	100	<5	<0.2	19	10	17	23000	16.0	570	<0.05	<5.0	13	<3	<1	43
RC1	Spring	16600	<5	9	78	0.4	0.1	32	16	**254**	34800	5.8	477	<0.10	<1.0	15	<1	<1	69
	Autumn	15000	<5	10	200	<5	<0.2	28	19	50	34000	9.0	2600	0.05	<5.0	15	<3	<1	59
SC1	Spring	12600	<5	**53**	140	0.7	0.2	28	22	63	36800	10.7	1530	<0.10	<1.0	16	1	<1	69
	Autumn	16000	<5	**22**	250	<5	<0.2	27	20	57	27000	10.0	1900	<0.05	<5.0	17	<3	<1	62

[2] Laboratory detection limit for Antimony exceeded the default guideline value so no comparison has been made

[3] Concentrations at CC2 during spring represent average values from duplicate samples

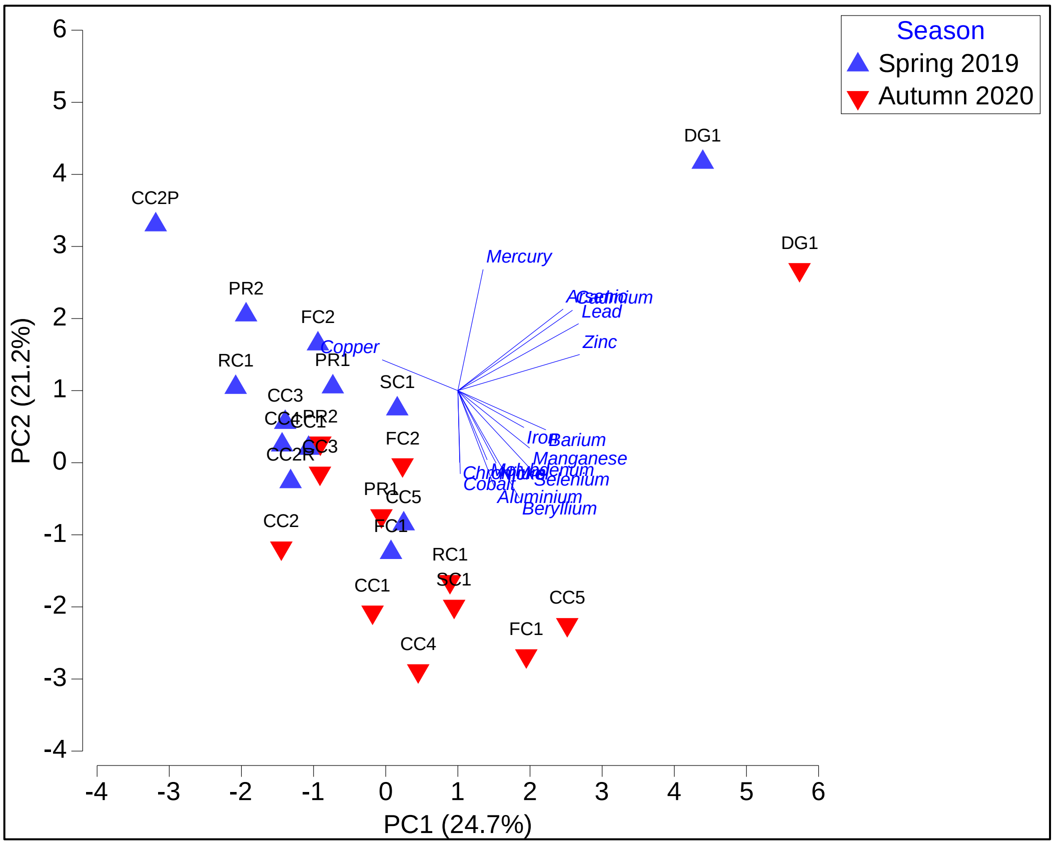

Figure 9 PCA ordination showing relationship between sediment concentrations and monitoring sites

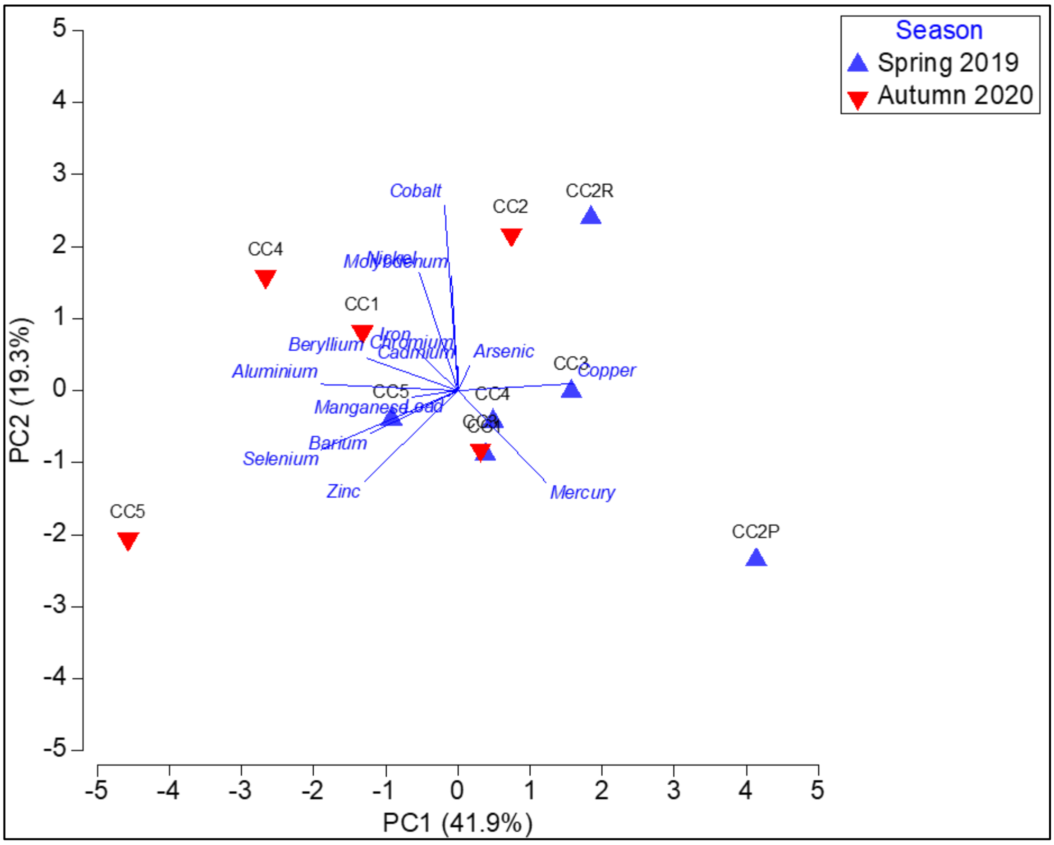

Figure 10 PCA ordination showing the relationship between sediment concentrations and monitoring sites (Cadiangullong Creek only)

Table 9 Coefficients in the linear combinations of variables making up the principal components

Variable	PC1	PC2	PC1	PC2
	All sites		Cadiangullong Creek sites	
Iron	0.220	-0.123	-0.146	0.142
Aluminium	0.121	-0.320	-0.457	0.021
Chromium	0.006	-0.240	-0.007	0.118
Manganese	0.239	-0.192	-0.154	-0.022
Zinc	0.406	0.121	-0.312	-0.304
Arsenic	0.351	0.272	0.041	0.086
Barium	0.293	-0.131	-0.294	-0.145
Beryllium	0.205	-0.359	-0.304	0.108
Cadmium	0.382	0.268	0.000	0.082
Cobalt	0.008	-0.278	-0.045	0.620
Copper	-0.252	0.103	0.388	0.024
Lead	0.402	0.223	-0.037	-0.021
Molybdenum	0.098	-0.231	-0.022	0.386
Nickel	0.127	-0.242	-0.130	0.397
Selenium	0.244	-0.263	-0.457	-0.197
Mercury	0.084	0.404	0.297	-0.309

3.5 Macroinvertebrates

A summary of the macroinvertebrate biological indices is presented in Table 10. AUSRIVAS results are coloured according to the Banding scheme presented in Table 4. Combined season AUSRIVAS model bands are included in the final column of Table 10.

3.5.1 Taxonomic richness and EPT

In Cadiangullong Creek, there was a decrease in taxa richness of edge habitats on-site at CC2 and downstream at CC3 compared to upstream sites CC5 and CC1 (Figure 11). However, there was evidence an increase further downstream at CC4. This pattern was also observed for riffle habitats although no riffle was present at CC5 in either season, or CC1 or CC2 during autumn. Other than CC2 and CC3, the taxa richness of Cadiangullong Creek was similar to or greater than that observed at the reference sites in Flyers Creek and Panuara Rivulet. Taxa richness of Rodd's Creek downstream of the tailings dam was consistent across both seasons and also similar or higher than reference sites.

EPT richness also decreased at CC2 and CC3 on Cadiangullong Creek compared to upstream (CC5) and the reference site (CC5) but again increased downstream at CC4 (Figure 11). Although there was some seasonal variation, EPT richness was generally lower at CC2 and CC3 compared to reference sites. Rodd's Creek was similar to the ETP richness at the reference sites in both seasons.

3.5.2 AUSRIVAS

For single season edge habitats, there were little difference between sites CC2 and CC3 compared to the upstream site CC1, the reference site CC5, and further downstream in Cadiangullong Creek at CC4 (Table 10). The edge habitat at all sites were regularly allocated to Band B indicating significant impairment, fewer families than expected and potential impact on water quality and/or habitat quality. The only exception to this was at CC1 during autumn that was allocated to Band A with most/all of the expected families found and water quality and/or habitat condition roughly equivalent to reference sites. However, for riffle habitats CC2 and CC3 were allocated to Band C, reflecting severe impairment and loss of biodiversity due to substantial impacts on water and/or habitat quality. The riffle habitat at CC4 was allocated to Band A during autumn. There was some variation in the AUSRIVAS Bands for the reference sites on Flyers Creek and Panuara Rivulet. The combined season results do suggests some impairment at CC2 and CC3 compared to other sites. Of note is the autumn riffle habitats in Panuara Rivulet that were allocated to Band D that demonstrates extreme impairment and extremely poor water and/or habitat quality. The edge habitat on Rodd's Creek was similar to reference conditions and allocated to Band A in both seasons.

3.5.3 SIGNAL-2

For edge habitats, there was a large degree of variation in SIGNAL-2 results amongst sites (Table 10). However, in both seasons CC2, CC3 and CC4 were less than the upstream sites (CC5 and CC1) on Cadiangullong Creek. The upstream sites were generally similar or even greater than scores observed on the Flyers Creek, Panuara Rivulet and Swallow Creek reference sites. SIGNAL-2 of Diggers Creek was usually less than the upstream sites on Cadiangullong Creek and the reference sites. The exception was during spring when Diggers Creek exceeded the SIGNAL-2 scores of Panuara Rivulet. There was variation in the patterns of SIGNAL-2 for riffle habitats. During spring there were little differences amongst sites on Cadiangullong Creek and all sites were less than the Flyers Creek reference sites. In autumn, CC3 had a lower score than CC4 and the reference sites.

All sites were within either quadrant 2 or quadrant 4 of the SIGNAL-2 family bi-plot (Figure 12 and Figure 13). The spread of samples across the two quadrants is not season specific, with SIGNAL-2 scores spread across the two quadrants for both edge and riffle habitats. Results in quadrant 2 may indicate high salinity or nutrient levels (may be natural), while results in quadrant 4 may indicate urban, industrial or agricultural pollution or the downstream impacts of dams (Chessman, 2001).

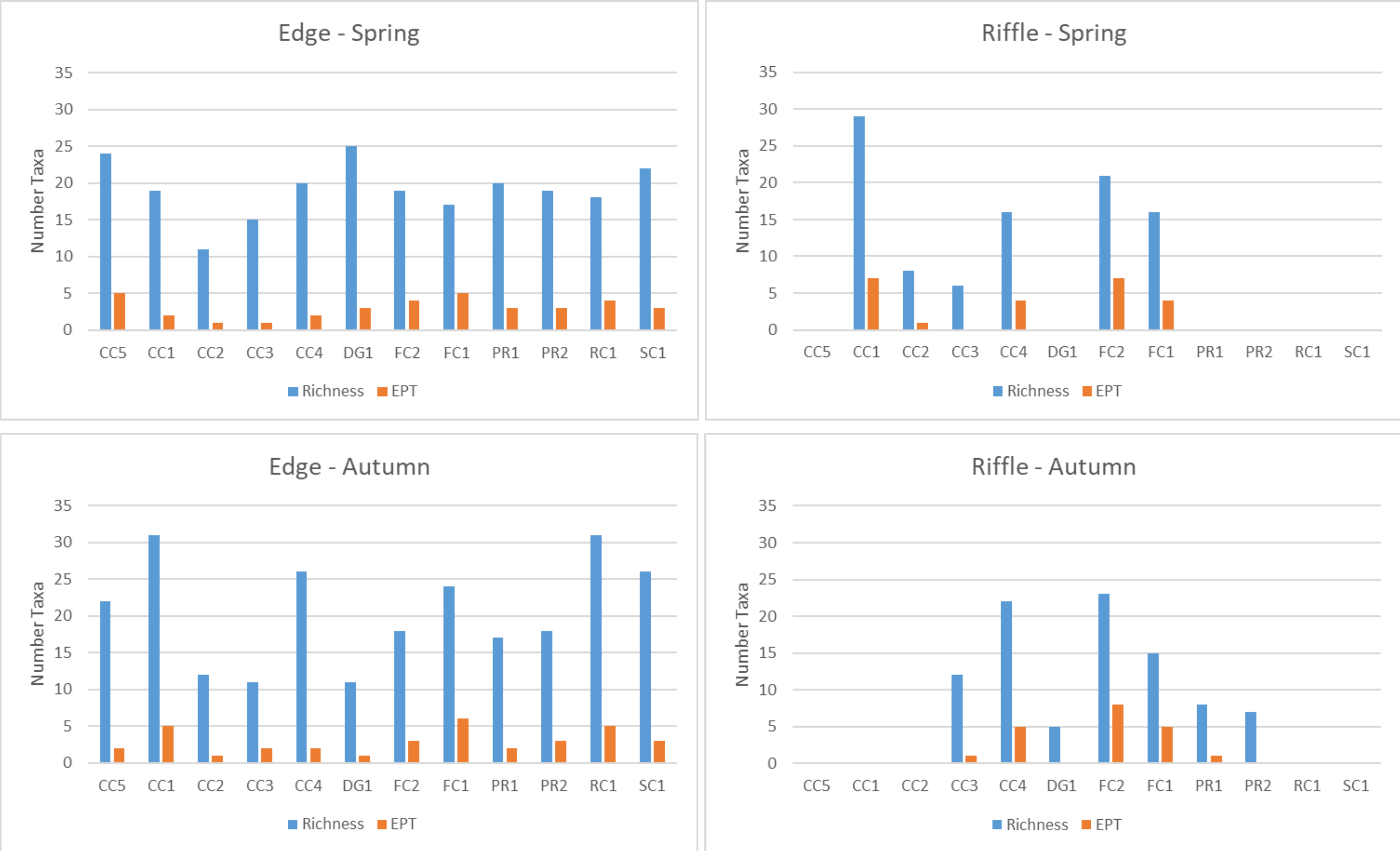

Figure 11 Taxa and EPT richness during spring and autumn for each site

Table 10 Summary of macroinvertebrate biological indices

Site	Habitat	Season	Taxa richness	EPT richness	SIGNAL-2 score	AUSRIVAS		
						O/E50	Band	Combined season Band
CC5	Riffle	Spring	No samples					
		Autumn						
	Edge	Spring	24	5	4.05	0.75	B	B
		Autumn	22	2	3.35	0.62	B	
CC1	Riffle	Spring	29	7	4.19	0.77	B	NA
		Autumn	No sample					
	Edge	Spring	19	2	3.73	0.56	B	A
		Autumn	31	5	3.48	1.06	A	
CC2	Riffle	Spring	8	1	4.29	0.23	C	NA
		Autumn	No sample					
	Edge	Spring	11	1	3.18	0.56	B	B
		Autumn	12	1	3.27	0.53	B	
CC3	Riffle	Spring	6	0	4.20	0.31	C	C
		Autumn	12	1	3.33	0.37	C	
	Edge	Spring	15	1	2.93	0.66	B	B
		Autumn	11	2	2.67	0.70	B	
CC4	Riffle	Spring	16	4	4.14	0.56	B	B
		Autumn	22	5	4.57	0.90	A	
	Edge	Spring	20	2	2.94	0.73	B	A
		Autumn	26	2	3.04	0.78	B	
FC1[4]	Riffle	Spring	16	4	4.79	0.62	B	B
		Autumn	15	5	4.54	0.75	B	
	Edge	Spring	17	5	3.50	0.73	B	A
		Autumn	24	6	3.65	0.96	A	
FC2[4]	Riffle	Spring	21	7	4.84	0.72	B	B
		Autumn	23	8	5.00	0.75	B	

[4] Site were originally outside experience of the model due to high alkalinity. Alkalinity was reduced to allow model to run.

Site	Habitat	Season	Taxa richness	EPT richness	SIGNAL-2 score	AUSRIVAS		
						O/E50	Band	Combined season Band
	Edge	Spring	19	4	3.67	0.65	B	A
		Autumn	18	3	3.06	0.87	A	
PR1	Riffle	Spring	No sample					NA
		Autumn	8	1	3.75	0.30	D	
	Edge	Spring	20	3	3.17	1.00	A	A
		Autumn	17	2	3.35	0.87	A	
PR2	Riffle	Spring	No sample					NA
		Autumn	7	0	3.29	0.30	D	
	Edge	Spring	19	0	3.29	0.91	A	A
		Autumn	18	3	3.53	0.78	B	
SC1	Riffle	Spring	No samples					
		Autumn						
	Edge	Spring	22	3	3.37	0.92	A	A
		Autumn	26	3	3.52	0.87	A	
DG1	Riffle	Spring	No sample					NA
		Autumn	5	0	3.67	OEX	OEX	
	Edge	Spring	25	3	3.43	OEX	OEX	OEX
		Autumn	11	1	3.00	0.44	C	
RC1[4]	Riffle	Spring	No samples					
		Autumn						
	Edge	Spring	18	4	3.56	1.01	A	A
		Autumn	31	5	3.46	0.96	A	

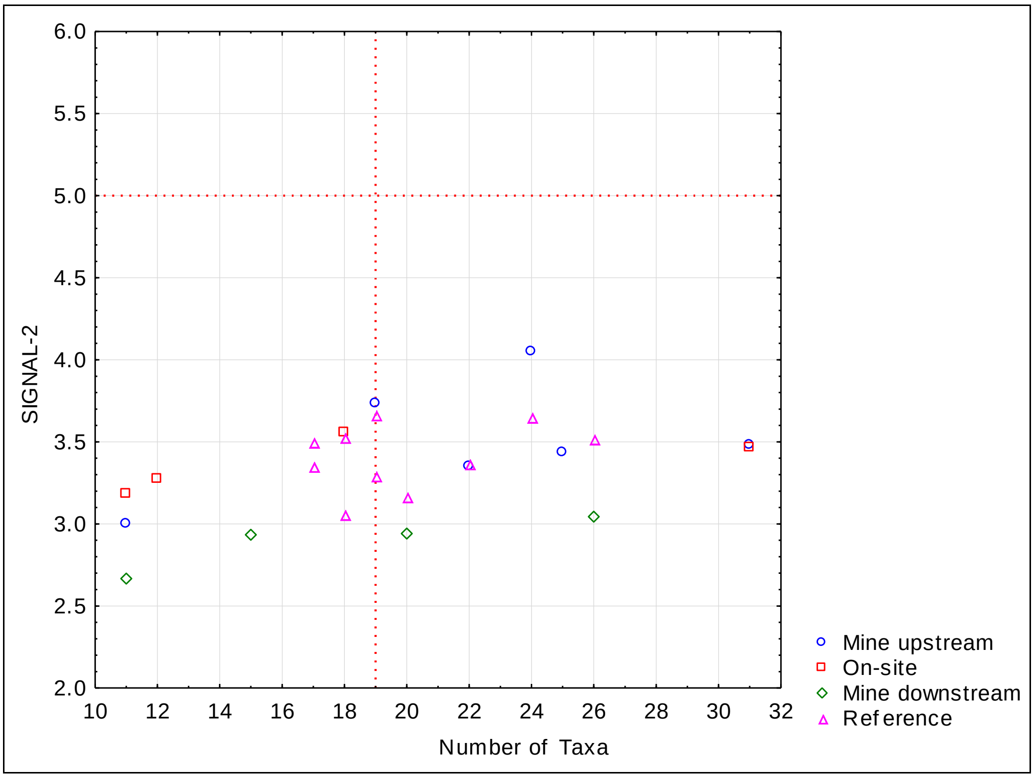

Figure 12 SIGNAL-2 bi-plot for the spring and autumn edge samples (red lines indicate the NSW interim SIGNAL-2 quadrant boundaries)

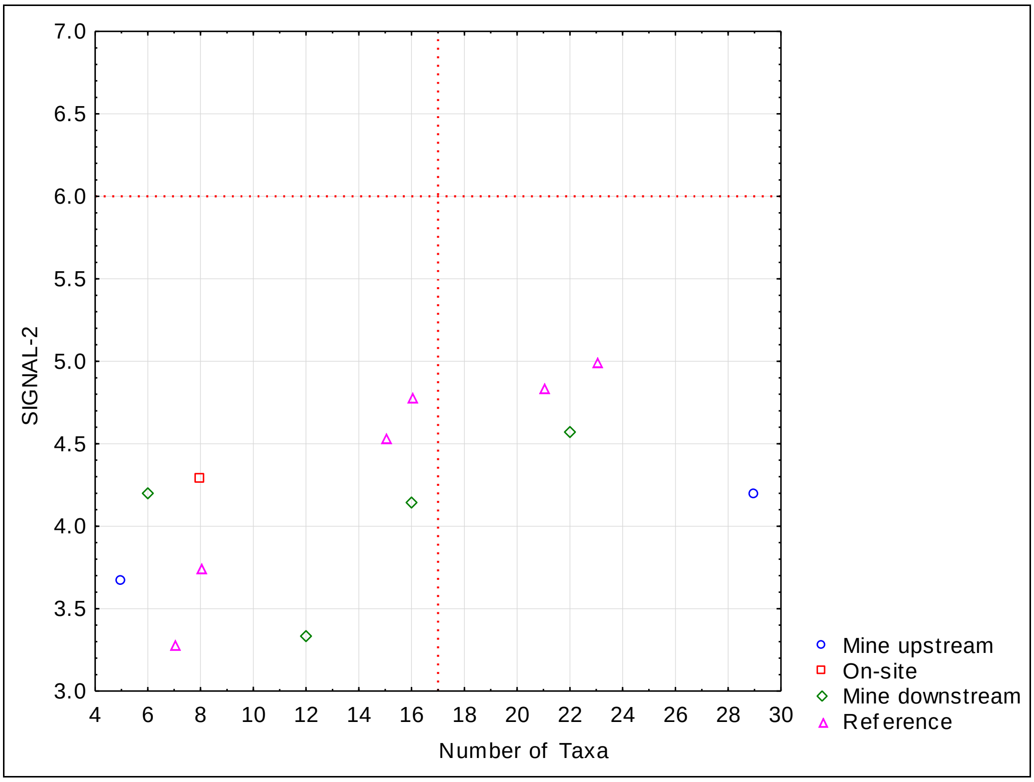

Figure 13 Combined season riffle SIGNAL-2 bi-plot (red lines indicate the NSW interim SIGNAL-2 quadrant boundaries)

3.5.4 Multivariate analyses

Riffle habitats

The nMDS ordination of spring riffle habitats shows separation of CC2 and CC3 from the other sites on Cadiangullong Creek (Figure 14). Furthermore, there is grouping of the upstream site CC1 and the downstream site CC4 with the references sites on Flyers Creek. This suggests there were different macroinvertebrate communities at CC2 and CC3 compared to the other sites. A similar pattern was also found for autumn although the reference sites on Panuara Rivulet were different to the other reference sites (Figure 15). The riffle on Diggers Creek was most different to all other sites. Despite these patterns, there were no significant differences in the riffle macroinvertebrates communities associated with the different treatment types detected by the ANOSIMs during spring (R = 0.346; *P* = 0.222) or autumn (R = 0.367; *P* = 0.105).

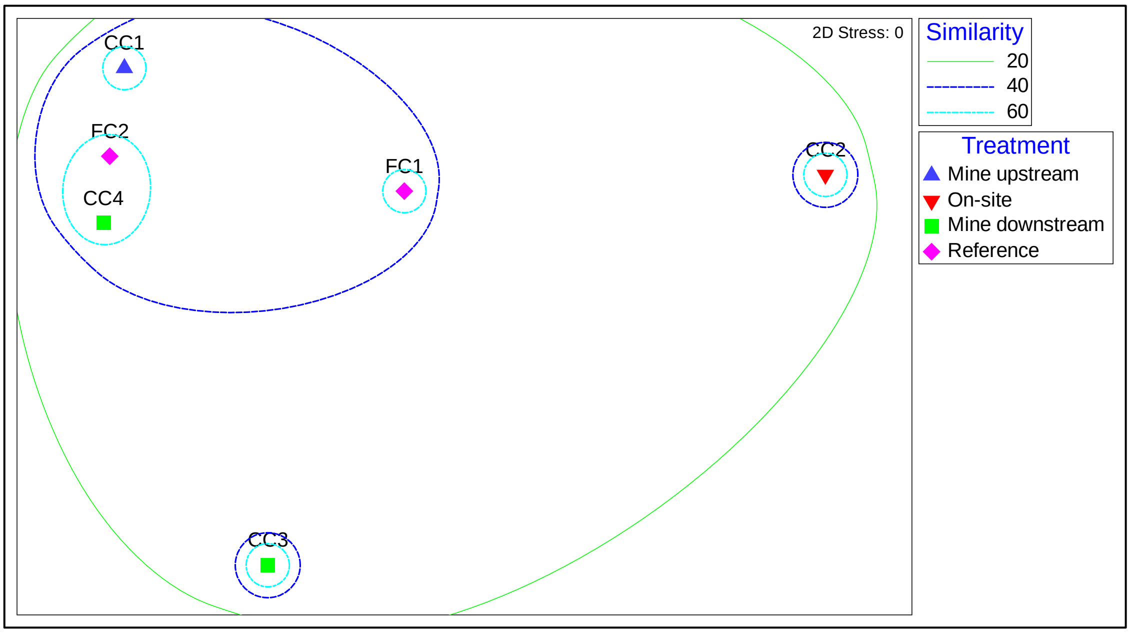

Figure 14 NMDS analysis of spring riffle data displaying influence of site treatment on the similarities of macroinvertebrate communities

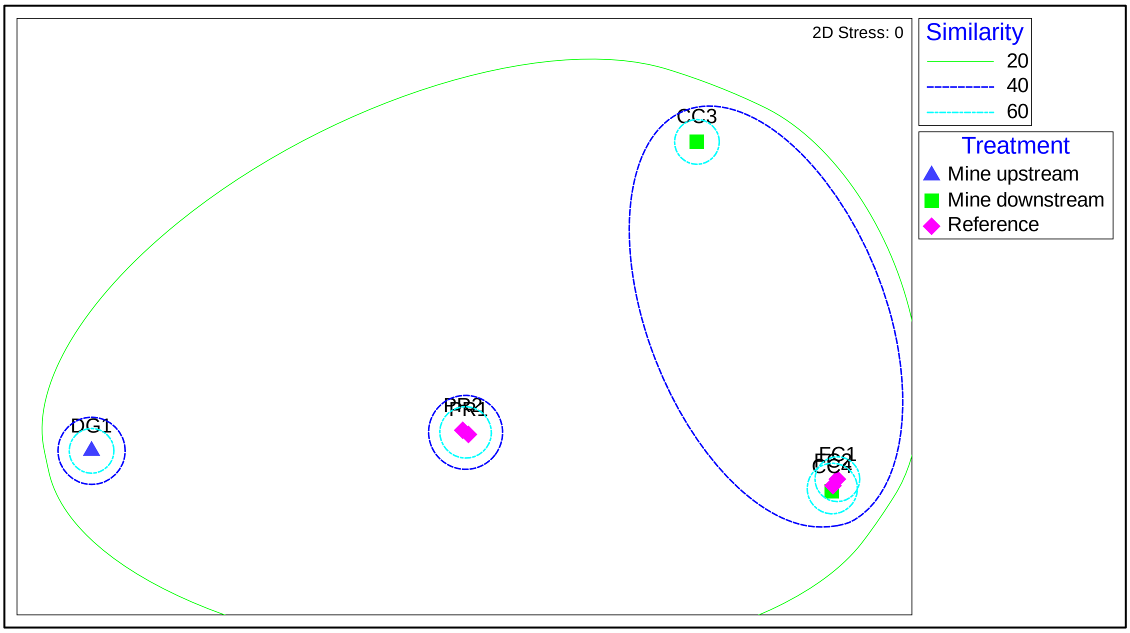

Figure 15 NMDS analysis of autumn riffle data displaying influence of site treatment on the similarities of macroinvertebrate communities

Edge habitats

The nMDS ordination for spring edge habitats also suggest that CC2 and CC3 had a different macroinvertebrate community than other Cadiangullong Creek sites (Figure 16). Although the reference sites on Flyers Creek and Panuara Rivulet were more similar to one other than those on Cadiangullong Creek, the upstream sites CC5 and CC1 and the downstream site CC4 were had a macroinvertebrate community more similar to the reference sites than the other Cadiangullong Creek sites, including Diggers Creek and Swallow Creek. Rodd's Creek also had a similar community to the reference sites. A similar pattern was detected for edge habitats during autumn although the on-site CC2 was more separated from all other sites (Figure 17).

Significant differences in the macroinvertebrates communities associated with the different treatment types were detected by the ANOSIMs for both spring (R = 0.306; P = 0.043) and autumn (R = 0.363; P = 0.019). However, there were no significant pairwise comparison amongst any of the treatments.

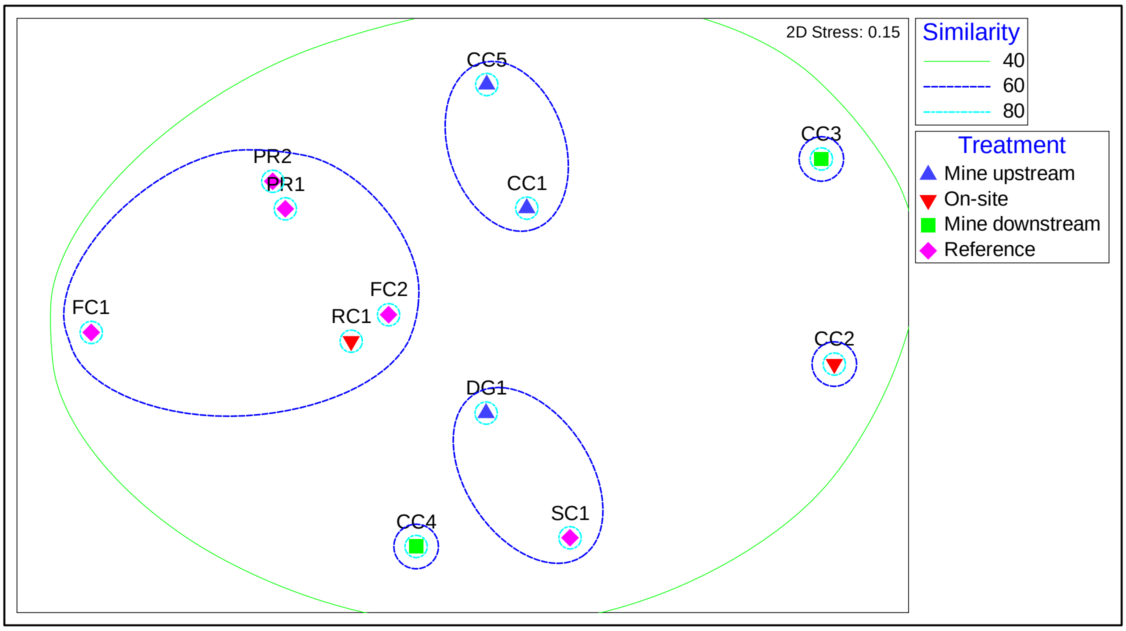

Figure 16 NMDS analysis of spring edge data displaying influence of site treatment on the similarities of macroinvertebrate communities

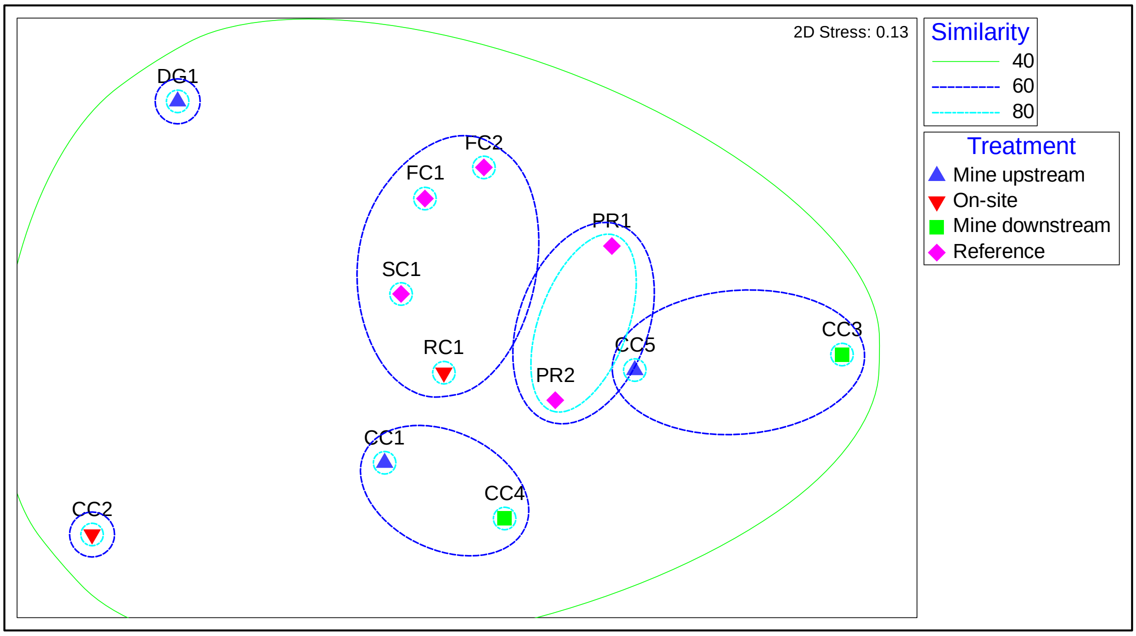

Figure 17 NMDS analysis of autumn edge data displaying influence of site treatment on the similarities of macroinvertebrate communities

3.6 Sediment / macroinvertebrate relationship

The sediment PCA ordination suggested there was Diggers Creek (DG1) differed to other sites due to a combination of relatively higher concentrations of arsenic, lead and zinc and mercury. For the other sites, there was elevated copper at CC2 and CC3 and seasonal variation with higher concentrations of mercury during spring, and higher beryllium and aluminium during autumn. Previous analyses of macroinvertebrate communities as part of the AEMP have also found significant seasonal differences (not presented in this report). The RELATE procedure determined that there was no significant correlation between patterns in the sediment quality and macroinvertebrate communities for edge samples (Rho 0.189, P = 0.069). For riffles samples, this correlation was significant (Rho 0.428, P = 0.014). However, the edge sample correlation was almost significant and for both habitats, significant correlations were detected when each season was analysed separately.

The BEST procedure determined there were four models that had significant correlations between sediment quality and macroinvertebrate communities (Table 11). The combination of sediment analytes that correlated varied for each of the models but overall, the analytes that correlated were aluminium, arsenic, beryllium, cadmium, copper, molybdenum, nickel and selenium.

Table 11 BEST results of associations between macroinvertebrate communities and sediment quality. Analyses completed for all sites and Cadiangullong Creek (CC) only, and for edge and riffle habitats separated and combined habitats. Significant results at the *P* = 0.050 level in red

Sites	Model	BEST Variables	Correlation	BEST *P*
All	Spring edge	Molybdenum, Selenium	0.620	0.050
All	Spring riffle	Aluminium, Arsenic, Copper, Molybdenum, Selenium	0.905	0.140
All	Spring combined	Molybdenum, Selenium	0.677	0.010
CC only	Spring edge	Aluminium, Arsenic, Cadmium, Nickel, Selenium	0.888	0.030
CC only	Spring riffle	Iron, Chromium, Zinc, Arsenic, Barium, Beryllium, Cadmium, Cobalt, Lead, Nickel, Selenium, Mercury	0.928	0.700
CC only	Spring combined	Aluminium, Chromium, Zinc, Arsenic, Cadmium	0.903	0.060
All	Autumn edge	Beryllium, Cadmium, Copper, Molybdenum	0.695	0.060
All	Autumn riffle	Chromium, Beryllium, Cadmium, Copper, Lead, Molybdenum, Selenium	0.757	0.090
All	Autumn combined	Beryllium, Cadmium, Copper, Molybdenum	0.738	0.020
CC only	Autumn edge	Chromium, Arsenic, Beryllium, Cadmium, Molybdenum	0.794	0.460
CC only	Autumn riffle	Not enough replication		
CC only	Autumn combined	Chromium, Arsenic, Beryllium, Cadmium, Molybdenum	0.721	0.660

Results of the DISTLM procedure are included in Table 12 and indicate that of the sediment analytes combinations that best correlated to the macroinvertebrate communities, only molybdenum and cadmium significantly correlated. Furthermore, molybdenum explained 25% of the variation to both the spring edge and spring combined habitat models for all sites, and cadmium 18% to the autumn combined habitat model for all sites. There was no significant correlation when Cadiangullong Creek was analysed alone, although aluminium and arsenic were close to being significant.

Table 12 DISTLM results of associations between macroinvertebrate communities and sediment quality. Significant results at the *P* = 0.050 level in red

Sites	Model	Variables	DISTLM *P*	Variation explained (%)
All	Spring edge	Molybdenum	0.002	25
		Selenium	0.157	13
All	Spring combined	Molybdenum	0.005	25
		Selenium	0.392	10
CC only	Spring edge	Aluminium	0.064	35
		Arsenic	0.054	36
		Cadmium	0.420	26
		Nickel	0.522	28
		Selenium	0.166	32
All	Autumn combined	Beryllium	1.000	<1
		Cadmium	0.012	18
		Copper	0.237	11
		Molybdenum	1.000	<1

The DISTLM results are included on the macroinvertebrate nMDS ordinations with the relative concentration of sediment analytes as bubble plots in Figure 18 to Figure 20. The ordinations illustrate the relatively higher molybdenum concentrations in Diggers Creek (DG1) and Cadiangullong Creek (CC5, CC2 and CC3). Selenium was also high at these sites (excluding CC2) and Swallow Creek. The results also indicate the low molybdenum and selenium concentrations at the reference sites, CC1, CC4 and Rodd's Creek. Beryllium was relatively similar at all sites, while cadmium was elevated at Diggers Creek. Copper was noticeably higher at CC2 and CC3 on Cadiangullong Creek.

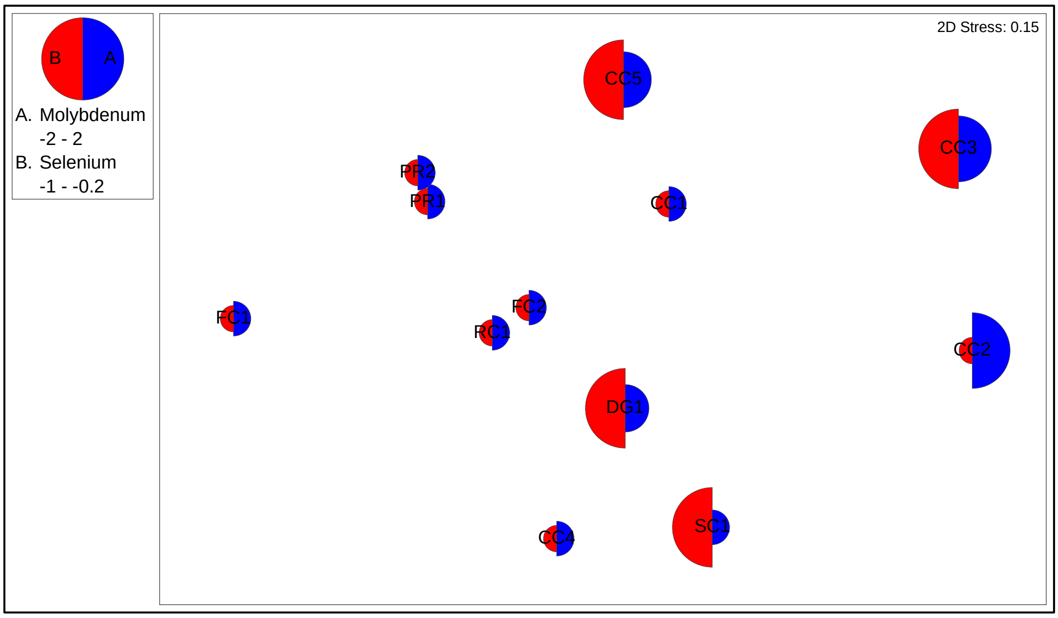

Figure 18 NMDS ordination indicating association between sediment analytes and macroinvertebrates from spring edge habitats for all sites. Bubble plots showing relative concentration of sediment analytes

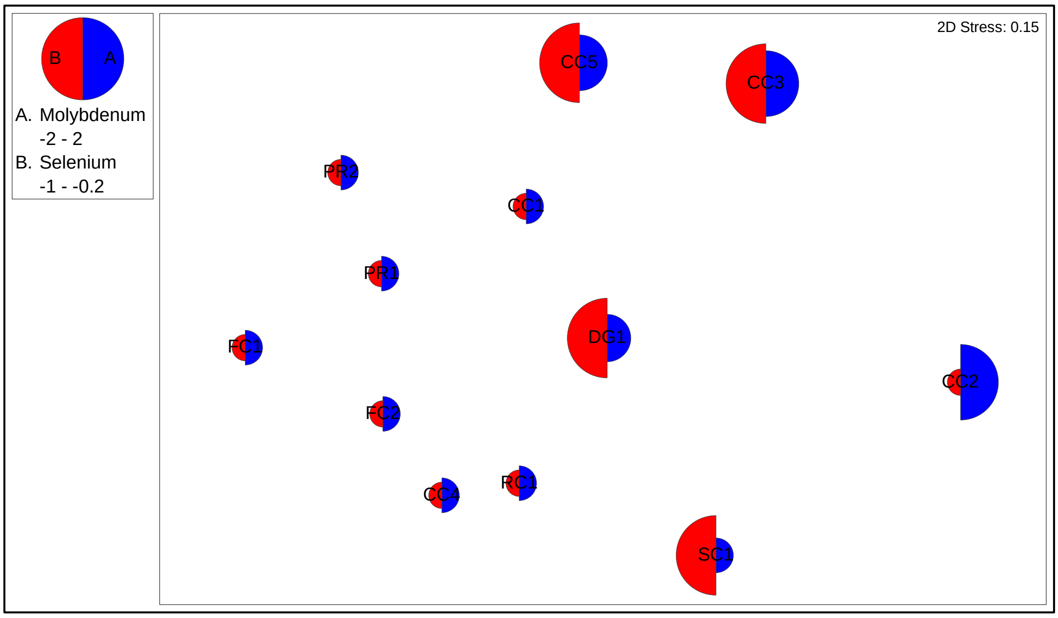

Figure 19 NMDS ordination indicating association between sediment analytes and macroinvertebrates from spring (combined habitats) habitats for all sites. Bubble plots showing relative concentration of sediment analytes

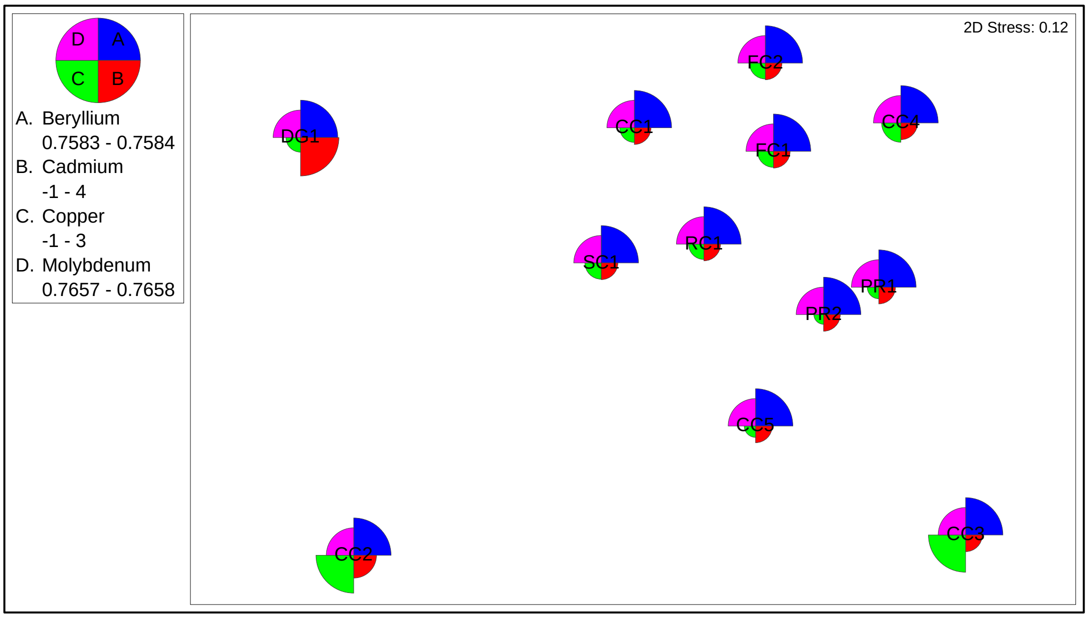

Figure 20 NMDS ordination indicating association between sediment analytes and macroinvertebrates from autumn (combined habitats) for all sites. Bubble plots showing relative concentration of sediment analytes

3.7 Fish

Mountain Galaxias (*Galaxias olidus*) were collected from all sites on Cadiangullong Creek with the exception of CC2. However, they were absent from CC5 and Swallow Creek during spring, and Panuara Rivulet in both seasons. Summary statistics of Mountain Galaxias collected in spring and autumn are presented in Table 13. In addition to the native *Galaxias olidus*, four introduced Mosquitofish (*Gambusia holbrooki*) were collected from FC1 and one from FC2 in Flyers Creek. Five freshwater crayfish were also collected from CC5 during autumn.

Table 13 Total catch and summary statistics of total tenth (mm) of Mountain Galaxias (*G. olidus*) caught at each site per season

Site	Season	N	Mean	Median	Min	Max	10th percentile	90th percentile	Std. Dev.
CC5	Spring	No fish collected							
	Autumn	1	62	62	62	62	62	62	NA
CC1	Spring	6	51	52	45	55	47	54	4
	Autumn	34	52	45	37	88	40	78	15
CC2	Spring	No fish collected							
	Autumn								
CC3	Spring	8	57	56	47	68	51	64	7
	Autumn	22	56	57	40	78	43	66	9
CC4	Spring	8	57	60	25	75	42	69	17
	Autumn	29	67	65	42	90	54	83	11
FC2	Spring	42	68	71	24	96	57	83	14
	Autumn	96	70	66	53	100	55	90	12
FC1	Spring	26	51	65	17	80	24	75	23
	Autumn	50	69	63	51	100	55	90	13
PR1	Spring	No fish collected							
	Autumn								
PR2	Spring								
	Autumn								
SC1	Spring	No fish collected							
	Autumn	17	67	68	50	84	52	82	12

Histograms of total length of Mountain Galaxias indicates all site treatments have a wide distribution of lengths, indicating a combination of recent recruits and older fish (Figure 21). This suggests that sites across all treatments are maintaining self-sustaining populations with adequate recruitment levels.

The Gaussian kernel curves indicate that during spring, smaller Mountain Galaxias were collected. There was also some variation in size amongst the site treatments. During spring, most individuals were in the 50 to 60 mm range upstream and downstream of the mine, while larger fish in the 70 to 80 mm range were collected at the Flyers Creek and Swallow Creek reference sites. During autumn smaller fish in the 40 to 45 mm range were collected upstream of the mine, with larger fish in the 60 to 70 mm range downstream of the mine and at the reference sites. It should be noted that the upstream treatment during spring is only represented by CC1 as no Mountain Galaxias were collected at CC5. Furthermore, no fish surveys are undertaken at DG1 (the other upstream treatment site).

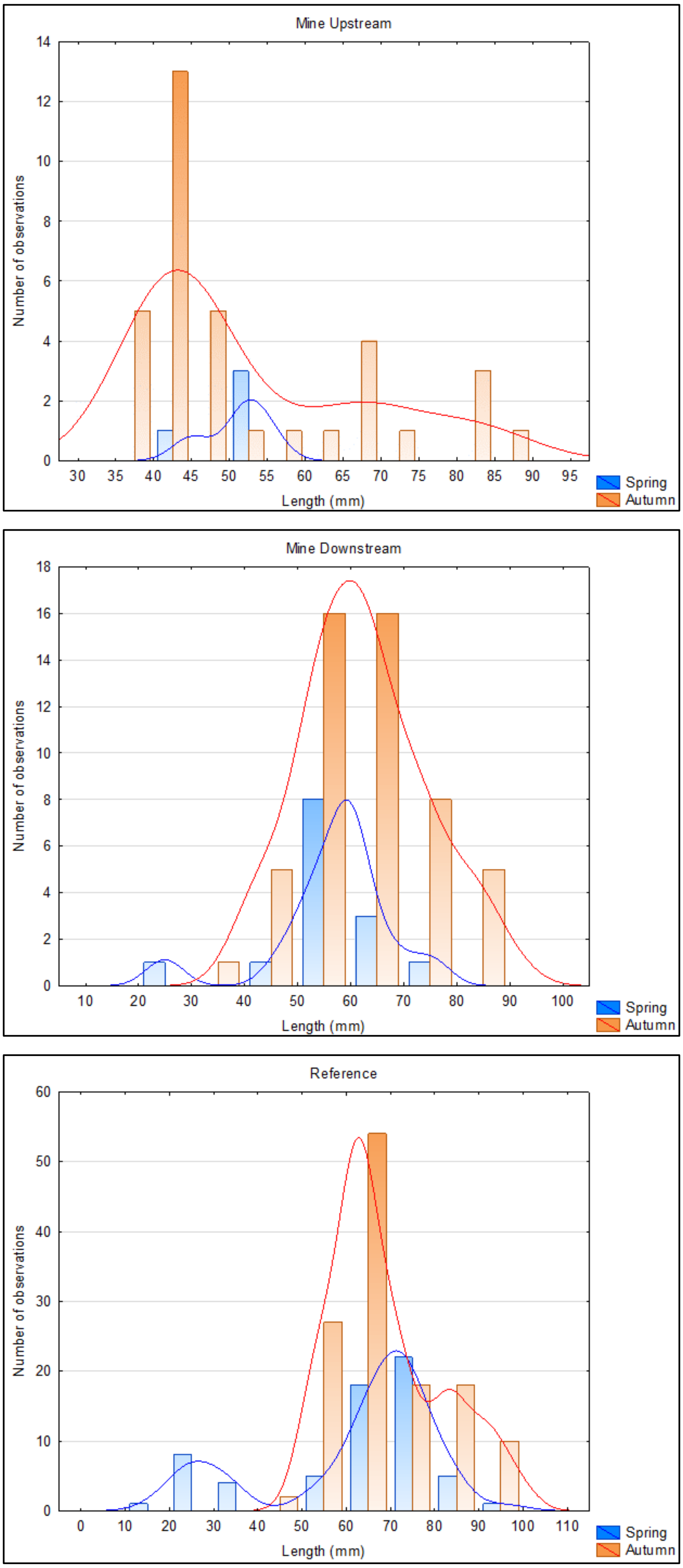

Figure 21 Histograms of total length (mm) of Mountain Galaxias categorised by site treatment with Gaussian kernel density curves

4. Discussion

4.1 Rainfall and hydrology

This report presents the results from the spring 2019 and autumn 2020 monitoring for the CVO AEMP. Over the five months prior to spring total monthly rainfall was consistently below the long-term average. However, significant rainfall events exceeded the long-term average by 189% and 335% during March and April respectively.

Discharge in Cadiangullong Creek upstream of the dam (CC5) reflected the pattern in rainfall with an increase in mean daily following increased spring rainfall from August to September and autumnal rainfall from March to May. Downstream of Cadiangullong Dam at CC1, flow generally remained low from June to late September, after which flow increased and remained relatively constant between 2.1 and 5.6 ML/day due to a combination of releases and natural flow events until mid-February. This was followed by another low flow period until increased rainfall from late March to the end of May contributed to increased flow events.

Under normal circumstances, releases are in accordance with Condition 27 of the Project Approval PA06_0295 to meet the criteria listed in Table 14. However, due to ongoing dry conditions and limited water availability in Cadiangullong Dam, CVO submitted a request to the Department of Industry (Water) for the following variations to the flow criteria:

Suspend condition 27 and 28 in Schedule 3 and insert the following:

27A Despite Condition 27 and 28, during the period 1 February 2019 and 31 December 2019, if the water stored in Cadiangullong Dam is:

a. Less than 1050 ML (25% capacity) of the Dam's capacity, then the Applicant may cease releasing water from the Dam entirely

b. Between 1050 ML (25% capacity) and 2100 (50% capacity) of the Dam's capacity, then the Applicant must release (as measured at the Dam wall's discharge point) a minimum of 0.4 ML/day measured at the Oakley Creek gauging stations

c. At any time exceeds 2100 ML (50% capacity) of the Dam's capacity, then releases are to be resumed in accordance with condition 27 for the remainder of the period

Table 14 Cadiangullong flow criteria

Cadiangullong Dam			Inflow	Downstream minimum	Other conditions
RL (masl)	Volume (ML)	Capacity (%)	ML/day @ GS412168	ML/day @ GS412702	
>778.8	420 to 4200	10 to 100	0 to 0.4	0.4	
			0.4 to 3.47	Inflow	
			>3.4	3.4	
773 – 778.8	170 to 420	4 to 10	0 to .04	0.4	No water to be extracted
			0.4 to 3.4	Inflow	
			>3.4	3.4	
762.8 – 773	5 to 170	0.1 to 4	0 to 0.4	Inflow*	
			>0.4	0.4*	
<762.8	5	0.1		No release required	

*Measured at the Dam GS412144

Permission was granted by the Department of Industry (Water) for the variations to flow criteria and releases from Cadiangullong Dam were ceased in May 2019. This contributed to the low flow and cease-to-flow events at sites downstream of the dam up until late September. Despite the variation in rainfall and discharge, flow conditions at the time of monitoring during spring 2019 and autumn 2020 were similar to previous seasons of the AEMP.

4.2 Aquatic habitat

All waterways assessed as part of the AEMP are subject to disturbance from different land use activities. This includes changes to Cadiangullong Creek due to activities within the CVO MLA, and agricultural uses further downstream. The upstream reference site (CC5) is also located in a modified landscape surrounded by pine plantations. During autumn 2020, harvesting of the plantations near CC5 was noted which is likely to lead to further changes in the condition of the waterway (Plate 4).

Plate 4 Bare landscape surrounding the reference site CC5 on Cadiangullong Creek following harvesting of pine plantations

The reference sites on Flyers Creek, Panuara Rivulet and Swallow Creek represent a degree of waterway health in the absence of direct activities associated with the CVO MLA. These reference sites have limited riparian vegetation and are subject to stock access and other agricultural pressures. Overall, all sites monitoring as part of the AEMP are generally consider to have a high or extreme level of disturbance.

4.3 Water quality

In Cadiangullong Creek, the longitudinal increase in electrical conductivity (EC) was consistent with previous monitoring periods. Downstream of the dam EC was elevated in autumn compared to spring, likely due to the reduced flow and an increase in groundwater contribution. Sites CC5, CC1 and CC2 remained relatively fresh in both seasons while the higher EC further downstream at CC3 and CC4 regularly exceeded the ANZG (2018) default guideline value.

The high pH levels and low Dissolved Oxygen (DO) were largely consistent with values seen in previous monitoring periods and often failed to comply with the ANZG (2018) default guideline values. This may be related to the time of day of monitoring due to photosynthesis reducing DO and increasing the proportion of carbon dioxide. Carbon dioxide (CO2) is acidic and the sequestration of CO2 during photosynthesis increases the pH of water. However, the increased pH may also be related to changing land use between sites, or a combination of this and photosynthesis. It should be noted that a recent review of the water quality guidelines at CC4 has been completed by GHD (2018). The review recommends a set of site-specific trigger values for CC4 based on the historical data for that site.

Overall, the results do not suggest that CVO had a detectable influence on the surface water quality during the spring 2019 and autumn 2020 monitoring. Increases in EC were not beyond expected levels for the region based on the other waterways monitored. The high pH and low dissolved oxygen observed in Cadiangullong Creek also occurred in other waterways. The tailing dam also appears to have negligible impact on water quality in Rodd's Creek (RC1) based on comparisons with the previous monitoring periods and other waterways.

4.4 Sediment quality

Of the metals that have DGVs published, only arsenic, chromium, copper, lead and nickel were exceeded. Of these, only arsenic and copper exceeded the ANZG (2018) upper default guideline value. Arsenic was exceeded in Diggers Creek (DG1) and copper in Cadiangullong Creek (CC2 and CC3) in both seasons. Compared with other sites, Diggers Creek was found to have higher concentrations of arsenic, lead and zinc and mercury.

As found in other monitoring periods, there was evidence of increased copper concentrations levels in Cadiangullong Creek downstream of the mine at CC2 and CC3 that dissipates further downstream. Due to the geomorphology of CC2, the pool at this site appears to act as sink for copper and other contaminants. For example, during spring copper in the pool was more than doubled that of the riffle. The pool acts as a settlement pond due to dense stands of *Typha* sp. that limits downstream sediment movement during low flows. Sediment transport may occur during higher flow events and the risk of contamination downstream appears to be dependent on a) the connectivity between CC2 and downstream reaches, b) the frequency and size of the high flow events, and c) the size of the sediment particles.

Other than copper, there was no evidence to suggest the CVO MLA is contributing to elevated metals in Cadiangullong Creek when compared to the reference waterways. All metal concentrations in Rodd's Creek were also below the ANZG (2018) default guideline value and there was no evidence to suggest an impact due to seepage from the tailings dam.

Arsenic and chromium was elevated in Flyers Creek as has been found in other seasons. The reason for this is unclear, though blackberry spraying and groundwater seepage may have contributed to the increased arsenic. Nickel was also elevated in Flyers Creek.

4.5 Macroinvertebrate communities

In Cadiangullong Creek, there was some evidence of reduced diversity at CC2 and CC3 compared to other sites. However, the SIGNAL-2 scores at CC2 and CC3 were comparable to, and on occasion greater than, those observed at reference sites on Flyers Creek and Panuara Rivulet. The SIGNAL-2 results also suggest that all waterways monitored may be subject to multiple disturbances irrespective of mine operations including high salinity or nutrient levels, agricultural pollution, or the downstream impacts of dams.

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The AUSRIVAS results also suggest that all waterways monitored regularly have fewer taxa than expected and potential impacts due to water quality and/or habitat quality. Rarely did any site have most/all of the expected taxa found and water quality and/or habitat condition roughly equivalent to reference sites. There was some evidence that sites CC2 and CC3 were less healthy than other sites on Cadiangullong Creek or the reference sites. In general, the EPA consider SIGNAL to be more sensitive to impacts of pollution while AUSRIVAS is relatively more sensitive to impacts on habitat (EPA, 2000). Consequently, it is likely that habitat conditions are more influential on the macroinvertebrate community health at CC2 and CC3 than water or sediment quality. Although all sites are subject to disturbance from different land use activities, extensive willows at CC2 and obvious impacts from stock access at CC3 have reduced habitat diversity at these sites. This would also explain the differences in these sites found by the multivariate analyses. There was also no indication the tailings dam impacted the macroinvertebrate health of Rodd's Creek.

4.6 Sediment / macroinvertebrate relationship

Within each season, there was some evidence to suggest the sediment quality and macroinvertebrate communities correlated. The combination of sediment analytes that correlated varied depending on season and habitat. Overall, the analytes that best correlated were aluminium, arsenic, beryllium, cadmium, copper, molybdenum, nickel and selenium. However, rarely did individual analytes significantly correlate with the macroinvertebrate communities. When there was a significant correlation, it only accounted for a maximum of 25% of the variation. As has been found in previous seasons, the high copper levels at CC2 and CC3 did not have a significant correlation with the macroinvertebrate community composition.

With the exception of copper, relatively high concentrations of metals that best correlated with the macroinvertebrate communities were found at multiple sites in different waterways. This again suggests that habitat quality is likely to be the main driver of macroinvertebrate and waterway health.

4.7 Fish

Overall, the results from the 2019-20 fish monitoring indicate a relatively healthy community dominated by the native Mountain Galaxias (*Galaxias olidus*). Low water levels during both spring and autumn prevented the captured of fish at CC2. However, the species remains distributed throughout Cadiangullong Creek, along with Flyers Creek and Swallow Creek. The absence of fish in Panuara Rivulet, which is consistent with previous seasons, is potentially due to the uncharacteristically low flows that have occurred over the past three years.

The low numbers of fish collected at CC5 and SC1 is consistent with previous seasons and may be due to predatory Trout upstream of Cadiangullong Dam and the small size of Swallow Creek and potentially (Plate 5). It is reported that the presence of trout has reduced the abundance of Mountain Galaxias in lowland streams and completely eliminated them in some upland streams (Lintermans, 2007). The barrier effect of Cadiangullong Dam may also prevent recruitment and recolonisation of upstream reaches. However, it should be noted electrofishing was not possible at CC5 and SC1 and this may have biased the results.

For all treatments (i.e. upstream, on-site, downstream and reference) there was a range of size classes in the fish community. Furthermore, there was an increase in length during autumn compared to spring. This may indicate the recruitment of juveniles during spring that had matured by the following autumn, indicating reasonably healthy self-sustaining with adequate recruitment. On current evidence, the mine does not appear to be negatively impacting populations of Mountain Galaxias.

Plate 5 Juvenile Rainbow Trout (*O. mykiss*) collected at CC5 during autumn 2019 (left) and habitat conditions at SC1 (right)

5. Conclusion

- Over the five months prior to spring total monthly rainfall was consistently below the long-term average. Significant rainfall events exceeded the long-term average by 189% and 335% during March and April respectively.
- Discharge in Cadiangullong Creek upstream of the dam (CC5) reflected the pattern in rainfall with an increase in mean daily following increased spring rainfall from August to September and autumn rainfall from March to May.
- Downstream of Cadiangullong Dam at CC1, flow generally remained low from June to late September, after which flow increased and remained relatively constant between 2.1 and 5.6 ML/day due to a combination of releases and natural flow events until mid-February.
- Disturbances to riparian zone vegetation and broader catchment scale land-use which, aside from mining and associated operations, is heavily influenced by grazing in the mid to lower catchment areas, and pine plantations in the upper catchments, are likely to be impacting on aquatic ecosystem health.
- The decreased flow during autumn was reflected by an increase in electrical conductivity in Cadiangullong Creek, likely due to a concentration effect, increased groundwater contributions, changing land use, or a combination of these factors.
- Variation in dissolved oxygen and pH are likely influenced by photosynthetic activity and land use between sites, or a combination of the two. Overall, the results do not suggest that CVO had a detectable influence on the surface water quality during the spring 2019 and autumn 2012 monitoring. Seepage from the tailing dam also appears to have negligible impact on water quality or sediment quality in Rodd’s Creek (RC1).
- There was evidence of increased copper in the sediments of Cadiangullong Creek downstream of the mine and the pool at CC2 appears to act as a sink for copper and other contaminants. Sediment transport may occur during high flow events thereby increasing the risk of contamination, downstream of CC2. This risk is dependent on a) the connectivity between CC2 and the reaches downstream, b) the frequency and size of the high flow events, and c) the size of the sediment particles.
- All waterways monitored regularly have fewer macroinvertebrate taxa than expected and potential impacts due to water quality and/or habitat quality. Results suggest that all waterways monitored may be subject to multiple disturbances irrespective of mine operations including high salinity or nutrient levels, agricultural pollution, or the downstream impacts of dams.
- There was some evidence that sites CC2 and CC3 were less healthy than other sites on Cadiangullong Creek or the reference sites. It is likely that habitat conditions are more influential on the macroinvertebrate community health at CC2 and CC3 than water or sediment quality.
- Sediment quality analytes that best correlated with macroinvertebrate communities (in no particular order) were aluminium, arsenic, beryllium, cadmium, copper, molybdenum, nickel and selenium. However, sediment analytes were not found to be a major contributor the macroinvertebrate health that is likely driven more by habitat conditions. This includes the relatively high copper concentrations at CC2 and CC3.
- A relatively healthy community fish dominated by the native Mountain Galaxias (*Galaxias olidus*) remains distributed throughout Cadiangullong Creek, along with Flyers Creek and Swallow Creek. There was a range of size classes in the fish community and an increase in length during autumn compared to spring. This may indicate the recruitment of juveniles during spring that had matured by the following autumn, indicating reasonably healthy self-sustaining with adequate recruitment.

6. Recommendations

Point 1 - Cadiangullong Creek was historically an ephemeral creek although operation of Cadiangullong Dam and associated environmental releases has created a permanent flowing system. Recent dry conditions in the region has altered the release requirements from the dam and low flow and cease-to-flow conditions have returned. On occasion, this resulted in low flow and cease-to-flow events in the Creek. Previous monitoring during cease-to-flow periods in Cadiangullong Creek found a loss of riffle habitat and decreased connectivity, increased salinity and decreased dissolved oxygen and a decrease in the health of the macroinvertebrate and Mountain Galaxias community (Ecowise, 2007).

- **Recommendation**: The AEMP should be maintained (and perhaps enhanced) during future non-release periods to provide information on how the aquatic ecosystem is performing and coping.

Point 2 - Groundwater seepage into Cadiangullong Creek has been observed downstream of CC2. This would have maintained some degree of base flow at the sites farther downstream and helped to maintain ecological health of the aquatic community during the no release period.

- **Recommendation**: Determining the contribution of groundwater to base flow in Cadiangullong Creek may support future cease to release applications for CVO. For example, the modelling of groundwater contribution may identify flow levels that are maintained in the absence of releases and may allow further amendments to flow criteria to be made.

Point 3 – The monitoring has identified elevated metals, particularly copper, in Cadiangullong Creek likely due to the mining activities. However, quantifying the potential risks of heavy metals in Cadiangullong Creek will require additional effort. For example, a maximum of two macroinvertebrate samples are collected from each site in a given season (if a riffle is present). This limits the power of statistical analyses and the ability to assess correlations between the macroinvertebrates and sediment quality. Although the findings in this report use a variety of approaches to investigate potential impacts (e.g. univariate and multivariate analyses), further investigation into the potential impacts of heavy metals may be warranted.

- **Recommendation:** Rather than increase sample size and subsequent costs, it is recommended to continue monitoring sediment as a means to further investigate the role of metals in waterway health. A long term analyses of correlations between sediment analytes and macroinvertebrates should be undertaken to further investigate potential impacts using the historical data to increase sample size.
- **Recommendation:** The high concentrations of copper at CC2 suggests that the mine may be the source. However, this is only inferred based on site locations and does not indicate causation. The source of contaminants in the waterways can be further examined using 2D sediment modelling or the tracking of sediments through the use of stable isotopes.

Point 3 – Although Mountain Galaxias populations in Cadiangullong Creek and the other waterways have been found to be in relatively good health, further stress on the populations may occur during ongoing low flow periods and cease to release periods. Continued monitoring should occur to further investigate threats to the populations.

- **Recommendation –** Due to variation in site characteristics, a standardised electrofishing survey was not possible at all sites. This makes comparison of sites problematic. Furthermore, the use of bait traps has an associated risk to Mountain Galaxias from predation by other species, and the stress of trapping. There is also a chance that fish will be missed during surveys, particularly when using bait traps.

  Environmental DNA (eDNA) has been proven an effective means of assessing the distribution of fish populations and removes ethical issues associated with bait traps and electrofishing. It is recommended to adopt an eDNA survey protocol to remove these ethical issues and allow for an intensive and standardised approach. This may also allow for a biodiversity screen to be done to determine additional species not targeted in the current surveys.

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Appendices

Appendix A – Site location details for the CVO AEMP

Site Code	Site Name	Position Relative to Potential Impacts and CVO	Latitude	Longitude	Catchment Area (km^2)
CC5	Cadiangullong Creek at Forestry gauging station	Downstream of Canobolas State Forest (pine plantation); upstream of CVO	-33.41563	148.98528	33.44
CC1	Cadiangullong Creek 200 m downstream of Cadiangullong Dam	Downstream of Cadiangullong Dam; upstream of CVO mining facilities	-33.43592	148.99287	40.28
CC2	Cadiangullong Creek at South Portal Road (lower cutting)	Downstream of Cadiangullong Dam; downstream of Cadiangullong Creek diversion; adjacent to Cadia pit (now in care and maintenance phase)	-33.46092	148.98957	58.16
CC3	Cadiangullong Creek at Southern Lease Boundary	Downstream of CVO facilities; upstream of tailings dams; grazing in surrounding lands	-33.49894	148.97604	72.71
CC4	Cadiangullong Creek at Oaky Creek Gauging Station	Downstream of CVO facilities; downstream of tailings dams; grazing in surrounding lands	-33.53951	148.97173	107.36
FC2	Flyers Creek at Extraction Weir	Catchment east and adjacent to Cadiangullong Creek catchment; grazing and pine plantation in surrounding lands; upstream of Flyers Creek Extraction Weir	-33.47829	149.04060	52.36
FC1	Flyers Creek at Martin Road Gauging Station	Catchment east and adjacent to Cadiangullong Creek catchment; grazing and pine plantation in surrounding lands; downstream of Flyers Creek Extraction Weir	-33.48849	149.03539	56.16
SC1	Swallow Creek at Gauging Station No. 412167	Catchment west and adjacent to Cadiangullong Creek catchment; grazing in surrounding lands; downstream of Ridgeway underground mine sinkhole	-33.48234	148.95974	17.97
PR1	Panuara Rivulet upstream of Revegetation Area	Catchment west of CVO; located on leased sheep grazing property; upstream of proposed revegetation area	-33.49671	148.89010	54.04
PR2	Panuara Rivulet downstream of Revegetation Area	Catchment west of CVO; located on leased sheep grazing property; downstream of proposed revegetation area	-33.52097	148.87873	58.72
RC1	Rodd's Creek upstream of Cadiangullong Creek	Downstream of tailing dams on Rodd's Creek; upstream of CVOCC4 confluence with Cadiangullong Creek	-33.53107	148.98513	21.14
DG1	Diggers Creek at Diggers Weir Station No. 412166	Upstream of Panuara Rivulet, catchment adjacent to, but not influenced by mining operations.	-33.43434	148.93373	5.29

Appendix B – Field sheets summarising habitat conditions

	Site	CC5	CC1	CC2	CC3	CC4	FC1	FC2	PR1	PR2	SC1	RC1	DG1
Site Attributes	Topography	Broad Valley	Steep Valley	Steep Valley	Broad Valley	Steep Valley	Steep Valley	Broad Valley	Broad Valley	Broad Valley	Broad Valley	Steep Valley	Broad Valley
	Water Level	Low	Moderate	Low	Low	Low	Low	Moderate	NF	NF	Low	Low	Low
	Shading of River	Moderate	High	Low	Moderate	Moderate	None	Low	Low	Low	None	None	Low
	Trees >10 m	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
	Trees <10 m	60	10	15	15	45	5	5	1	5	15	2	5
	Shrubs / Vines / Rushes	30	30	5	5	10	5	3	0	30	5	5	0
	Grasses / Herbs / Ferns	40	90	40	80	3	80	95	30	15	90	90	90
	Stream Width - Min	1	1	1	0.5	3	0.5	2	0	0	51	1	1
	Stream Width - Max	5	6	5	2	7	2	12	4	3	2	2	1
	Stream Width - Mode	3	3	1.5	1	4	1.5	5	0.5	1.5	1	1	1
Land Use	Left Bank	Forestry	Exotic Grassland (no grazing)	Mining (Open Cut)	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing
	Right Bank	Forestry	Exotic Grassland (no grazing)	Exotic Grassland (no grazing)	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing	Grazing
Riffle	Bedrock	/	10	/	5	0	5	15	30	/	/	/	/
	Boulder	/	20	/	20	2	10	10	40	0	/	/	/
	Cobble	/	40	/	40	30	45	20	20	/	/	/	/
	Pebble	/	5	/	10	35	15	20	5	/	/	/	/
	Gravel	/	5	/	10	20	10	10	1	/	/	/	/
	Sand	/	10	/	5	5	10	10	0	/	/	/	/
	Silt	/	10	/	10	4	5	10	2	/	/	/	/
	Clay	/	0	/	0	4	0	5	2	/	/	/	/
	Depth - Mode	/	4	12	10	15	9	14	0	/	/	/	/
Edge	Bedrock	15	0	10	0	0	0	0	40	15	0	0	20
	Boulder	10	0	30	0	5	0	0	5	0	0	0	10
	Cobble	10	0	20	30	30	0	0	30	10	15	20	5
	Pebble	20	15	2	0	30	15	5	15	2	10	10	5
	Gravel	15	10	2	0	15	15	5	5	3	10	10	10
	Sand	15	20	1	10	5	40	5	0	5	15	40	20
	Silt	20	50	30	50	8	20	70	3	60	35	10	25
	Clay	5	5	5	10	7	10	15	2	5	15	10	5
	Detritus Cover	30	60	30	60	15	25	65	20	30	40	30	15
	Bank Overhang	20	30	5	40	25	15	5	5	10	20	10	40
	Total Macrophytes	60	80	80	70	20	70	20	0	60	90	80	70
Site Assessment	Water Quality	2	2	2	2	2	2	3	3	2	2	2	2
	Instream	2	2	4	3	3	2	3	4	2	3	2	2
	Riparian Zone	3	1	3	2	3	4	3	4	3	4	4	3
	Catchment Assessment	2	2	3	3	3	3	3	3	3	4	3	3
	Total	9	7	12	10	11	11	12	14	10	13	11	10

Appendix C – Sediment quality analytes schedule and results (spring 2019 and autumn 2020)

CERTIFICATE OF ANALYSIS

Work Order	: **CA1906970**	Page	: 1 of 5
Client	: **GHD**	Laboratory	: ALS Water Resources Group
Contact	: Mr Phil Taylor	Contact	: Client Services
Address	: GHD Services Pty Ltd Level 7 16 Marcus Clarke Sreet Canberra ACT 2601	Address	: 16B Lithgow Street Fyshwick ACT Australia 2609
Telephone	: 02 6113 3477	Telephone	: +61 2 6202 5404
Project	: CVO AEMP	Date Samples Received	: 25-Oct-2019 12:50
Order number	: ----	Date Analysis Commenced	: 30-Oct-2019
C-O-C number	: ----	Issue Date	: 07-Nov-2019 10:55
Sampler	: ----		
Site	: S19		
Quote number	: CA2013GHD0001		
No. of samples received	: 13		
No. of samples analysed	: 13		

Accreditation No. 992
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Titus Vimalasiri	Metals Teamleader	Inorganics, Fyshwick, ACT

General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- **For samples collected by ALS WRG, sampling was carried out in accordance with Procedure EN67**

Analytical Results

Sub-Matrix: **SOLID**
(Matrix: **SOLID**)

			Client sample ID	---- RC-1	---- SC-1	---- PR-1	---- PR-2	---- FC-1
			Client sampling date / time	23-Oct-2019 14:35	23-Oct-2019 15:20	24-Oct-2019 09:00	24-Oct-2019 11:20	23-Oct-2019 10:30
Compound	CAS Number	LOR	Unit	CA1906970-001	CA1906970-002	CA1906970-003	CA1906970-004	CA1906970-005
				Result	Result	Result	Result	Result
EG005CA: Total Metals by ICP-OES								
ø Iron	7439-89-6	20	mg/kg	**34800**	**36800**	**31900**	**23600**	**67500**
ø Aluminium	7429-90-5	20	mg/kg	**16600**	**12600**	**11900**	**8900**	**11800**
ø Chromium	7440-47-3	5	mg/kg	**32**	**28**	**24**	**21**	**93**
ø Manganese	7439-96-5	1	mg/kg	**477**	**1530**	**924**	**442**	**584**
ø Zinc	7440-66-6	5	mg/kg	**69**	**69**	**72**	**51**	**85**
EG020CA: Total Metals by ICP-MS								
Antimony	7440-36-0	5	mg/kg	<5	<5	<5	<5	<5
Arsenic	7440-38-2	1	mg/kg	**9**	**53**	**12**	**8**	**31**
Barium	7440-39-3	1	mg/kg	**78**	**140**	**177**	**98**	**65**
Beryllium	7440-41-7	0.1	mg/kg	**0.4**	**0.7**	**0.8**	**0.7**	**2.2**
Cadmium	7440-43-9	0.1	mg/kg	**0.1**	**0.2**	<0.1	<0.1	<0.1
Cobalt	7440-48-4	1	mg/kg	**16**	**22**	**14**	**10**	**23**
Copper	7440-50-8	1	mg/kg	**254**	**63**	**28**	**22**	**52**
Lead	7439-92-1	0.2	mg/kg	**5.8**	**10.7**	**13.3**	**13.6**	**13.7**
Molybdenum	7439-98-7	1.0	mg/kg	<1.0	<1.0	<1.0	<1.0	<1.0
Nickel	7440-02-0	1	mg/kg	**15**	**16**	**15**	**13**	**29**
Selenium	7782-49-2	1	mg/kg	<1	**1**	<1	<1	<1
Silver	7440-22-4	1	mg/kg	<1	<1	<1	<1	<1
ø Mercury	7439-97-6	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: **SOLID**
(Matrix: **SOLID**)

Compound	CAS Number	LOR	Unit	FC-2	CC4	CC3	CC5	CC1
Client sample ID				---- FC-2	---- CC4	---- CC3	---- CC5	---- CC1
Client sampling date / time				23-Oct-2019 09:00	23-Oct-2019 13:10	23-Oct-2019 15:10	21-Oct-2019 15:00	22-Oct-2019 08:45
				CA1906970-006	CA1906970-007	CA1906970-008	CA1906970-009	CA1906970-010
				Result	Result	Result	Result	Result
EG005CA: Total Metals by ICP-OES								
ø **Iron**	7439-89-6	20	mg/kg	**28300**	**37500**	**49000**	**67900**	**38200**
ø **Aluminium**	7429-90-5	20	mg/kg	**12700**	**15200**	**8830**	**12100**	**12600**
ø **Chromium**	7440-47-3	5	mg/kg	**38**	**34**	**47**	**52**	**46**
ø **Manganese**	7439-96-5	1	mg/kg	**683**	**438**	**444**	**602**	**1040**
ø **Zinc**	7440-66-6	5	mg/kg	**104**	**73**	**86**	**107**	**71**
EG020CA: Total Metals by ICP-MS								
Antimony	7440-36-0	5	mg/kg	<5	<5	<5	<5	<5
Arsenic	7440-38-2	1	mg/kg	**8**	**7**	**18**	**11**	**8**
Barium	7440-39-3	1	mg/kg	**67**	**112**	**59**	**86**	**131**
Beryllium	7440-41-7	0.1	mg/kg	**0.6**	**0.9**	**1.3**	**3.3**	**1.1**
Cadmium	7440-43-9	0.1	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1
Cobalt	7440-48-4	1	mg/kg	**21**	**23**	**21**	**19**	**21**
Copper	7440-50-8	1	mg/kg	**57**	**116**	**280**	**25**	**50**
Lead	7439-92-1	0.2	mg/kg	**14.8**	**8.2**	**12.1**	**10.2**	**8.0**
Molybdenum	7439-98-7	1.0	mg/kg	<1.0	<1.0	**2.3**	**1.6**	<1.0
Nickel	7440-02-0	1	mg/kg	**19**	**17**	**15**	**14**	**14**
Selenium	7782-49-2	1	mg/kg	<1	<1	**1**	**1**	<1
Silver	7440-22-4	1	mg/kg	<1	<1	<1	<1	<1
ø **Mercury**	7439-97-6	0.1	mg/kg	**0.1**	<0.1	<0.1	<0.1	<0.1

Analytical Results

Sub-Matrix: SOLID (Matrix: SOLID)			Client sample ID	---- DG1	---- CC 2a - Pool	---- CC 2b - Riffle	----	----
			Client sampling date / time	21-Oct-2019 13:30	22-Oct-2019 12:30	22-Oct-2019 12:30	----	----
Compound	CAS Number	LOR	Unit	CA1906970-011	CA1906970-012	CA1906970-013	--------	--------
				Result	Result	Result	----	----
EG005CA: Total Metals by ICP-OES								
ø Iron	7439-89-6	20	mg/kg	**62100**	**27000**	**48600**	----	----
ø Aluminium	7429-90-5	20	mg/kg	**12200**	**8190**	**8990**	----	----
ø Chromium	7440-47-3	5	mg/kg	**21**	**24**	**45**	----	----
ø Manganese	7439-96-5	1	mg/kg	**424**	**323**	**739**	----	----
ø Zinc	7440-66-6	5	mg/kg	**166**	**51**	**48**	----	----
EG020CA: Total Metals by ICP-MS								
Antimony	7440-36-0	5	mg/kg	<5	<5	<5	----	----
Arsenic	7440-38-2	1	mg/kg	**178**	**11**	**35**	----	----
Barium	7440-39-3	1	mg/kg	**128**	**28**	**51**	----	----
Beryllium	7440-41-7	0.1	mg/kg	**0.9**	**0.5**	**0.9**	----	----
Cadmium	7440-43-9	0.1	mg/kg	**0.6**	**0.1**	**0.1**	----	----
Cobalt	7440-48-4	1	mg/kg	**17**	**11**	**29**	----	----
Copper	7440-50-8	1	mg/kg	**54**	**376**	**205**	----	----
Lead	7439-92-1	0.2	mg/kg	**31.1**	**5.2**	**9.1**	----	----
Molybdenum	7439-98-7	1.0	mg/kg	**1.1**	**1.5**	**4.7**	----	----
Nickel	7440-02-0	1	mg/kg	**18**	**10**	**18**	----	----
Selenium	7782-49-2	1	mg/kg	**1**	<1	<1	----	----
Silver	7440-22-4	1	mg/kg	<1	<1	<1	----	----
ø Mercury	7439-97-6	0.1	mg/kg	**0.1**	**0.1**	<0.1	----	----

CERTIFICATE OF ANALYSIS

Batch No:	**20-19588**	*Page*	**Page 1 of 4**
Final Report	**819966**	*Laboratory*	Scoresby Laboratory
		Address	Caribbean Business Park, 22 Dalmore Drive, Scoresby, VIC 3179
Client:	**GHD Pty Ltd**	*Phone*	03 8756 8000
Contact:	**Peter Lind**	*Fax*	03 9763 1862
Address:	PO Box 5403 HUNTER REGION MAIL CENTRE NSW 2310 AUSTRALIA	Contact:	Brad Snibson Client Manager Brad.Snibson@alsglobal.com
PO No:	**Not Available**	Date Sampled:	**09-Apr-2020 - 12-Apr-2020**
Sampler Name:	**P.Lind**	Date Samples Received:	**14-Apr-2020**
ALS Program Ref:	**GHD**	*Date Issued:*	**17-Apr-2020**
Program Description:	**GHD**		
Client Ref:	**CVO-AEMP**		

The hash (#) below indicates methods not covered by NATA accreditation in the performance of this service .

Analysis	*Method*	*Laboratory*	*Analysis*	*Method*	*Laboratory*
MS Total Metals	WG020B	Scoresby			

Signatories

Name	*Title*	*Name*	*Title*
John Levvey	**Principal Trace Metals Chemist**		

Accreditation No. 992
Accredited for compliance with ISO/IEC 17025 - Testing

Samples not collected by ALS and are tested as received.

Soil microbiological testing was commenced within 4 days from the day collected unless otherwise stated.
Water microbiological testing was commenced on the day received and within 24 hours of sampling unless otherwise stated.
MM524: Plate count results <10 per mL and >300 per mL are deemed as approximate.
MM526: Plate count results <2,500 per mL and >250,000 per mL are deemed as approximate.
Calculated results are based on raw data.
Legionella species refers to Legionella species other than Legionella pneumophila
Measurement Uncertainties values for your compliance results are available at this link

Batch No: 20-19588
Report Number: 819966
Client: GHD Pty Ltd
ALS Program Ref: GHD
Program Description: GHD

Sample No	Site Code	Site Description	Sample Type	Sampled Date/Time
6522618		CC1	SEDIMENT	09/04/20
6522619		CC2	SEDIMENT	09/04/20
6522620		CC3	SEDIMENT	09/04/20
6522621		CC4	SEDIMENT	10/04/20

Analysis - Analyte	*Sample No. Site Code Units*	6522618	6522619	6522620	6522621
MS Total Metals - Aluminium	mg/kg	15000	11000	16000	23000
MS Total Metals - Antimony	mg/kg	<5	<5	<5	<5
MS Total Metals - Arsenic	mg/kg	6	13	6	12
MS Total Metals - Barium	mg/kg	88	54	110	130
MS Total Metals - Beryllium	mg/kg	<5	<5	<5	<5
MS Total Metals - Cadmium	mg/kg	<0.2	0.2	<0.2	<0.2
MS Total Metals - Chromium	mg/kg	43	34	21	33
MS Total Metals - Cobalt	mg/kg	25	32	21	27
MS Total Metals - Copper	mg/kg	45	330	320	82
MS Total Metals - Iron	mg/kg	46000	31000	25000	50000
MS Total Metals - Lead	mg/kg	6	7	10	8
MS Total Metals - Manganese	mg/kg	1500	540	960	570
MS Total Metals - Mercury	mg/kg	<0.05	<0.05	0.07	<0.05
MS Total Metals - Molybdenum	mg/kg	<5	<5	<5	<5
MS Total Metals - Nickel	mg/kg	15	20	12	23
MS Total Metals - Selenium	mg/kg	<3	<3	<3	<3
MS Total Metals - Zinc	mg/kg	63	47	70	78

Batch No: **20-19588**
Report Number: **819966**
Client: **GHD Pty Ltd**
ALS Program Ref: **GHD**
Program Description: **GHD**

Sample No	Site Code	Site Description	Sample Type	Sampled Date/Time
6522622		RC1	SEDIMENT	10/04/20
6522623		SC1	SEDIMENT	10/04/20
6522627		CC5	SEDIMENT	11/04/20
6522628		DG1	SEDIMENT	11/04/20

Analysis - Analyte	*Sample No. Site Code Units*	6522622	6522623	6522627	6522628
MS Total Metals - Aluminium	mg/kg	15000	16000	18000	11000
MS Total Metals - Antimony	mg/kg	<5	<5	<5	<5
MS Total Metals - Arsenic	mg/kg	10	22	5	91
MS Total Metals - Barium	mg/kg	200	250	170	180
MS Total Metals - Beryllium	mg/kg	<5	<5	<5	<5
MS Total Metals - Cadmium	mg/kg	<0.2	<0.2	<0.2	0.6
MS Total Metals - Chromium	mg/kg	28	27	30	21
MS Total Metals - Cobalt	mg/kg	19	20	16	17
MS Total Metals - Copper	mg/kg	50	57		
MS Total Metals - Iron	mg/kg	34000	27000	43000	43000
MS Total Metals - Lead	mg/kg	9	10	12	55
MS Total Metals - Manganese	mg/kg	2600	1900	1200	1800
MS Total Metals - Mercury	mg/kg	0.05	<0.05	<0.05	0.09
MS Total Metals - Molybdenum	mg/kg	<5	<5	<5	<5
MS Total Metals - Nickel	mg/kg	15	17	15	15
MS Total Metals - Selenium	mg/kg	<3	<3	4	<3
MS Total Metals - Zinc	mg/kg	59	62	180	180

Sample No	Site Code	Site Description	Sample Type	Sampled Date/Time
6522629		FC2	SEDIMENT	11/04/20
6522630		PR1	SEDIMENT	12/04/20
6522631		PR2	SEDIMENT	12/04/20
6522632		FC1	SEDIMENT	12/04/20

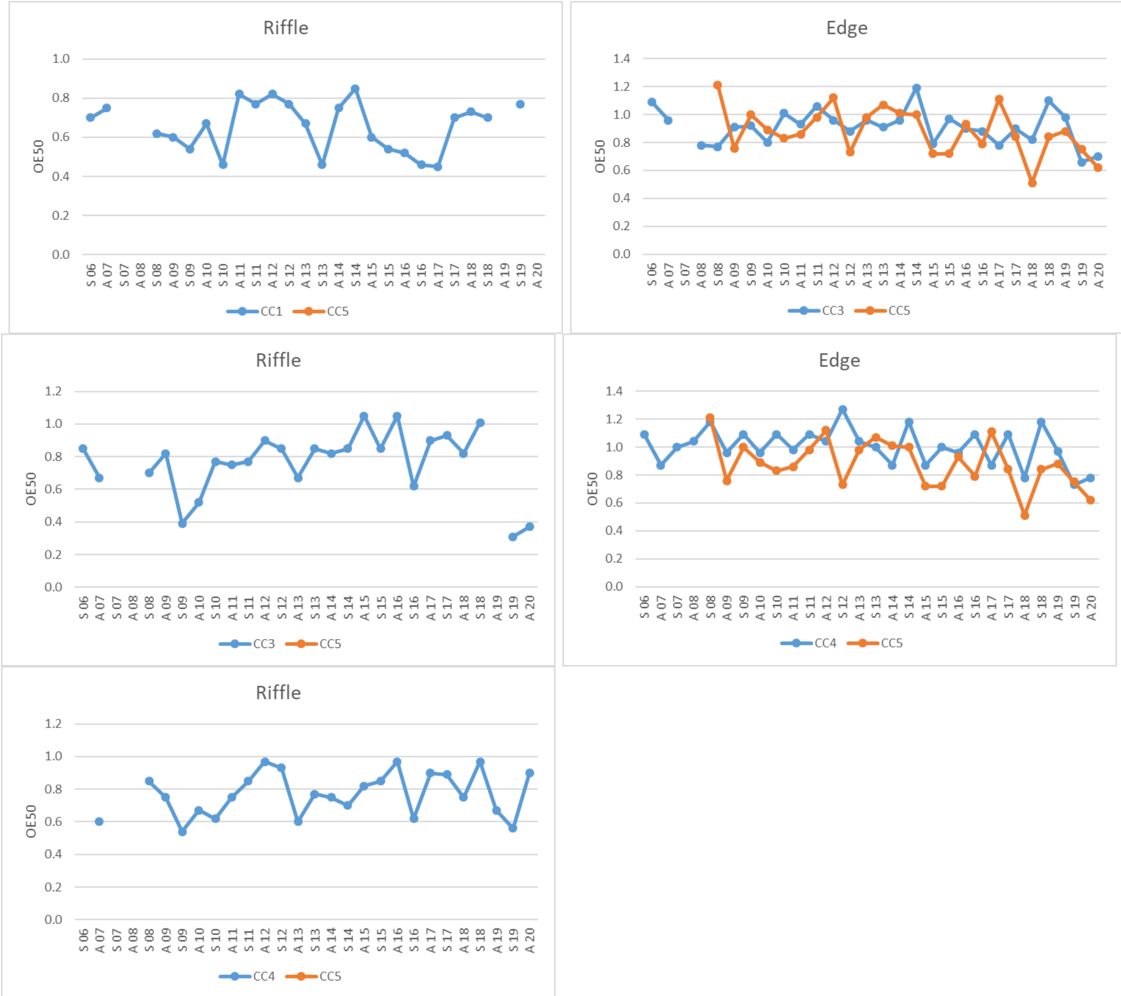
Analysis - Analyte	*Sample No. Site Code Units*	6522629	6522630	6522631	6522632
MS Total Metals - Aluminium	mg/kg	13000	14000	8800	15000
MS Total Metals - Antimony	mg/kg	<5	<5	<5	<5
MS Total Metals - Arsenic	mg/kg	14	10	8	39
MS Total Metals - Barium	mg/kg	110	130	100	130
MS Total Metals - Beryllium	mg/kg	<5	<5	<5	<5
MS Total Metals - Cadmium	mg/kg	<0.2	<0.2	<0.2	<0.2
MS Total Metals - Chromium	mg/kg	46	27	19	91
MS Total Metals - Cobalt	mg/kg	16	13	10	26
MS Total Metals - Iron	mg/kg	30000	34000	23000	67000
MS Total Metals - Lead	mg/kg	14	16	16	21
MS Total Metals - Manganese	mg/kg	1200	640	570	1400
MS Total Metals - Mercury	mg/kg	0.09	<0.05	<0.05	0.05
MS Total Metals - Molybdenum	mg/kg	<5	<5	<5	<5
MS Total Metals - Nickel	mg/kg	16	16	13	29
MS Total Metals - Selenium	mg/kg	<3	<3	<3	<3
MS Total Metals - Zinc	mg/kg	76	62	43	85

A blank space indicates no test performed.

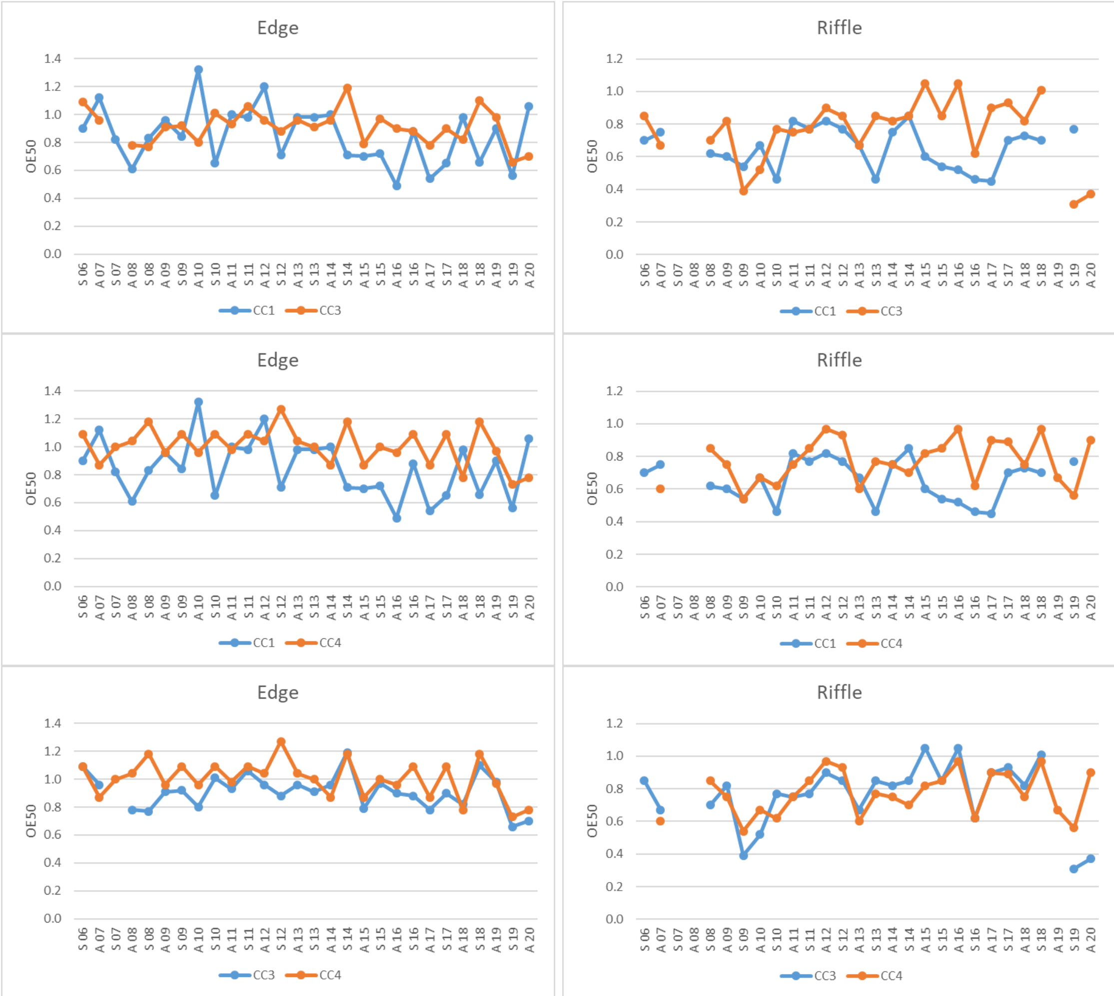
Appendix D – Long term patterns in macroinvertebrate indices

This appendix includes long term plots for the macroinvertebrate indices measured as part of the Cadia Valley Operations AEMP. These graphs include all monitoring sites for the period, spring 2006 – autumn 2020, and are grouped into the sites pairings that were described in the recent 10 year data review. Pairwise comparisons of water quality monitoring sites were investigated to determine the key factors that may influence the water quality and streamflow of Cadiangullong Creek. The site comparisons and rationale are as follows:

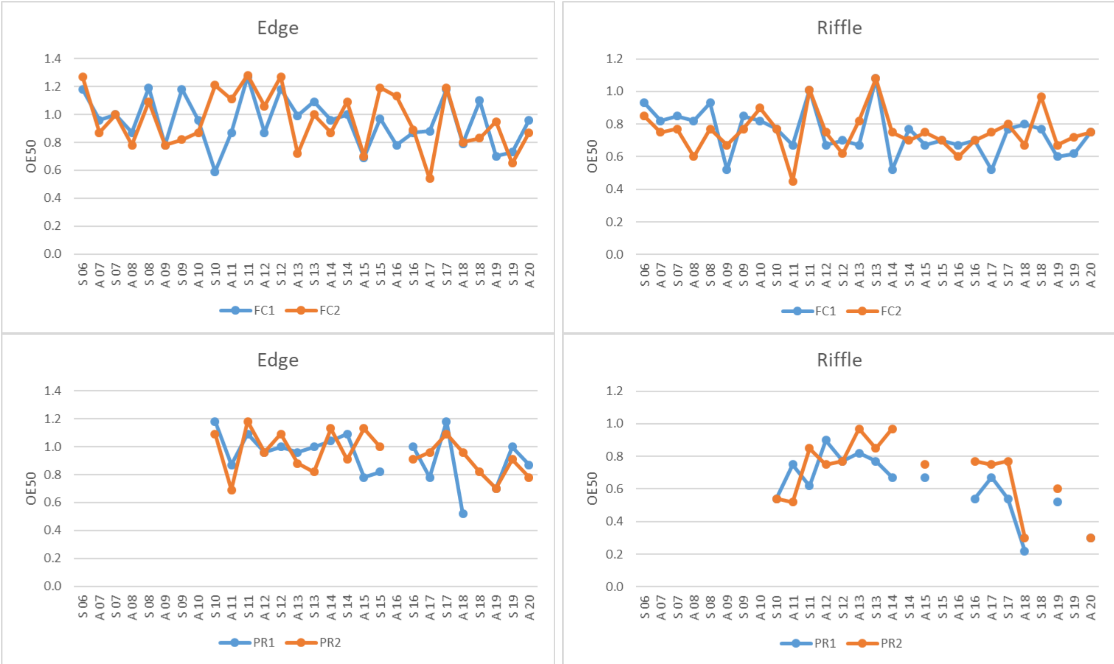
- CC5 vs CC1 - Cadiangullong Creek upstream of Cadiangullong Dam vs downstream of Cadiangullong Dam; investigating the influence of Cadiangullong dam on the water quality and streamflow of the waterway
- CC5 vs CC3 - Cadiangullong Creek upstream of Cadiangullong Dam vs Cadiangullong Creek at Southern Lease Boundary, downstream of the main areas of mining operations; investigating the influence of Cadiangullong Dam and mining operations on the water quality of Cadiangullong Creek
- CC5 vs CC4 - Cadiangullong Creek upstream of Cadiangullong Dam vs Cadiangullong Creek at Oaky Creek gauging station: investigating the influence of all CVO operations including Cadiangullong Dam, CVO facilities and tailing dams on the water quality and stream flow of Cadiangullong Creek
- CC1 vs CC3 – Cadiangullong Creek downstream of Cadiangullong Dam vs Cadiangullong Creek at Southern Lease Boundary; investigating the influence of CVO main area of operations on the water quality of Cadiangullong Creek, separated from the influence of Cadiangullong Dam
- CC1 vs CC4- Cadiangullong Creek downstream of Cadiangullong Dam vs Cadiangullong Creek at Oaky Creek gauging station; investigating the influence of CVO main area of operations and tailing dams on the water quality and stream flow of Cadiangullong Creek without separated from the influence of Cadiangullong Dam
- CC3 vs CC4 - Cadiangullong Creek at Southern Lease Boundary vs Cadiangullong Creek at Oaky Creek gauging station; investigating the influence of land use and tailings dams in the Rodds Creek catchment on Cadiangullong Creek, separated from the influence of CVO main operations, and Cadiangullong Dam upstream
- All of the other sites are grouped by their catchments



Macroinvertebrate OE50 scores in Cadiangullong Creek between spring 2006 and autumn 2020

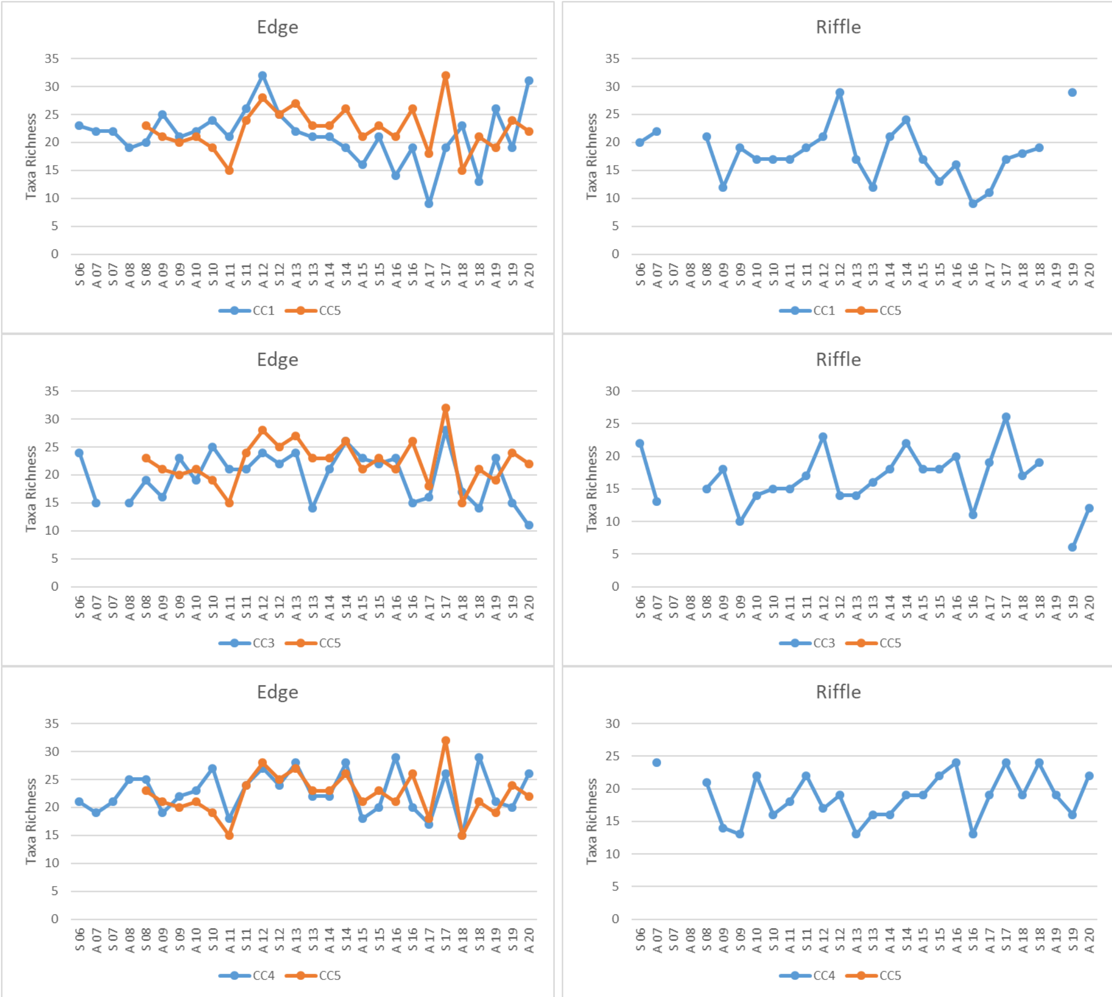


Macroinvertebrate OE50 scores in Cadiangullong Creek between spring 2006 and autumn 2020

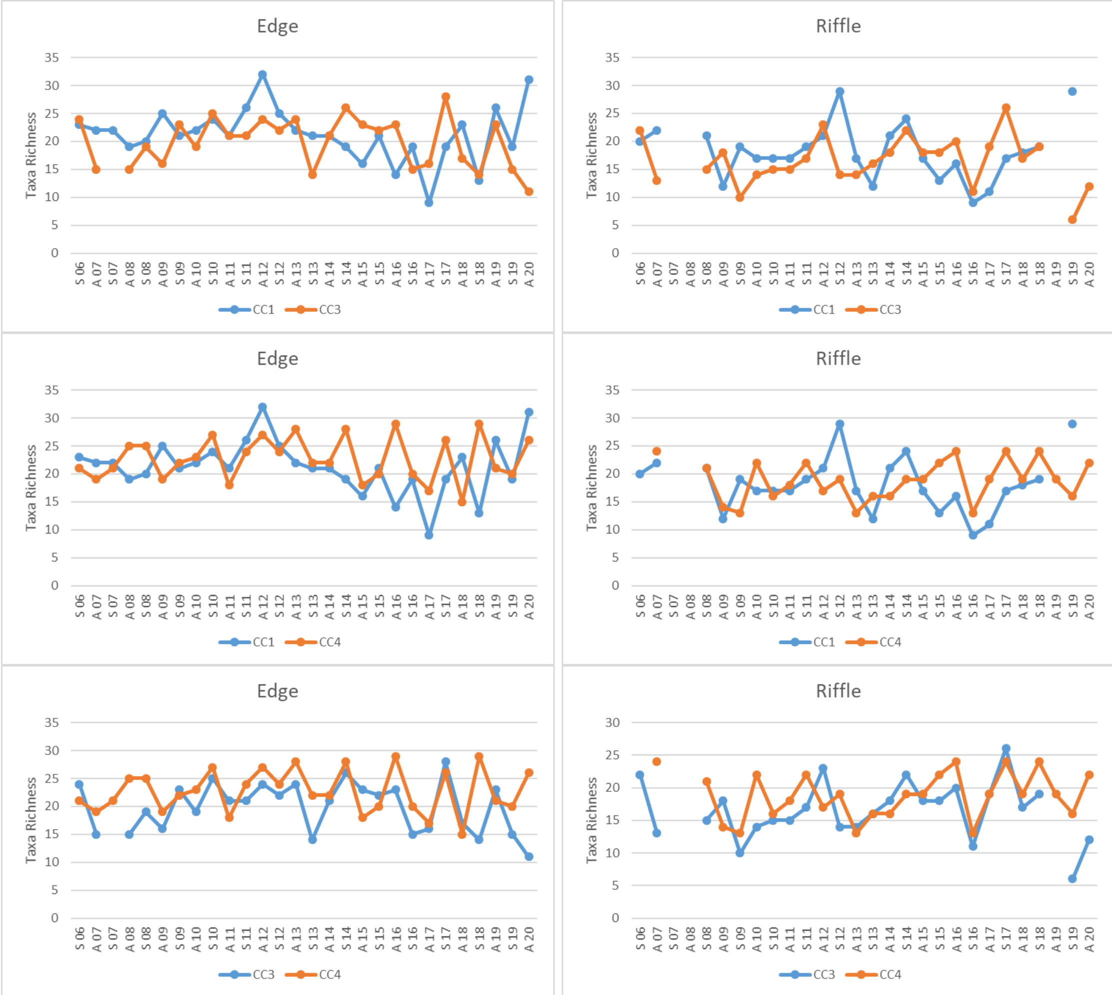


Macroinvertebrate OE50 scores in Flyers Creek (top) and Panuara Rivulet (bottom) between spring 2006 and autumn 2020

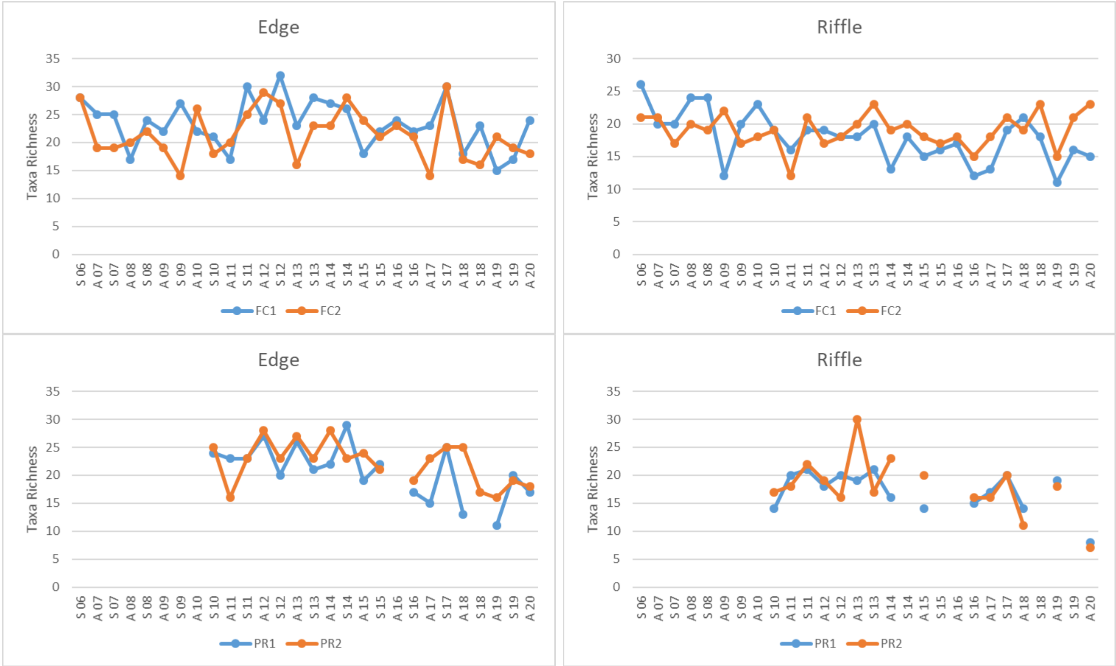
Macroinvertebrate OE50 scores in Diggers Creek (top), Swallow Creek (middle) and Rodd's Creek (bottom) between spring 2006 and autumn 2020



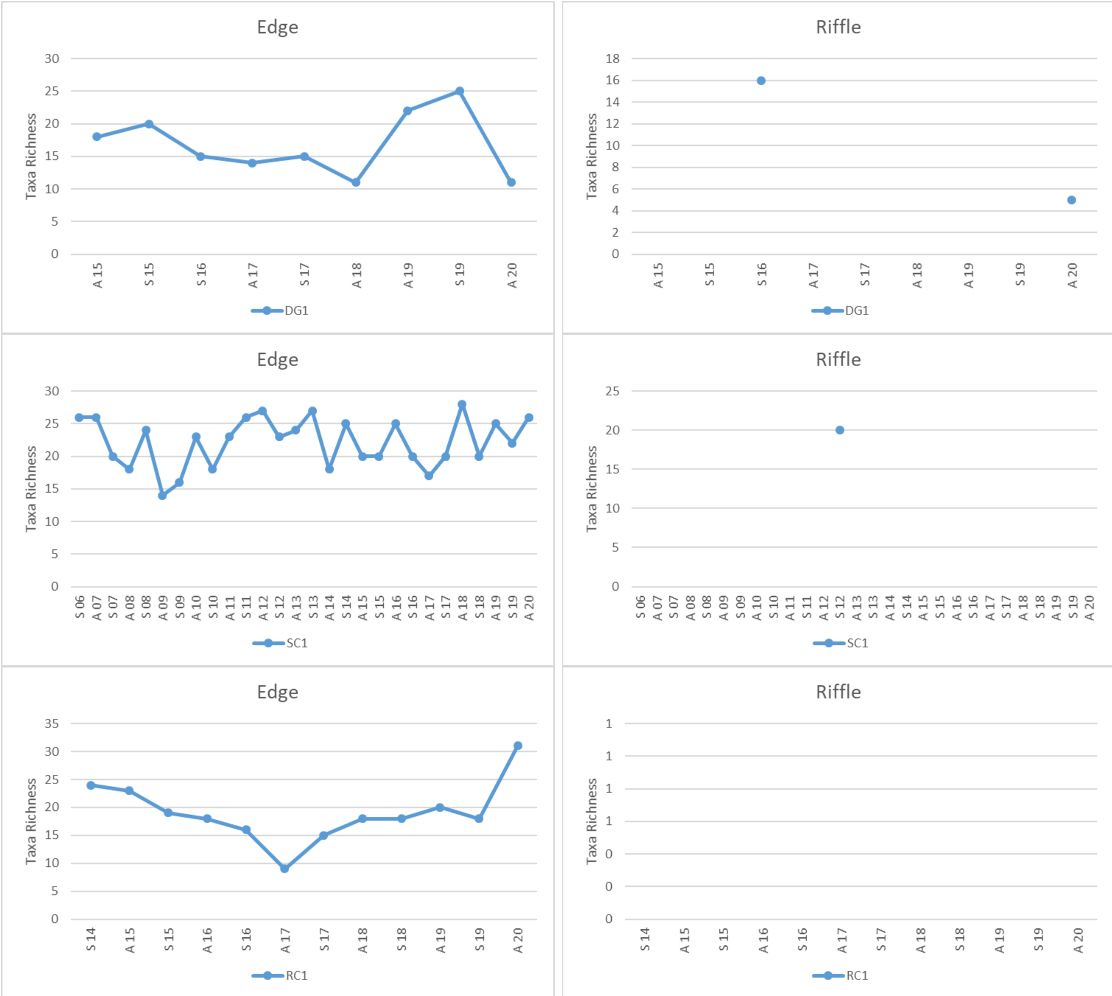
Macroinvertebrate taxa richness in Cadiangullong Creek between spring 2006 and autumn 2020



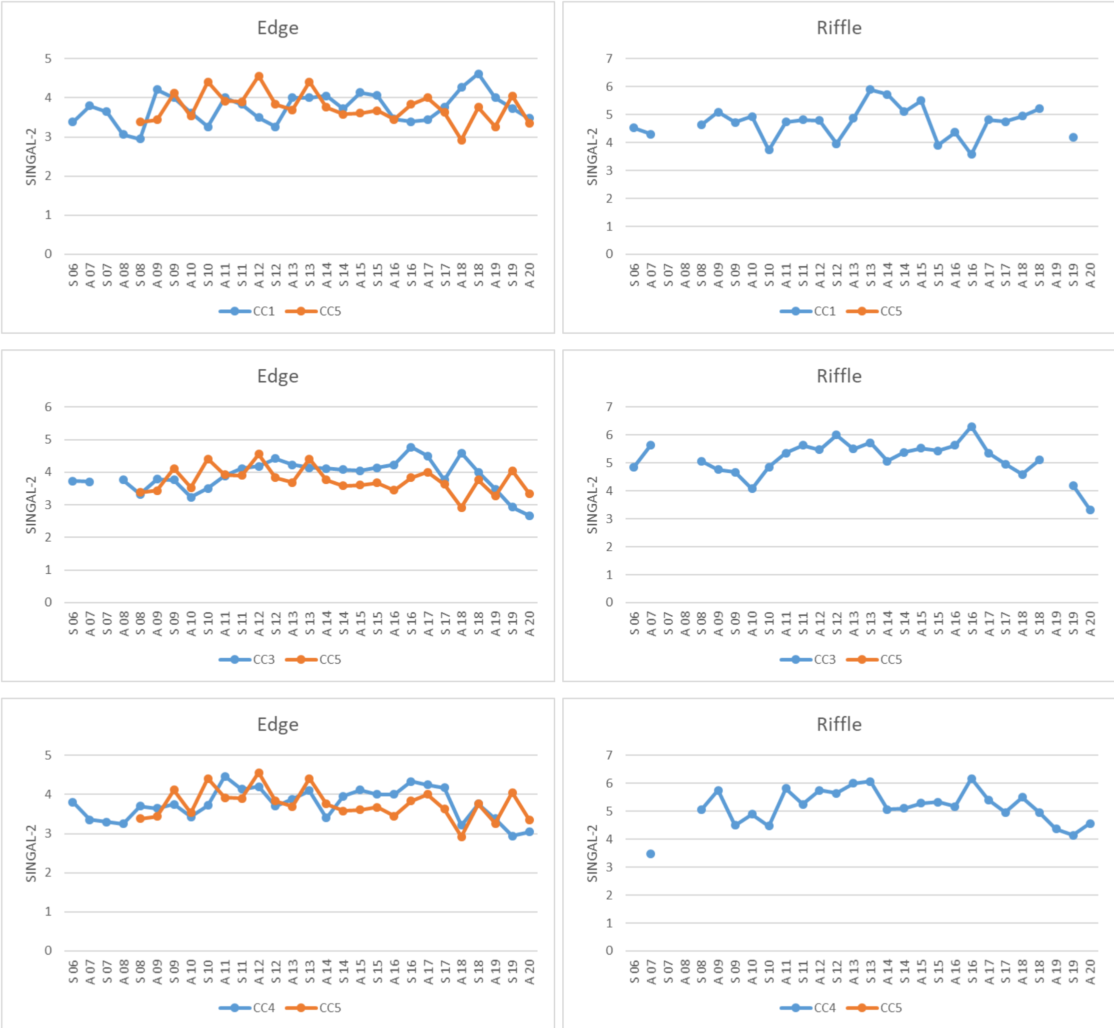
Macroinvertebrate taxa richness in Cadiangullong Creek between spring 2006 and autumn 2020



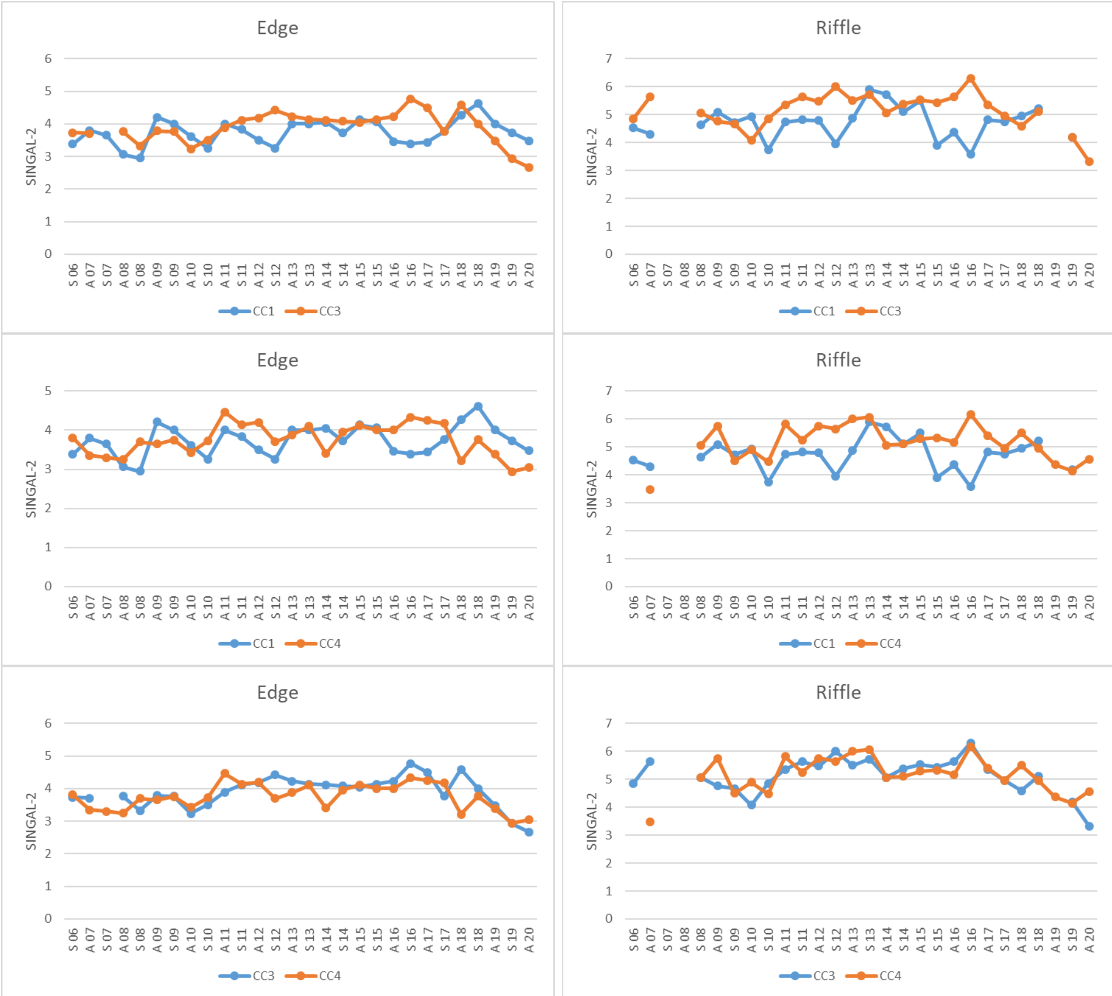
Macroinvertebrate taxa richness in Flyers Creek (top) and Panuara Rivulet (bottom) between spring 2006 and autumn 2020



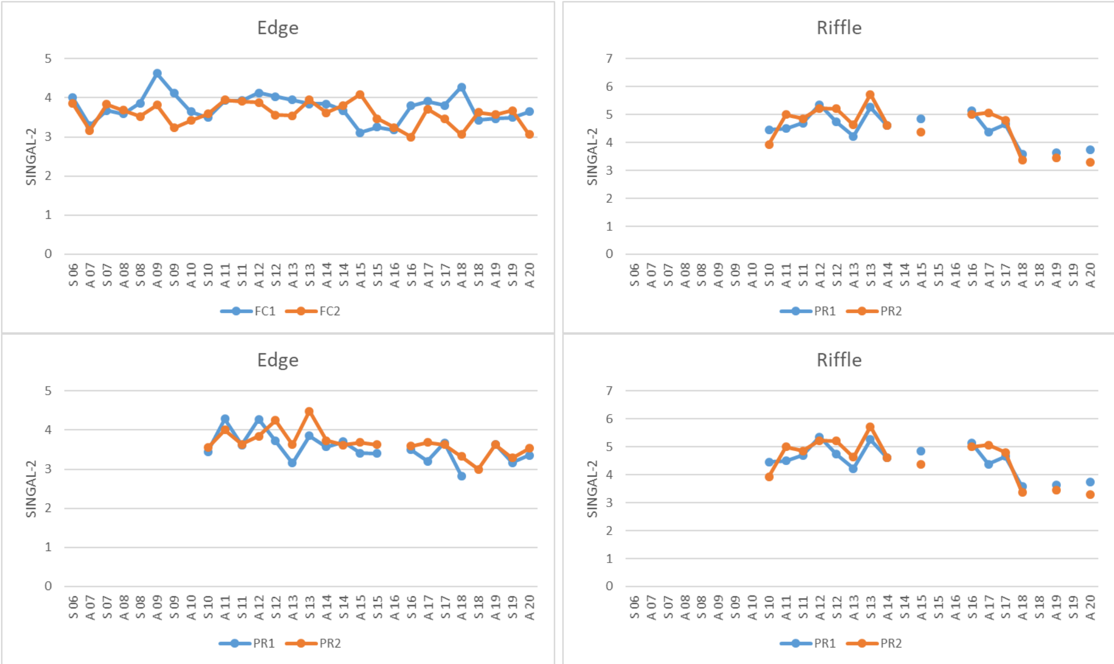
Macroinvertebrate taxa richness in Diggers Creek (top), Swallow Creek (middle) and Rodd's Creek (bottom) between spring 2006 and autumn 2020



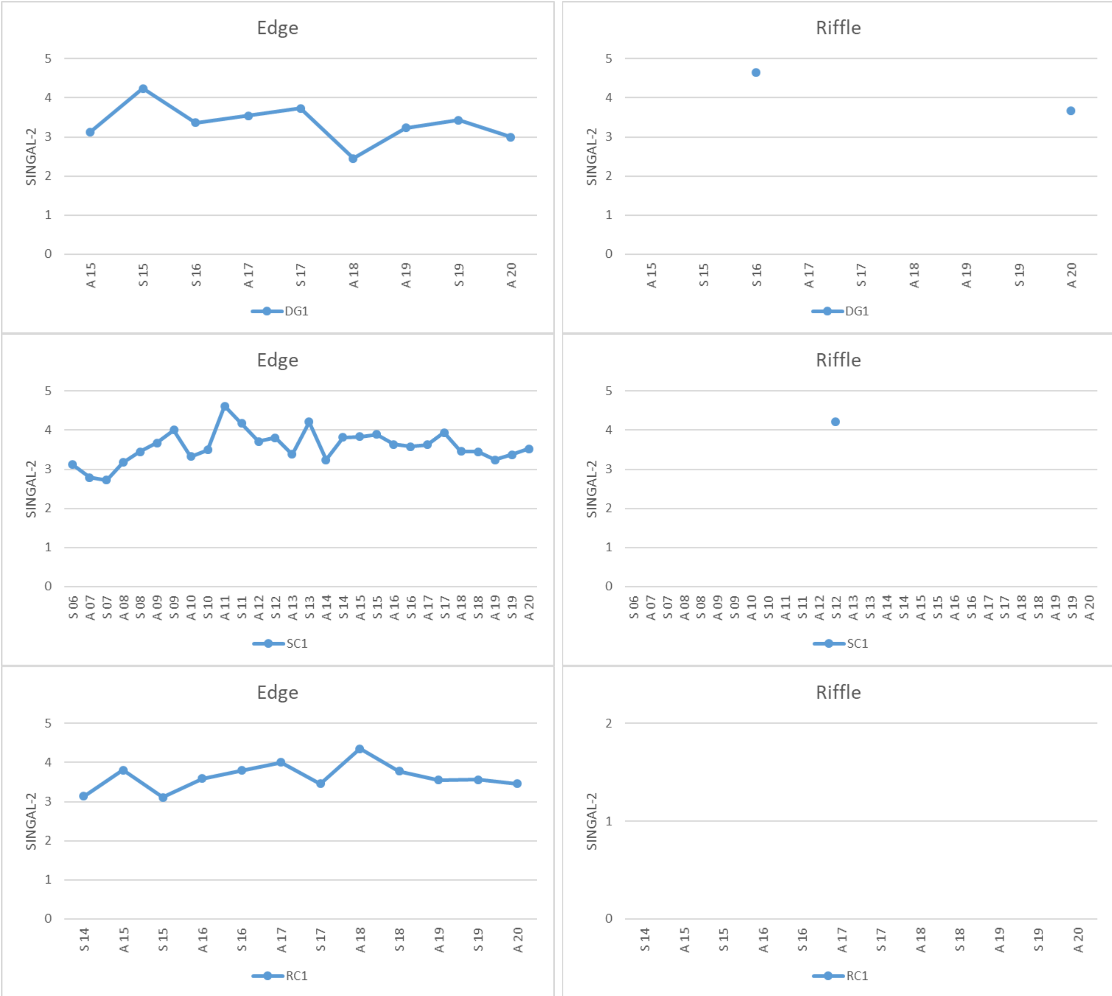
Macroinvertebrate SIGNAL-2 scores in Cadiangullong Creek between spring 2006 and autumn 2020



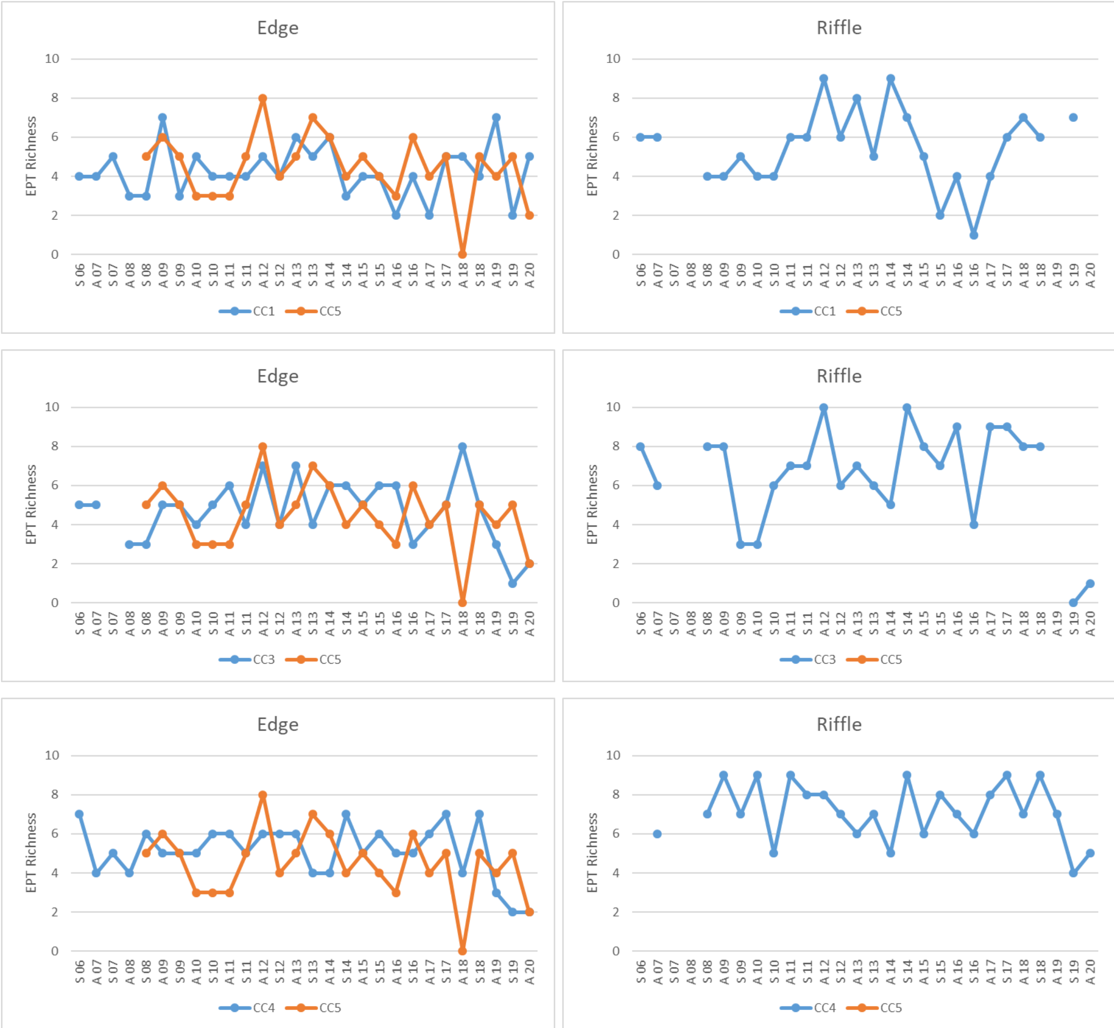
Macroinvertebrate SIGNAL-2 scores in Cadiangullong Creek between spring 2006 and autumn 2020



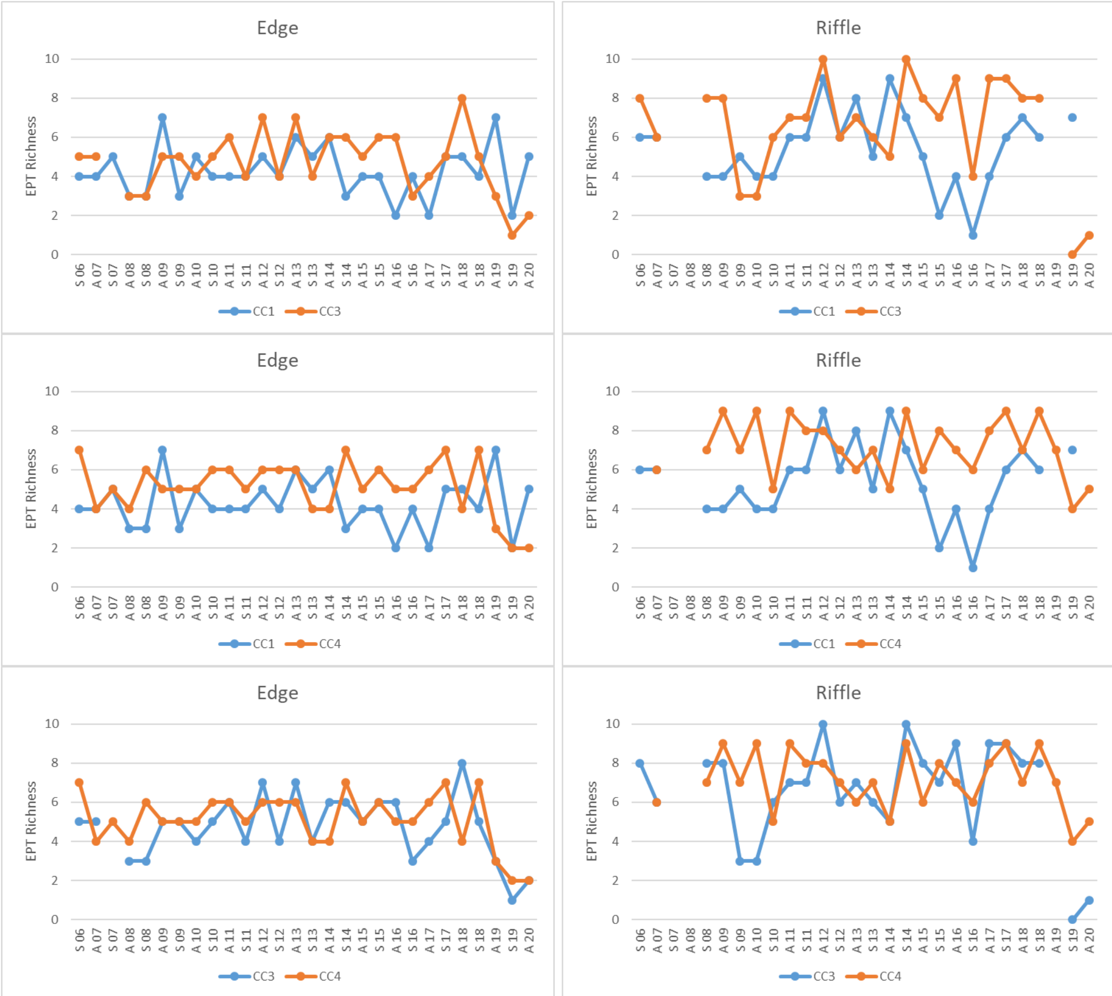
Macroinvertebrate SIGNAL-2 scores in Flyers Creek (top) and Panuara Rivulet (bottom) between spring 2006 and autumn 2020



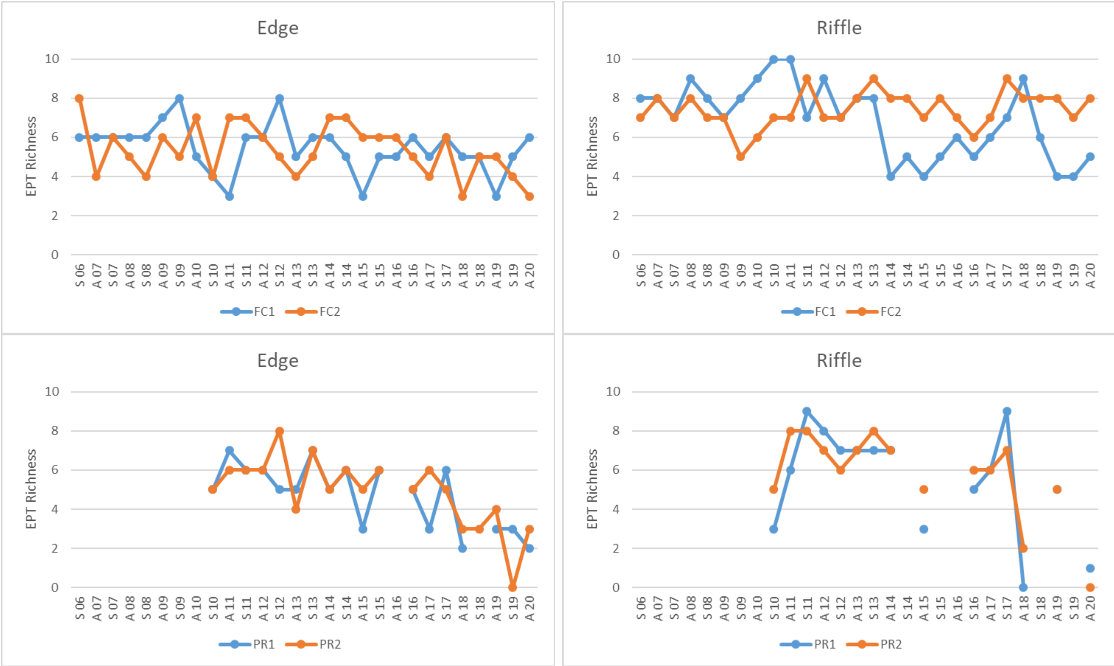
Macroinvertebrate SIGNAL-2 scores in Diggers Creek (top), Swallow Creek (middle) and Rodd's Creek (bottom) between spring 2006 and autumn 2020



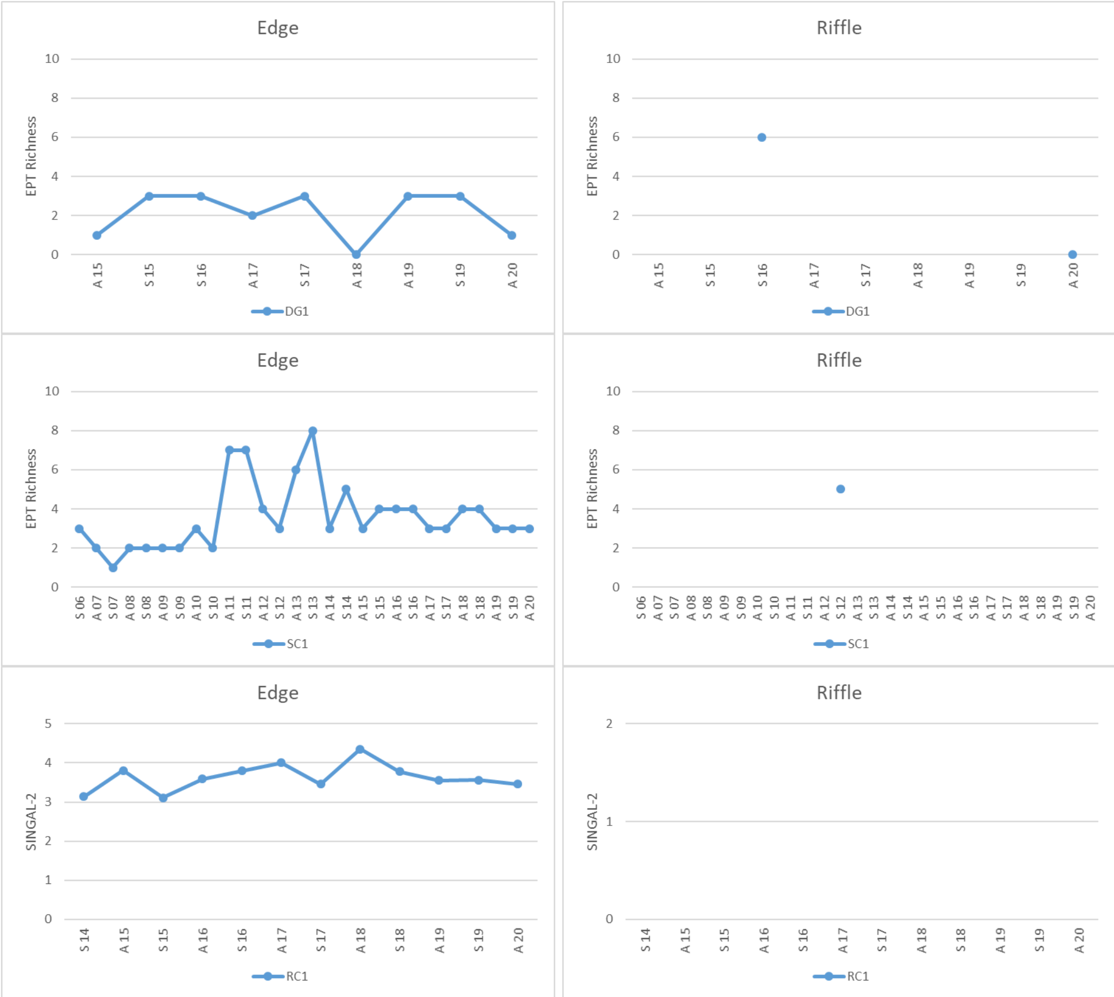
Macroinvertebrate EPT richness in Cadiangullong Creek between spring 2006 and autumn 2020



Macroinvertebrate EPT richness scores in Cadiangullong Creek between spring 2006 and autumn 2020



Macroinvertebrate EPT richness in Flyers Creek (top) and Panuara Rivulet (bottom) between spring 2006 and autumn 2020



Macroinvertebrate EPT richness in Diggers Creek (top), Swallow Creek (middle) and Rodd's Creek (bottom) between spring 2006 and autumn 2020

GHD

16 Marcus Street, Canberra ACT 2601
T: +61 2 6113 3200   F: +61 2 6113 3299   E: cbrmail@ghd.com

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Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
Draft A						12/06/2020
0	P. Lind	S. Harrow		P. Chier		14/08/2020

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