Sydney WATER

# City of Ryde
# Biological and Chemical Monitoring

## Macroinvertebrates & Water Quality

## Spring 2013

**Sydney Water Monitoring Services**

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# Executive summary

This report encapsulates the spring 2013 macroinvertebrate and water quality survey and forms part of the City of Ryde Water Quality Monitoring Strategy. Macroinvertebrates and water quality were sampled once at five core sites in Archers, Buffalo, Porters, Shrimptons and Terrys creeks. Water quality only was also sampled once at eight additional sites at Buffalo, Porters and Shrimptons creeks.

Macroinvertebrates were collected according to AUSRIVAS protocols for New South Wales (Turak et al., 2004) and in compliance with Sydney Water in-house test method SS0001 *Rapid Field Assessment of Macroinvertebrates for River, Stream (lotic) and Wetland (lentic) Waters*. Macroinvertebrates were identified to the Family taxonomic level where possible at Sydney Water's NATA accredited Analytical Services Laboratories. The macroinvertebrate data was analysed utilising an array of univariate, biological indices and multivariate techniques. Baseline data collected in previous surveys from spring 2004 to autumn 2011 were used for historical comparison and benchmarking the current survey results.

The spring 2013 survey was conducted during November which experienced very high rainfall events. Sampling was conducted during as close to base flow conditions as possible, however due to the need to sample within the required timeframes samples were likely effected by the rainfall conditions.

pH, turbidity and conductivity were within guideline levels for all sites. Dissolved oxygen percent saturation levels were outside the guideline levels for most sites across all five creeks. Bacteriological and nutrient levels were often elevated above guideline levels at all sites. Both the Buffalo Creek additional sites were extremely elevated and faecal coliforms were observed at the highest levels recorded from the entire program. All metals and hardness results were within guideline levels except for copper and zinc which were outside guideline levels at some sites.

Taxa richness in spring 2013 was largely reflective of what had been previously observed, except for Buffalo Creek which was lower. EPT taxa were collected in very low numbers, as has historically been the case. No EPT taxa were collected at Shrimptons and Buffalo creeks.

Survey results suggest that the macroinvertebrate community assemblages in the five creeks in spring 2013 were reflective of typical impacted urban systems. SIGNAL-SF and AUSRIVAS results were reflective of what has been previously recorded, except Buffalo Creeks OE50 spring edge score which was significantly lower than the historic average.

Multivariate analysis indicated that the macroinvertebrate community assemblages collected in spring 2013 were very similar to previous survey seasons. However, the assemblages did appear to have some small differences in taxa presence and abundances compared to previous seasons within all five creeks. This may have been attributable to sampling being conducted during a period of very high rainfall, affecting the presence and abundances of some key taxa.

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# 1 Introduction

## 1.1 Background

Sydney Water has developed this report in response to engagement under the City of Ryde Council Tender Number COR-RFT-30/13. This report is in accordance with Water Quality Monitoring Strategy for the City Of Ryde for spring 2013. Under this engagement Sydney Water will also conduct the autumn 2014 survey, which will complement surveys conducted under the same strategy from spring 2004 to autumn 2011.

This current survey recommences the biological and chemical monitoring of the five main catchments within the Ryde LGA; Shrimptons, Archers, Porters, Buffalo and Terrys creeks. During the full term of the strategy the frequency of site sampling and survey specifics have been modified and developed to the current program. Macroinvertebrates and water quality was sampled once per season at five core sites in each catchment; water quality was also sampled at eight additional sites, located on Shrimptons, Porters and Buffalo creeks. The additional water quality sites were added in 2008 to allow a spatial investigation into the chemistry of the creeks.

## 1.2 Objectives

The Ryde LGA catchments are exposed to any number of anthropogenic impacts and sources associated with the variety and density of land uses present. Understanding what drives these impacts and how ecosystems respond is essential to their ongoing management. Baseline understanding of the natural variation that occur and a greater understanding of the relative health of these catchments is an important environmental management process for the City of Ryde.

Biological and chemical monitoring enables the City of Ryde to;

- Build on baseline data that enables the temporal evaluation and analysis of the health of the catchments of the strategy
- Identify and track new and existing impacts affecting the catchments
- Provide direction and monitor potential infrastructural works within the LGA, i.e. in-stream or riparian rehabilitation and stormwater treatment projects.
- Build on the known taxa list for each catchment and to aid in the identification of key indicator taxa
- Provide the basis for potential standard monitoring strategies and information that could be integrated into a community monitoring/education program
- Provide guidance on future programs; sampling frequency and protocols, site locations, suitability of current and potential analyses

# 2 Study area

## 2.1 Catchment

The City of Ryde LGA has a total area of 40,651 km$^2$ and is located 12 km north west of central Sydney. It is comprised of 16 suburbs and 14 separate stormwater catchments predominated mainly by residential housing including several important retail centers and light industry/manufacturing sectors (CoR, 2014).

There are a limited number of natural bushland areas fringing the urban infrastructure including several important natural bush corridors and areas of open space that support recreation and sporting activities. There are also small sections of Lane Cove National Park present on the eastern and northern borders of Shrimptons, Porters and Buffalo creeks.

The creeks surveyed in the strategy all drain into the greater Parramatta River catchment. Archers creek enters Parramatta River directly and the remaining creeks through the Lane Cove River catchment.

### 2.1.1 Sampling sites

The five core sites sampled for macroinvertebrates and water quality are shown in Table 1 and Figure 1. The eight additional water quality sites are shown in Table 2 and Figure 1.

All core and additional sites were sampled once for water quality on the 15th November except the Spur Branch Porters Creek site as a bank collapse had damaged and covered the access point. Macroinvertebrates were sampled once each at the core sites on the 15th, 22nd and 28th November. There were significant delays to the macroinvertebrate sampling due to rainfall events during November.

**Table 1 Core sampling sites**

| Site code | Site Name | Lat/Long |
|---|---|---|
| Site 1 | Terry's Creek @ Somerset Rd | -33.765792, 151.098345 |
| Site 2 | Shrimpton's Creek @ Wilga Park | -33.780530, 151.118628 |
| Site 3 | Porter's Creek @ Ryde City Depot | -33.783362, 151.137671 |
| Site 4 | Buffalo Creek @ Higginbotham Rd | -33.816451, 151.125705 |
| Site 5 | Archers Creek @ Maze Park | -33.805555, 151.074272 |

**Table 2 Additional water quality sites**

| Site code | Site Name | Lat/Long |
|---|---|---|
| CR1SA | Shrimpton's Creek @ Kent Rd | -33.789246, 151.113419 |
| CR1SB | Shrimpton's Creek @ Bridge St | -33.794061, 151.109779 |
| CR1SC | Shrimpton's Creek @ Quarry Rd | -33.796856, 151.106775 |
| CR4BA | Buffalo Creek d/s Burrows Park | -33.814392, 151.116656 |
| CR4BB | Buffalo Creek u/s Burrows Park | -33.815060, 151.113502 |
| CR5PA | Porter's Creek @ Main Branch | -33.786500, 151.134839 |
| CR5PB | Porter's Creek @ Spur Branch | -33.784181, 151.134708 |
| CR5PC | Porter's Creek @ Wicks Rd | -33.788613, 151.133557 |


**Figure 1 City of Ryde LGA map with catchments and core sampling sites indicated (supplied by City of Ryde)**

# 3 Sampling methodology

## 3.1 Water quality

The water quality monitoring program design and site locations for this study were provided by City of Ryde and are consistent with their previous monitoring programs.

Water quality sampling was conducted by Sydney Water staff trained in sample collection, preservation, storage and transport techniques (conforming to AS/NZS 5667:1998) as well as relevant Sydney Water occupational health and safety procedures. To ensure traceability samples were collected in bottles pre-labeled with a unique identifying laboratory number as well as the sample site code, location and date of collection. Field measurements and observations for each site were recorded at the time of sampling. A general outline of sampling procedures is detailed below.

### 3.1.1 Sampling schedule

A schedule was prepared by the Aquatic Ecology Project Leader responsible for this project to ensure sampling frequency requirements were met. The schedule was forwarded to the appropriate Analytical Services Laboratory Supervisors to provide forewarning of incoming samples. The sampling schedule is prepared in communication with the client to ensure milestones and deliverables are met according to the agreed timeframes.

### 3.1.2 Frequency of sampling

Routine water quality monitoring was undertaken in November 2013 (spring) at the five core sites and additional eight sites.

### 3.1.3 Sampling methodology

To avoid contamination during the sampling process the following practices occurred:

- sampling Officers wore disposable latex gloves
- samples were collected using aseptic techniques
- sampling equipment was sterilised and rinsed between sites
- sample bottles not containing preservative were rinsed before filling
- microbiological samples were collected before other samples

To ensure representativeness of samples, the following practices occurred:

- disturbed areas of the creek bank were avoided; where disturbance was evident the sample was collected upstream
- rinse water was discarded downstream or away from the sampling point
- issues impacting sample integrity, such as distance from bank(s), number and distribution of samples, substrate, ponds and aeration, were considered in determining sampling sites
- surface scum was avoided

Samples were collected from 20-30 cm below the water surface. Where the depth was less than 50 cm, the sample was taken at half the depth.

Surface samples were collected when the waterway was too shallow to allow sampling without disturbing the sediment. This has the potential to compromise sample quality as surface samples may contain surface contaminates, such as scum, dust or pollen, which may not be present below the waterway surface. Therefore, where applicable, collection of surface samples was noted on the Water Chemical Field Sheet.

A sampling pole and/or jug were used to collect samples. A list of water chemistry analytes sampled, along with their unit of measurement and collection container are provided in Appendix 2.

## Field measurements

It is necessary to measure some water chemistry analytes in the field using various field instruments (Table 3). To ensure accuracy of results, instruments are calibrated according to manufacturers' recommendations, field procedure requirements, relevant sections of NATA ISO/IEC 17025 Field Application Document and other reference material.

**Table 3 Water chemistry parameters and field analysis methods**

| Analyte | Method |
|---|---|
| Dissolved Oxygen (% saturation) | WTW Multiliner Universal Meter |
| Dissolved Oxygen (mg/L) | WTW Multiliner Universal Meter |
| Conductivity (µS/cm) | WTW Multiliner Universal Meter |
| pH (pH units) | WTW Multiliner Universal Meter |
| Turbidity (NTU) | HACH Turbidimeter |
| Temperature ($^{o}$C) | Digital Thermometer |

To ensure traceability of calibration in accordance with NATA ISO/IEC 17025 2009, Sydney Water uses a mixture of in-house and purchased calibration standards. In-house standards are made only from analytical grade materials of appropriate purity. The assay of these materials is traceable to the National Institute of Standards & Testing (NIST). Purchased calibration standards are regarded as critical materials and are accompanied with a certificate of analysis showing traceability to NIST.

## Field observations

Field observations were recorded to assist in the interpretation of results. At each site the field observations listed below were recorded:

- sample clarity
- algae presence
- recent rain
- visual pollution
- flow rate (visual assessment)

### Sample preservation and transportation

Samples that require storage between 1-10$^0$C were placed in an ice filled esky immediately following collection. To avoid contamination, all samples were transported in an upright position.

Samples were delivered to the Sydney Water analytical laboratory at West Ryde with the appropriate Chain of Custody form and/or analysis request sheet.

### Analysis

All Sydney Water laboratory analytical work was performed as per the requirements of AS ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories. In general, most of the methodologies used are American Public Health Association (APHA) or United States Environmental Protection Agency (USEPA) standard methods. Where standard methods are not available, analytical procedures have been developed from in-house research or published methods from analytical journals.

All analysis was carried out according to the requirements of the customer and the laws and regulations of relevant authorities. Sydney Water laboratories' NATA technical accreditation numbers are listed below.

**Table 4 Sydney Water laboratories NATA accreditation numbers**

| Field of Testing | Number | Accredited | Standard |
|---|---|---|---|
| Chemical Testing | 63 | 1952 | ISO/IEC 17025 |
| Biological Testing | 610 | 1966 | ISO/IEC 17025 |

## 3.2 Macroinvertebrate sampling

Macroinvertebrate sampling was conducted in accordance with AUSRIVAS protocols for New South Wales (Turak et al., 2004). The Sydney Water Biology Group carry out sampling activities according to the requirements of in-house test method SS0001 *Rapid Field Assessment of Macroinvertebrates for River, Stream (lotic) and Wetland (lentic) Waters*. This ensures compliance with the NSW AUSRIVAS protocols for rapid assessment field sampling and processing techniques for all habitats.

Field staff were required to be competent to a minimum of family level identification of macroinvertebrates in the laboratory. As identifiers they must comply with the requirements of SSWI433 *In-house test method Macroinvertebrate Cataloguing, Identification and Counting* (see NATA accreditation details, Section 3.3). This requirement ensures that field staff were given the widest possible exposure to animals of varying morphology and to facilitate high quality field sampling and processing techniques. This results in a reduction of sampling error, addressing issues identified by Metzeling et al. (2003). All field trips to a sampling site are led by staff that have previously visited that site (where possible), maintaining continuity in sampling over time.

Macroinvertebrates were sampled from the edge habitats for all survey sites using a hand-held dip net. Edge habitats are defined as areas with little or no current. The sampling net was swept from open water towards the stream bank, working over a bank length of about 10 m. In the process, deposits of silt and detritus on the stream bottom were stirred up so that benthic animals were suspended and caught in the net. Three replicate samples were collected from the edge habitat at each of the five sampling sites.

The net contents were emptied into a large white sorting tray with a small amount of water to allow live macroinvertebrate specimens to be picked out with fine forceps and pipettes for a minimum period of 40 minutes. If new taxa were collected between 30 and 40 minutes, sorting continued for a further 10 minutes. If no new taxa were found after 10 minutes, picking ceased. If new taxa were found, the 10 minute processing cycle continued up to a maximum total sorting time of 1 hour. There is no set maximum number of animals to be collected under the NSW protocols (Turak, et al., 2004).

All specimens collected were preserved in small glass specimen jars containing 70% un-denatured ethanol with a clear label indicating site code and location, date, habitat and name of staff sampler and picker. Sampling equipment was washed thoroughly between samples to prevent the cross contamination of animals.

**Figure 2 Sample jars and a picked specimen, Hemipteran, Notonectidae *Enithares* (Back-swimmer)**

## 3.3 Macroinvertebrate sample processing

Macroinvertebrate samples were processed as per SSWI433 *In-house Test Method Macroinvertebrate Cataloguing, Identification and Counting*. Quality assurance was conducted as per SSWI434 *In-house test method Quality Control of Macroinvertebrate Identification, Counting and Archiving of Collections*. Both methods are in compliance with the requirements of AS ISO/IEC 17025 *General Requirements for the Competence of Testing and Calibration Laboratories* under technical accreditation number 610 issued by the National Association of Testing Authorities (NATA). Refer to Appendix 1 for further quality assurance information.

Macroinvertebrate identifications were performed using modern compound and stereo microscopes (Leica Microsystems) that are maintained via a strict service schedule. Reference material used in the AE laboratory includes:

- Current published taxonomic keys
- Up to date descriptions and records of taxonomic developments from national experts
- Voucher specimens, many confirmed by national experts
- Sydney Water in-house keys and digital voucher photograph database

Macroinvertebrates were identified and enumerated to the family taxonomic level, except Chironomids which were identified to sub-family. For AUSRIVAS analysis specimens were combined for Oligochaeta at Class and Acarina at Order level.

Macroinvertebrate data were entered into Sydney Water's custom LIMNOS electronic database. A suitably trained staff member checked identification sheets before electronic entry and then verified electronic datasheets after this process. Raw macroinvertebrate data files were extracted and verified by a senior staff member before analyses were performed.

At the end of this process, quality assurance was conducted on 5% of edge samples identified for this study. Identifications are chosen at random for quality assessment.


**Figure 3 Laboratory processing and resources, voucher specimen – Coleoptera, Hydrophilidae *Berosus* (Beetle)**

## 3.4 Rainfall data

Continuous rainfall data is collected and recorded by the Sydney Water Hydrometric Services Team within the Service Delivery division. Rainfall is collected using TB3 rain gauges (Hydrological Services Pty Ltd) and data is collected and analysed in accordance with NATA guidelines following industry standards (WMO 1996) and Observation Specification No 2013.1 of the Australian Bureau of Meteorology. For the purpose of this study, daily rainfall measurements were extracted from HYDSTRA time-series data management software and analysed within Microsoft Excel. The West Ryde rain gauge (566037) was used for this report.

# 4 Analysis methods

## 4.1 Water quality

While not sampled at the frequency suggested by ANZECC (2000), the water quality results do allow characterisation of each study creek against ANZECC (2000) guidelines for Aquatic Ecosystems (Lowland River in south eastern Australia), Recreational Water Quality and Aesthetics (Secondary) and toxicants (95% species protection level).

The ANZECC (2000) toxicant trigger values have been used for metals. These guidelines provide four sets of protection levels derived as chemical-specific estimates of the concentrations of contaminants that should have no adverse effects on aquatic ecosystems (ANZECC 2000). The 95% species protection level is the most commonly applied to aquatic ecosystems that have been modified in some way, and this is the level used in this report to compare the stream water sample results.

ANZECC (2000) recommends that the toxicity trigger values for hardness-related metals (in this study: cadmium, copper, lead, nickel and zinc) are adjusted to account for local water hardness. This is important because the trigger values for these metals have been derived for a low water hardness (30 g/m3 CaCO3), corresponding to high toxicity. The adjustment values for water hardness categories are detailed in Table 6.

Although the ANZECC (2000) guidelines (default trigger values) detailed below (Table 5) are for slightly disturbed ecosystems, they do provide an indication of water quality compared to other systems within south eastern Australia.

The median, the middle value when data are arranged in numerical order, has been calculated for historical data, when available. For the five core sites this is between 2004 and 2011, and for eight additional sites between 2008 and 2011. The median is a robust estimator of central tendency because it is relatively unaffected by extremes in the data, and is the preferred statistic for describing an 'average' concentration. Where concentrations of chemicals were below detection level, half the detection level is used for the calculations of historical medians.

**Table 5 ANZECC (2000) indicators and trigger values**

| Indicator | Guideline Value | Unit | Source |
|---|---|---|---|
| Dissolved Oxygen | 85 to 110 | % saturation | Protection of aquatic ecosystem (ANZECC 2000) |
| pH | 6.5 to 8.5 | pH unit | Protection of aquatic ecosystem (ANZECC 2000) |
| Turbidity | 50 | NTU | Protection of aquatic ecosystem (ANZECC 2000) |
| Conductivity | 125-2,500 | µS/cm | Protection of aquatic ecosystem (ANZECC 2000) |
| Ammonia nitrogen | 20 | µg/L | Protection of aquatic ecosystem (ANZECC 2000) |
| Oxidised nitrogen | 40 | µg/L | Protection of aquatic ecosystem (ANZECC 2000) |
| Total nitrogen | 350 | µg/L | Protection of aquatic ecosystem (ANZECC 2000) |
| Total phosphorus | 25 | µg/L | Protection of aquatic ecosystem (ANZECC 2000) |
| Faecal coliforms | 1,000 | CFU/100mL | Secondary contact recreation (ANZECC 2000) |
| Chromium H | 0.001 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Manganese | 1.9 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Iron | ID | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |

| Indicator | | Guideline Value | Unit | Source |
|---|---|---|---|---|
| Copper | H | 0.0014 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Zinc | H | 0.008 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Arsenic | | 0.013 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Cadmium | H | 0.002 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Lead | H | 0.0034 | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |
| Mercury | B | ID | mg/L | Toxicants at 95% level of protection (ANZECC 2000) |

**Table 6 ANZECC (2000) trigger value adjustments for water hardness**

| Hardness category ($mg/L$ as $CaCO_3$) | Hardness range (mg/L as CaCO3) | Cd | Cu | Pb | Zn |
|---|---|---|---|---|---|
| Soft | 85 to 110 | TV | TV | TV | TV |
| Moderate | 6.5 to 8.5 | x 2.7 | x 2.5 | x 4.0 | x 2.5 |
| Hard | 50 | x 4.2 | x 3.9 | x 7.6 | x 3.9 |
| Very hard | 125-2,500 | x 5.7 | x 5.2 | x 11.8 | x 5.2 |
| Extremely hard | 20 | x 10.0 | x 9.0 | x 26.7 | x 9.0 |

## 4.2 Macroinvertebrate analyses

Macroinvertebrate data from was analysed using the analyses listed below. The analyses are introduced and briefly explained at the start of the respective sections in the results section of this report, a thorough description is available, Appendix 3.

Univariate Analyses;

- Taxa Richness
- EPT Taxa Richness

Biological Indices;

- SIGNAL2
- SIGNAL-SF
- AUSRIVAS

Multivariate Analyses;

- Cluster
- SIMPROF
- MDS ordination
- SIMPER
- ANOSIM

# 5 Rainfall data

Daily rainfall data from the Sydney Water rain gauge located at Ryde Pumping Station, West Ryde, are presented in Figure 4. The total rainfall recorded for each month, for the three months prior to and including sampling, are listed in Table 7. November 2013 was a comparably wet month with a total of 190 mm of rainfall, including a maximum daily rainfall of 45.5 mm recorded on the 12th November 2013. This was the highest rainfall recorded from a single month during the sampling periods from any of the monitoring seasons.

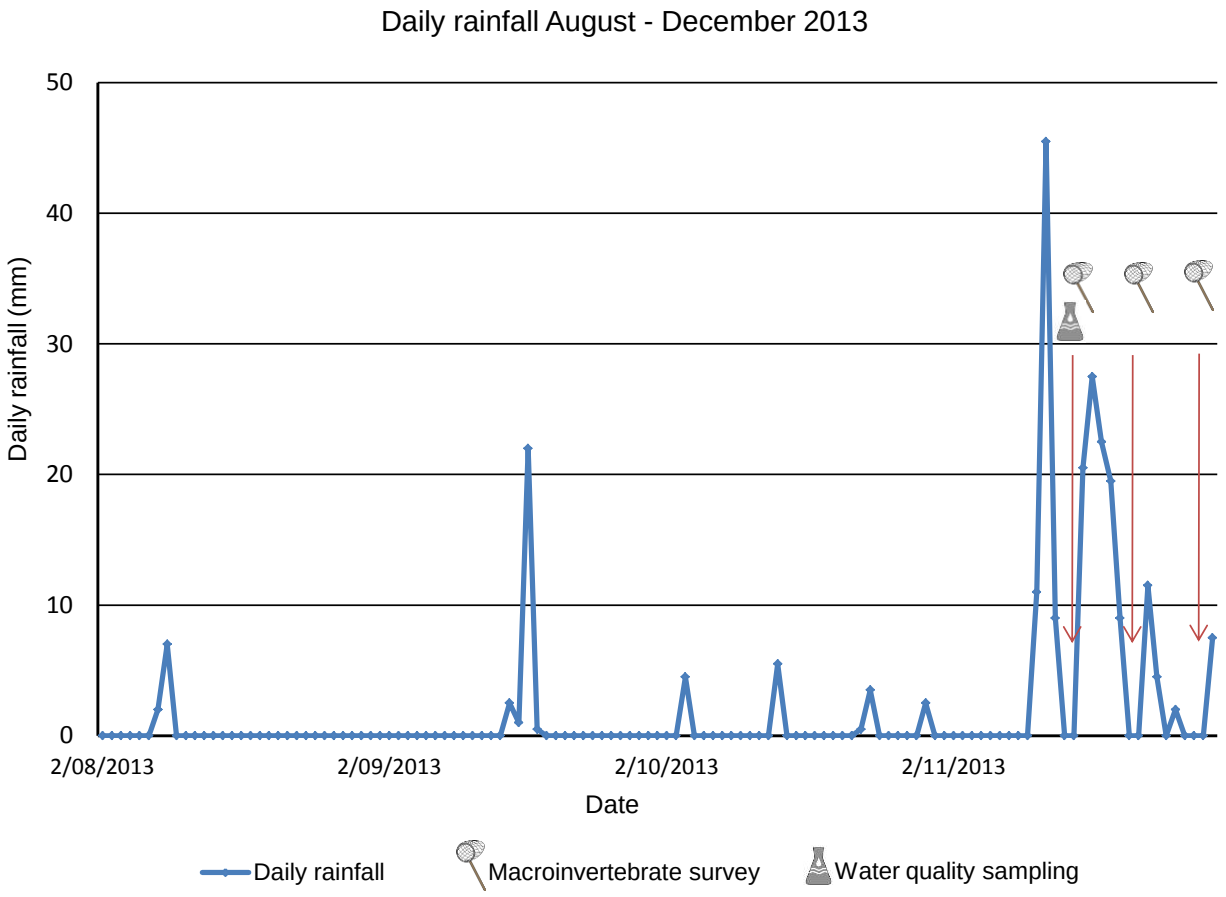



**Figure 4 Daily rainfall data August 2013 to November 2013**

**Table 7 Total rainfall by month**

| Month | Rainfall (mm) |
|---|---|
| August | 9.0 |
| September | 26.0 |
| October | 16.5 |
| November | 190.0 |

# 6 Site observations

## Site 1: Terrys Creek

The Terrys Creek core sampling site is located in Somerset Park under the M2 overpass in the suburb of Epping. The surrounding land use is residential, and the creek flows through a bushland corridor. The surrounding riparian area and bank edge is a mix of native and exotic plant species. The creek bed is predominately bedrock, gravel and sand. There is no macrophyte or algal growth within the sampling area, and hasn't been observed in past surveys.

During the recent survey there were signs of flooding and some bank erosion, there was domestic rubbish strewn within the creek and in surrounding vegetation. Similar conditions have been observed in past surveys.

When the site was visited for the final sampling survey in autumn 2011 the site was largely inaccessible due to maintenance work on the M2 overpass and both the eastern and western banks. This resulted in extensive clearing, removal of vegetation and stabilisation of the surrounding area. When visited for this survey this work has resulted in noticeably less bank vegetation (Figure 5) and possibly some sedimentation in the creek pool in which sampling is carried out.

**Figure 5 Terrys Creek, spring 2007 (L) and spring 2013 (R)**

## Site 2: Shrimptons Creek

The Shrimptons Creek core sampling site is located in Wilga Park in the suburb of Macquarie Park and the surrounding land use comprises a mix of residential, commercial and light industrial. The creek flows through a thin riparian/vegetation corridor, which is a mix of native and exotic species. The riparian area is periodically cleared but at times has been overgrown with exotic plant species. The creek bed is predominately bedrock and sand/silt. There is little macrophyte or algal growth within the sampling area, and hasn't been observed in past surveys.

The creeks banks are relatively stable and the western bank has sections that have been realigned and reinforced. There is gross pollutant traps placed at points along the sampling site, however domestic rubbish, excessive organic debris and other refuse has been periodically observed at the site (Figure 6). The Wilga Park site has been one of the more stable environments visited during the program, although a bank collapse was observed in spring 2007.

**Figure 6 Shrimptons Creek, spring 2009, downstream sampling point (L) and upstream (R)**

*CR1SA - Shrimptons Creek at Kent Road*

The Kent Road site is situated amongst a residential area and is lined by a thin section of riparian vegetation that completely shades the creek and comprises a mix of native and exotic species. The site has changed little during the program.

*CR1SB - Shrimptons Creek at Bridge Street*

The Bridge Street site is located at the downstream section of Burrows Park, just before it flows under Bridge St and is surrounded by residential areas. Burrows Park consists largely of cleared grass fields. The riparian area has gone through several significant changes during the program with significant clearing and revegetation occurring twice since the autumn 2008 survey. The riparian area has at times been thickly vegetated with native and exotic weeds and shrubs that have choked the creek. When sampled for this survey the creek had a thick growth of predominately *Eleocharis sp* and *Myriophylum* (Figure 7).

*CR1SC – Shrimptons Creek at Quarry Road*

The Quarry Road site is located at the upstream section of Burrows Park, at the point where Shrimptons Creek emerges from the underground stormwater system. This site has had similar changes as Bridge St with the clearing and revegetation. There have been oil/scum, organic/ domestic debris and odours observed at the site in during past and the recent survey (Figure 7).

**Figure 7 Shrimptons Creek, spring 2013, Bridge St (L) and Quarry Rd (R)**

## Site 3: Porters Creek

The Porters Creek core sampling site is located on the eastern boundary of the Ryde City Depot (Macquarie Park) where Porters Creek emerges after flowing mostly underground in its upper reaches. Water quality was collected within the Ryde Waste Disposal Depot close to where Porters Creek drains from an underground system. Macroinvertebrates were collected within the boundaries of the Lane Cove National Park just downstream of the depot and the bridge for the main park access road. The surrounding riparian area is dominated by native plants with a small amount of exotic species. The creek bed is mostly bedrock with some cobble, boulder and sand. The creek and surrounding environment downstream of the bridge is in a relatively natural state. No macrophyte growth has been observed at the site however there has been varying levels of algal growth.

The creek bank and environment has remained relatively stable, although varying degrees of sedimentation has occurred immediately downstream of the bridge. At times there has been odour, milky and turbid water, oil, scum and domestic refuse observed at the site likely due to the close proximity of the depot.

**Figure 8 Porters Creek, core site in autumn 2010 (L) and at Wicks Rd in spring 2013 (R)**

*CR5PA - Porters Creek at Main Branch*

The Main Branch site is located on the western boundary of the depot and consists of an open concrete channel. The sampling point is in a retention section of the channel immediately before the creek flows underground for the remainder of its path through the depot.

There is usually extensive algal growth along the edge of the concrete channel and there is often a varying amount of oil and scum on the water surface.

*CR5PB - Porters Creek at Spur Branch*

The Spur Branch site is located in the north western corner of the depot in an underground drainage pit where several underground stormwater lines meet before joining and draining to the main Porters Creek line. It is accessed through a drainage grate and the spur branch is about three metres below ground.

When visited in spring 2013 there had been a ground collapse, which collapsed the drainage grate and surrounding concrete. The grate could not be moved and the ground was unsafe to remain upon. This meant that the site could not be sampled and as such there is no data for spring 2013.

*CR5PC - Porters Creek at Wicks Road*

The Wicks Road site is located upstream from the depot in small section of vegetation. This site is at the first point that Porters Creek drains from the underground stormwater system. The site is surrounded by commercial and industrial land use and the vegetation mostly consists of exotic trees and shrubs.

There are several stormwater drainage points noticeable at final stormwater pipe which exits into the creek and at the site there is several piped drainage lines entering the creek with unknown sources. There has been oil and scum regularly observed on the water surface in past surveys

## Site 4: Buffalo Creek

The Buffalo Creek core sampling site is located in a bush corridor in the suburb of Gladesville and is accessed through private property. The surrounding land use is a mix of residential, light industry/commercial and reserves. The surrounding vegetation is a mix of native and exotic species however exotic species dominate. The southern bank is mostly manicured lawns. The creek bed is mostly a mix of sand, silt and gravel. There is usually some macrophyte growth, *Egeria* and *Potamogeton*, and little algal growth has been observed.

The creek has had periods of increased sedimentation which after heavy rain has been scoured out, other than this the habitat has been stable. The most notable observations had been in the minor stormwater tributary immediately downstream of the sampling area being a milky/grey colour with considerable flow even during dry periods. This drained from an industrial/commercial area. In 2011 City of Ryde reclaimed land above this drainage point and now the stormwater goes through a series of wetlands before flowing down into Buffalo Creek.

**Figure 9 Buffalo Creek, core site in spring 2009 (L) and downstream Burrows Park site in late 2008 (R)**

*CR4BA – Buffalo Creek downstream of Burrows Park*

The downstream Burrows Park site is accessed off Buffalo Rd in the suburb of Ryde and is positioned just before the creek flows under the road. The surrounding land use is residential and Burrows Park consists mostly of a bush corridor. The site is quite open and the bank edge has been realigned with sandstone boulders. There have been increased turbidity levels observed at this site most notably in autumn 2008 and on several non-scheduled visits (Figure 9).

*CR4BB – Buffalo Creek upstream of Burrows Park*

The upstream Burrows Park site is about 300 metres upstream of Buffalo Rd, and is in the middle of the bush corridor. The site is surrounded by mostly native vegetation that completely shades the creek. The creek is shallow at this point and has little flow. There has been little observable change at this site throughout past surveys.

## Site 5: Archers Creek

The core Archers Creek sampling site is located at Maze Park in the suburb of West Ryde and is positioned just upstream of the Victoria Rd crossing. The surrounding land use is mostly residential and a golf course is present downstream. There is mostly native vegetation along both banks of the creek. The creek bed is mostly bedrock with banks of sediment (sand, silt and organic matter). There is thick growth of various native and exotic semiaquatic macrophyte plants along much of the sampling area as well as consistent algal growth.

Archers Creek had extensive rehabilitation work in late 2007 to early 2008. The creek line totally re-lined and the riparian edge cleared and replaced with large sandstone boulders along with replanting of native trees and shrubs (Figure 10). Before the rehabilitation work there was a large section of bank that was being eroded and there was thick growth of exotic shrubs and plants. The creek is now largely unshaded and the creek bank is very stable. Since the rehabilitation work however there has been a noticeable increase in sediment and excessive plant and algal growth throughout the sampling site. An increase in plant growth and organic matter loads have resulted in anoxic conditions being observed at the site on several sampling occasions.

**Figure 10 Archers Creek in autumn 2008 (L) and spring 2009 (R)**

# 7 Water quality

## 7.1 Terrys Creek

*Site 1 – Terrys Ck near M2 Motorway overpass*

The water quality results for Terrys Creek are presented in Table 8 (physico-chemical), Table 9 (bacteriological and nutrients) and Table 10 (metals and hardness). Most results for November 2013 were within the recommended ANZECC (2000) guidelines. The exceptions were for dissolved oxygen saturation (64.1%) which was slightly low, total nitrogen (1,020 µg/L), oxidised nitrogen (380 µg/L), total phosphorus (49 µg/L) and total copper (0.005 mg/L) which were all elevated.

Results from the spring 2013 were mostly reflective of what had been previously recorded, when compared to the historical median. The exceptions being the elevated levels mentioned above and conductivity was moderately higher than the historical median.

**Table 8 Terrys Creek physico-chemical results**

| Analyte Unit | Guideline | Site 1 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Temperature $^{O}C$ | NA | 15.7 | 17.1 |
| Dissolved Oxygen mg/L | NA | 6.5 | 6.2 |
| Dissolved Oxygen % saturation | 85-110[2] | **65** | **64.1** |
| pH pH units | 6.8-8.5[2] | 7.20 | 7.22 |
| Turbidity NTU | 50 | 2.38 | 3.82 |
| Conductivity µS/cm | 125-2,200[2] | 355 | 522 |
| Alkalinity (Total) mg CaCO3/L | NA | 61.4 | 76.7 |

**Table 9 Terrys Creek bacteriological and nutrient results**

| Analyte Unit | Guideline | Site 1 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Faecal Coliform CFU/100mL | 1,000 | 155 | 150 |
| Ammonia NH3 -N µg/L | 20[2] | 20 | 10 |
| Total Nitrogen µg/L | 350[2] | **515** | **1,020** |
| Total Kjeldahl Nitrogen µg/L | NA | 310 | 640 |
| Oxidised Nitrogen NOx-N µg/L | 40[2] | **140** | **380** |
| Total Phosphorus µg/L | 25[2] | **32** | **49** |

**Table 10 Terrys Creek metal and hardness results**

| Analyte Unit | Guideline | Site 1 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Total Chromium mg/L | 0.001 | NA | 0.0005 |
| Total Manganese mg/L | 1.9 | NA | 0.033 |
| Total Iron mg/L | NA | NA | 0.653 |
| Total Copper mg/L | 0.0035 | NA | **0.005** |
| Total Zinc mg/L | 0.02 | NA | 0.016 |
| Total Arsenic mg/L | 0.013 | NA | 0.0005 |
| Total Cadmium mg/L | 0.00054 | NA | 0.0005 |
| Total Lead mg/L | 0.0136 | NA | 0.0005 |
| Total Mercury mg/L | 0.0006 | NA | 0.00015 |
| Total Magnesium mg/L | NA | NA | 7.7 |
| Total Calcium mg/L | NA | NA | 30.3 |
| Total Hardness mg CaCO3/L | NA | NA | 107 |

## 7.2 Shrimptons Creek

*Site 2 - Shrimptons Creek at Wilga Park*

*CR1SA - Shrimptons Creek at Kent Road*

*CR1SB - Shrimptons Creek at Bridge Street (downstream of Santa Rosa Park)*

*CR1SC – Shrimptons Creek at Quarry Road (upstream of Santa Rosa Park)*

Water quality results for the four Shrimptons Creek sites are presented in Table 11 (physico-chemical), Table 12 (bacteriological and nutrients) and Table 13 (metals and hardness). Results for physico-chemical, bacteriological and metals were generally within the ANZECC (2000) guidelines. The exceptions were low dissolved oxygen saturation levels at Bridge St (24.3 %), Kent Road (44.5 %) and Wilga Park (52.8 %) and slightly elevated total zinc concentrations at Bridge St (0.022 mg/L) and Wilga Park (0.033 mg/L), and total copper at Wilga Park (0.006 mg/L).

Conductivity and alkalinity results were lower than the historical median at Quarry Road and dissolved oxygen was lower than the historical median at Bridge Street.

Nutrient concentrations were elevated above the ANZECC (2000) guidelines at most sites for both the current sampling and the historical medians. Total nitrogen and oxidised nitrogen concentrations at Quarry Road were particularly high for both the historical median (1,425 µg/L and 670 µg/L, respectively) and the current sampling (1,320 µg/L and 660 µg/L, respectively) and at Wilga Park for the current sampling (1,250 µg/L and 440 µg/L, respectively). Total phosphorus concentrations were also elevated, with the exception of Quarry Road for the current sampling.

**Table 11 Shrimptons Creek physico-chemical results**

| Analyte Unit | Guideline | CR1SC | | CR1SB | | CR1SA | | Site 2 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Temperature $^{O}C$ | NA | 17.7 | 19.2 | 17.6 | 19.2 | 17.0 | 18.7 | 17.2 | 19.1 |
| Dissolved Oxygen mg/L | NA | 6.6 | 8.8 | 5.9 | 2.2 | 5.0 | 4.2 | 4.3 | 4.8 |
| Dissolved Oxygen % saturation | 85-110[2] | **71** | 95.1 | **59** | **24.3** | **54** | **44.5** | **46** | **52.8** |
| pH pH units | 6.8-8.5[2] | 7.30 | 7.23 | 7.10 | 7.09 | 7.07 | 7.08 | 7.10 | 7.25 |
| Turbidity NTU | 50[2] | 3.54 | 1.69 | 4.94 | 5.58 | 4.28 | 4.60 | 4.91 | 4.65 |
| Conductivity µS/cm | 125-2,200[2] | 901 | 546 | 669 | 522 | 435 | 408 | 325 | 428 |
| Alkalinity (Total) mg CaCO3/L | NA | 91 | 52.1 | 92 | 69.8 | 63 | 52.3 | 64 | 57.2 |

**Table 12 Shrimptons Creek bacteriological and nutrient results**

| Analyte Unit | Guideline | CR1SC | | CR1SB | | CR1SA | | Site 2 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Faecal Coliform CFU/100mL | 1,000[1] | 500 | 250 | 245 | 220 | 450 | 590 | 450 | 260 |
| Ammonia NH3 -N µg/L | 20[2] | **35** | **80** | **25** | 10 | **25** | 10 | 20 | **40** |
| Total Nitrogen µg/L | 350[2] | **1,425** | **1,320** | **530** | **680** | **605** | **790** | **560** | **1,250** |
| Total Kjeldahl Nitrogen µg/L | NA | 490 | 660 | 375 | 670 | 445 | 720 | 380 | 810 |
| Oxidised Nitrogen NOx-N µg/L | 40[2] | **670** | **660** | 40 | 10 | **75** | **70** | **60** | **440** |
| Total Phosphorus µg/L | 25[2] | **65.5** | 25 | **25.5** | **41** | **41** | **45** | **53** | **58** |

**Table 13 Shrimptons Creek metal and hardness results**

| Analyte Unit | Guideline | CR1SC | | CR1SB | | CR1SA | | Site 2 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Total Chromium mg/L | 0.001 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 |
| Total Manganese mg/L | 1.9 | NA | 0.045 | NA | 0.132 | NA | 0.063 | NA | 0.043 |
| Total Iron mg/L | NA | NA | 0.381 | NA | 2.56 | NA | 1.3 | NA | 0.836 |
| Total Copper mg/L | 0.0035 | NA | 0.002 | NA | 0.002 | NA | 0.002 | NA | **0.006** |
| Total Zinc mg/L | 0.02 | NA | 0.014 | NA | **0.022** | NA | 0.015 | NA | **0.033** |
| Total Arsenic mg/L | 0.013 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 | NA | 0.001 |
| Total Cadmium mg/L | 0.00054 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 |
| Total Lead mg/L | 0.0136 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 | NA | 0.002 |
| Total Mercury mg/L | 0.0006 | NA | 0.00015 | NA | 0.00015 | NA | 0.00015 | NA | 0.00015 |
| Total Magnesium mg/L | NA | NA | 8.34 | NA | 7.69 | NA | 6.04 | NA | 4.66 |
| Total Calcium mg/L | NA | NA | 21.5 | NA | 27 | NA | 20.9 | NA | 21.1 |
| Total Hardness mg CaCO3/L | NA | NA | 88.1 | NA | 99.2 | NA | 77.1 | NA | 71.9 |

## 7.3 Porters Creek

*Site 3 - Porters Creek downstream of Council Depot*

*CR5PA - Porters Creek at Main Branch*

*CR5PB - Porters Creek at Spur Branch*

*CR5PC - Porters Creek at Wicks Road*

Water quality results for the Porters Creek sites are presented in Table 14 (physico-chemical), Table 15 (bacteriological and nutrients) and Table 16 (metals and hardness). The Spur Branch was not sampled in November 2013 due to a bank collapse that blocked and rendered the access point unsafe.

Results for physico-chemical, bacteriological and metals were generally within the ANZECC (2000) guidelines. The exceptions were for slightly low dissolved oxygen saturation levels at Wicks Road (84.0 %) and downstream of the Council Depot (78.9 %), elevated faecal coliforms at Wicks Road (7,700 CFU/100 mL) and elevated total zinc and total copper at each of the sampled sites.

Turbidity was higher than the historical median at Wicks Road and the Main Branch. Conductivity and alkalinity was lower than the historical median at the Main Branch.

Nutrient concentrations were elevated above the ANZECC (2000) guidelines at most sites for both the current sampling and the historical medians. Total phosphorus concentrations were also elevated, exceeding the guideline and the historical medians for each site.

**Table 14 Porters Creek physico-chemical results**

| Analyte Unit | Guideline | CR5PC | | CR5PA | | CR5PB | | Site 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Temperature $^{O}C$ | NA | 18.7 | 18.4 | 17.7 | 21.9 | 18.2 | NA | 18.0 | 19.0 |
| Dissolved Oxygen mg/L | NA | 8.9 | 7.4 | 7.9 | 8.3 | 9.5 | NA | 8.4 | 7.8 |
| Dissolved Oxygen % saturation | 85-110[2] | 94 | **84.0** | **78** | 94.8 | 99 | NA | 91 | **78.9** |
| pH pH units | 6.8-8.5[2] | 7.70 | 7.30 | 7.13 | 7.45 | 7.60 | NA | 7.63 | 7.53 |
| Turbidity NTU | 50 | 3.44 | 16.00 | 3.22 | 14.80 | 4.36 | NA | 3.67 | 4.96 |
| Conductivity µS/cm | 125-2,200[2] | 512 | 438 | 363 | 140 | 343 | NA | 610 | 512 |
| Alkalinity (Total) mg CaCO3/L | NA | 78.9 | 77.9 | 90 | 33.2 | 70.05 | NA | 85.3 | 118 |

**Table 15 Porters Creek bacteriological and nutrient results**

| Analyte Unit | Guideline | CR5PC | | CR5PA | | CR5PB | | Site 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Faecal Coliform CFU/100mL | 1,000 | 525 | **7,700** | 47 | 420 | 122 | NA | 370 | 210 |
| Ammonia NH3 -N µg/L | 20[2] | **40** | **210** | **90** | **30** | **75** | NA | **580** | **320** |
| Total Nitrogen µg/L | 350[2] | **1,405** | **3,360** | **670** | **900** | **745** | NA | **2,300** | **2,730** |
| Total Kjeldahl Nitrogen µg/L | NA | 375 | 1,450 | 505 | 670 | 430 | NA | 1,100 | 1,370 |
| Oxidised Nitrogen NOx-N µg/L | 40[2] | **935** | **1,910** | **155** | **230** | **260** | NA | **1,070** | **1,360** |
| Total Phosphorus µg/L | 25[2] | **28.5** | **276** | **37.5** | **63** | **38.5** | NA | 24 | **98** |

**Table 16 Porters Creek metal and hardness results**

| Analyte Unit | Guideline | CR5PC | | CR5PA | | CR5PB | | Site 3 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Total Chromium mg/L | 0.001 | NA | 0.001 | NA | 0.001 | NA | NA | NA | 0.0005 |
| Total Manganese mg/L | 1.9 | NA | 0.026 | NA | 0.011 | NA | NA | NA | 0.055 |
| Total Iron mg/L | NA | NA | 2.29 | NA | 0.491 | NA | NA | NA | 1.1 |
| Total Copper mg/L | 0.0035 | NA | **0.018** | NA | **0.005** | NA | NA | NA | **0.004** |
| Total Zinc mg/L | 0.02 | NA | **0.099** | NA | **0.027** | NA | NA | NA | **0.023** |
| Total Arsenic mg/L | 0.013 | NA | 0.0005 | NA | 0.0005 | NA | NA | NA | 0.0005 |
| Total Cadmium mg/L | 0.00054 | NA | 0.0005 | NA | 0.0005 | NA | NA | NA | 0.0005 |
| Total Lead mg/L | 0.0136 | NA | 0.002 | NA | 0.002 | NA | NA | NA | 0.0005 |
| Total Mercury mg/L | 0.0006 | NA | 0.00015 | NA | 0.00015 | NA | NA | NA | 0.00015 |
| Total Magnesium mg/L | NA | NA | 7.19 | NA | 2.21 | NA | NA | NA | 8.76 |
| Total Calcium mg/L | NA | NA | 28.7 | NA | 10.8 | NA | NA | NA | 36 |
| Total Hardness mg CaCO3/L | NA | NA | 101 | NA | 36.1 | NA | NA | NA | 126 |

## 7.4 Buffalo Creek

*Site 3 – Buffalo Creek at Higginbotham Road*

*CR4BA – Buffalo Creek downstream of Burrows Park*

*CR4BB – Buffalo Creek upstream of Burrows Park*

Water quality results for Buffalo Creek are presented in Table 17 (physico-chemical), Table 18 (bacteriological and nutrients) and Table 19 (metals and hardness). Results for pH, turbidity and conductivity were within the respective ANZECC guideline range at the three sites, while dissolved oxygen saturation levels were below the recommended guideline range of 85%.

Dissolved oxygen was lower than the historical median at all sites and conductivity was lower at the upstream and downstream Burrows Park sites.

Of particular note are the extremely high results for faecal coliforms at the sites upstream and downstream of Burrows Park (1,300,000 CFU/100 mL and 320,000 CFU/100 mL, respectively). The result for the site at Higginbotham Road was below the guideline and consistent with past results for this site.

Nutrient concentrations, with the exception of ammonia at the Higginbotham Road site, were high exceeding the respective ANZECC (2000) guidelines and the historical medians.

The current faecal coliform and nutrient levels indicate that a contamination event had occurred in Buffalo Creek, though there were no visual or olfactory indications of pollution at the time of sampling. Results were highest at the site upstream of Burrows Park, indicating that contamination had occurred above this site.

**Table 17 Buffalo Creek physico-chemical results**

| Analyte Unit | Guideline | CR4BB | | CR4BA | | Site 4 | |
|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Temperature $^{O}C$ | NA | 17.5 | 18.6 | 17.8 | 18.7 | 17.2 | 19.6 |
| Dissolved Oxygen mg/L | NA | 8.2 | 5.2 | 7.6 | 5.2 | 6.8 | 7.3 |
| Dissolved Oxygen % saturation | 85-110[2] | 85 | **56.3** | **81** | **56.4** | **70** | **80.3** |
| pH pH units | 6.8-8.5[2] | 7.68 | 7.55 | 7.16 | 7.48 | 7.30 | 7.43 |
| Turbidity NTU | 50 | 2.94 | 9.05 | 7.25 | 6.59 | 5.50 | 3.33 |
| Conductivity µS/cm | 125-2,200[2] | 968 | 547 | 1188 | 620 | 694 | 472 |
| Alkalinity (Total) mg CaCO3/L | NA | 102 | 107 | 95.1 | 82.8 | 79 | 58.1 |

**Table 18 Buffalo Creek bacteriological and nutrient results**

| Analyte Unit | Guideline | CR4BB | | CR4BA | | Site 4 | |
|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Faecal Coliform CFU/100mL | 1,000 | 465 | **1,300,000** | 840 | **320,000** | 170 | 270 |
| Ammonia NH3 -N µg/L | 20[2] | 15 | **6,600** | 13 | **1,070** | **40** | 10 |
| Total Nitrogen µg/L | 350[2] | **1,280** | **12,200** | **880** | **3,430** | **650** | **1,080** |
| Total Kjeldahl Nitrogen µg/L | NA | 435 | 10,900 | 470 | 2,580 | 400 | 690 |
| Oxidised Nitrogen NOx-N µg/L | 40[2] | **765** | **1,250** | **525** | **850** | **220** | **390** |
| Total Phosphorus µg/L | 25[2] | **57** | **820** | **43.5** | **214** | **37** | **58** |

**Table 19 Buffalo Creek metal and hardness results**

| Analyte Unit | Guideline | CR4BB | | CR4BA | | Site 4 | |
|---|---|---|---|---|---|---|---|
| | | Historical median | 15/11/13 | Historical median | 15/11/13 | Historical median | 15/11/13 |
| Total Chromium mg/L | 0.001 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 |
| Total Manganese mg/L | 1.9 | NA | 0.042 | NA | 0.094 | NA | 0.04 |
| Total Iron mg/L | NA | NA | 0.513 | NA | 1.29 | NA | 1.17 |
| Total Copper mg/L | 0.0035 | NA | **0.014** | NA | **0.006** | NA | **0.004** |
| Total Zinc mg/L | 0.02 | NA | **0.034** | NA | **0.027** | NA | 0.016 |
| Total Arsenic mg/L | 0.013 | NA | 0.001 | NA | 0.0005 | NA | 0.0005 |
| Total Cadmium mg/L | 0.00054 | NA | 0.0005 | NA | 0.0005 | NA | 0.0005 |
| Total Lead mg/L | 0.0136 | NA | 0.0005 | NA | 0.001 | NA | 0.0005 |
| Total Mercury mg/L | 0.0006 | NA | 0.00015 | NA | 0.00015 | NA | 0.00015 |
| Total Magnesium mg/L | NA | NA | 7.36 | NA | 9.56 | NA | 7.62 |
| Total Calcium mg/L | NA | NA | 23.1 | NA | 25.6 | NA | 22.9 |
| Total Hardness mg CaCO3/L | NA | NA | 88.1 | NA | 103 | NA | 88.6 |

## 7.5 Archers Creek

*Site 5 – Archers Creek at Maze Park*

Water quality results for Archers Creek are presented in Table 20 (physico-chemical), Table 21 (bacteriological and nutrients) and Table 22 (metals and hardness).The current results for pH, turbidity and conductivity were within the respective ANZECC (2000) guidelines. However, dissolved oxygen levels were very low with a saturation level of only 9.6 %.

Faecal coliform densities were slightly elevated above the ANZECC (2000) guideline. Total nitrogen and total phosphorus concentrations also exceeded the guidelines.

Results from spring 2013 were mostly reflective of what had been previously recorded, when compared to the historical median apart from the results discussed above. The result for copper was slightly elevated, while the zinc concentration was eight times above the recommended guideline. This was the highest result for zinc from across all the sites sampled in November 2013.

**Table 20 Archers Creek physico-chemical results**

| Analyte Unit | Guideline | Site 5 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Temperature $^{O}C$ | NA | 17.4 | 21.5 |
| Dissolved Oxygen mg/L | NA | 5.9 | 0.8 |
| Dissolved Oxygen % saturation | 85-110[2] | 61 | **9.6** |
| pH pH units | 6.8-8.5[2] | 7.16 | 7.15 |
| Turbidity NTU | 50 | 2.66 | 3.16 |
| Conductivity µS/cm | 125-2,200[2] | 397 | 499 |
| Alkalinity (Total) mg CaCO3/L | NA | 74 | 67.1 |

**Table 21 Archers Creek bacteriological nutrient results**

| | Guideline | Site 5 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Faecal Coliform CFU/100mL | 1,000 | 310 | **2,100** |
| Ammonia NH3 -N µg/L | 20[2] | **30** | 10 |
| Total Nitrogen µg/L | 350[2] | **520** | **900** |
| Total Kjeldahl Nitrogen µg/L | NA | 350 | 900 |
| Oxidised Nitrogen NOx-N µg/L | 40[2] | **70** | 5 |
| Total Phosphorus µg/L | 25[2] | **40** | **80** |

**Table 22 Archers Creek metal and hardness results**

| Analyte Unit | Guideline | Site 5 | |
|---|---|---|---|
| | | Historical median | 15/11/13 |
| Total Chromium mg/L | 0.001 | NA | 0.0005 |
| Total Manganese mg/L | 1.9 | NA | 0.903 |
| Total Iron mg/L | NA | NA | 0.828 |
| Total Copper mg/L | 0.0035 | NA | **0.005** |
| Total Zinc mg/L | 0.02 | NA | **0.161** |
| Total Arsenic mg/L | 0.013 | NA | 0.0005 |
| Total Cadmium mg/L | 0.00054 | NA | 0.0005 |
| Total Lead mg/L | 0.0136 | NA | 0.0005 |
| Total Mercury mg/L | 0.0006 | NA | 0.00015 |
| Total Magnesium mg/L | NA | NA | 8.7 |
| Total Calcium mg/L | NA | NA | 24.4 |
| Total Hardness mg CaCO3/L | NA | NA | 96.8 |

# 8 Macroinvertebrates

## 8.1 Univariate analyses

### 8.1.1 Taxa richness

> ***Taxa richness*** *is the overall variety (total taxa) of macroinvertebrates in a given community assemblage. It is an indicator of stream health that can be measured at any specific taxonomic level and operates under the assumption that taxa richness will be higher in healthy streams and lower in streams of poor health.*

A total of 738 individual macroinvertebrate specimens (Terrys Ck - 130, Shrimptons Ck - 135, Porters Ck - 122, Buffalo Ck - 108, Archers Ck - 243) were collected from all five sites during the spring 2013 survey, from 41 confirmed taxa (Appendix 4). A total of 79 confirmed taxa have been collected since 2004.

The average taxa richness, represented as total families collected during the spring 2013 survey is presented in Figure 11, including the historical average from the previous surveys.

Archers Creek recorded the highest taxa richness with an average of 16.3, while Buffalo Creek had the lowest with 9.7 from spring 2013. The spring 2013 averages for Terrys, Shrimptons, Porters and Archers creeks fell within the range of what had been previously recorded. The average taxa richness was slightly lower than the historical average for Terrys and Porters creeks and slightly higher for Shrimptons and Archers creeks. The average taxa richness recorded for Buffalo Creek fell below the historical range of 14.6 to 9.7 in spring 2013.

The larvae of the Sydney Hawk dragonfly, Austrocordulia leonardi and the Adams Emerald dragonfly, Archaeophya adamsi, both listed as endangered under the Fisheries Management Act 1994, are potentially found in the Sydney basin region. Neither of these macroinverebrates was observed in any of the samples collected during the monitoring program.

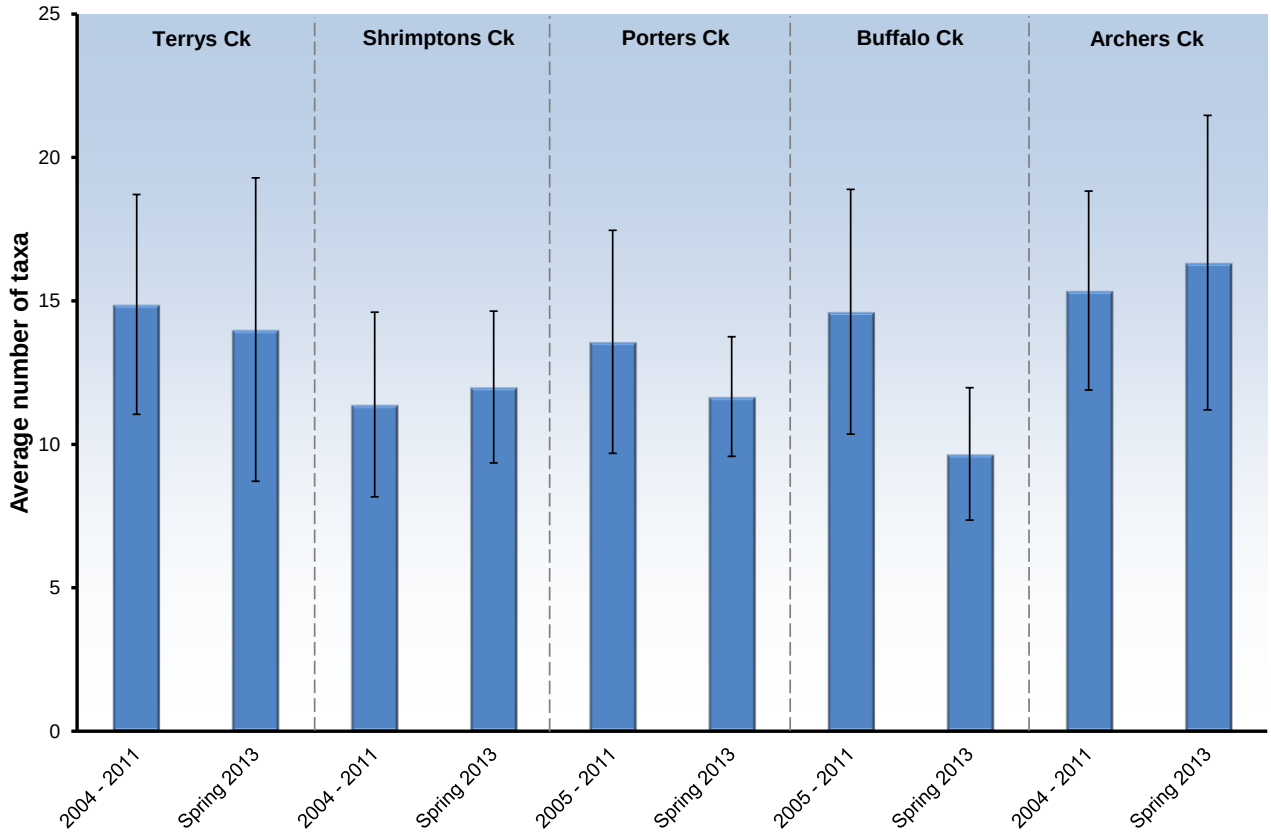



**Figure 11 Average taxa for all creeks of the monitoring program**

***Taxa group percent composition*** *is a visual display of the contribution of each of the main macroinvertebrate taxa in a given community assemblage. Percent contribution shows the dominant groups within each study creek.*

*The generic names given to the taxa within the groups are listed below;*

*Annelida – worms*
*Coleoptera – beetles*
*Crustacea – yabbies, shrimp & slaters*
*Diptera – true flies*
*EPT – mayflies, stoneflies & caddisflies*
*Hemiptera – true bugs*
*Mollusca – snails and mussels*
*Odonata – dragonflies & damselflies*
*Other Taxa – various incl. mites, lacewings & flatworms*

The single most dominant taxa group contributing to the biggest proportion of specimens within the community assemblages at three of the five core sites (Terrys, Shrimptons and Buffalo creeks) was Mollusca. The second most dominant taxa group was Diptera within Porters and Archers creeks. Odonata was the third most dominant taxa group within all five creeks. These three groups contributed 68-80% of the total taxa present in the five creeks of the program (Figure 12 - Figure 16).

The important indicator taxa group, EPT, have been found in very low numbers within all five creeks. Archers Creek had proportionately the highest EPT taxa, contributing 5% to the total. Coleoptera and Crustacea were also very low contributors within all five creeks (Figure 12 - Figure 16).

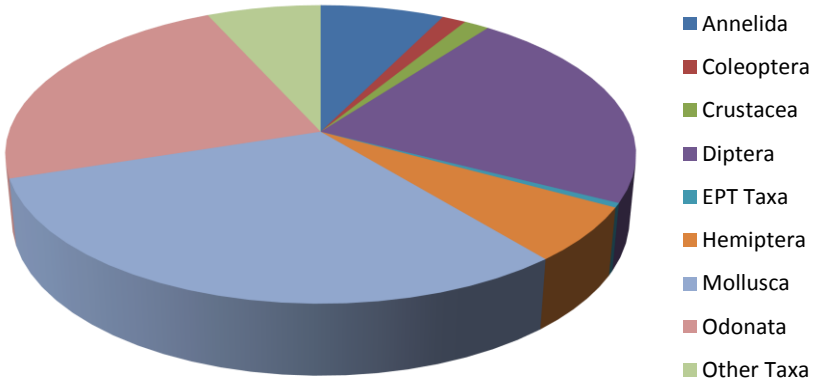



**Figure 12 Taxa group composition for Terrys Creek, spring 2004 - spring 2013**

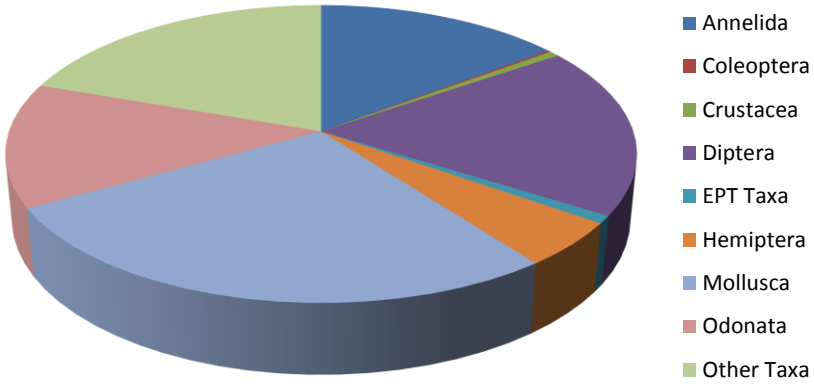



**Figure 13 Taxa group composition for Shrimptons Creek, spring 2004 - spring 2013**

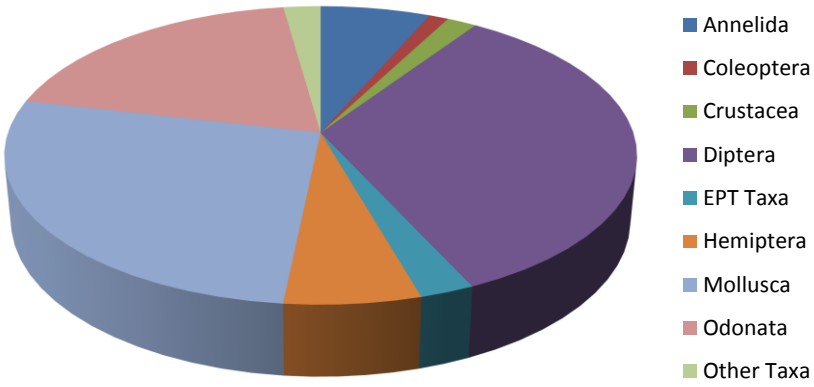



**Figure 14 Taxa group composition for Porters Creek, autumn 2005 - spring 2013**

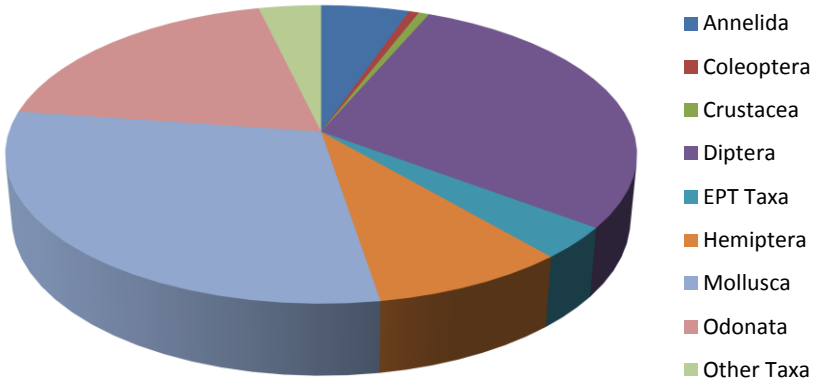



**Figure 15 Taxa group composition for Buffalo Creek, autumn 2005 - spring 2013**

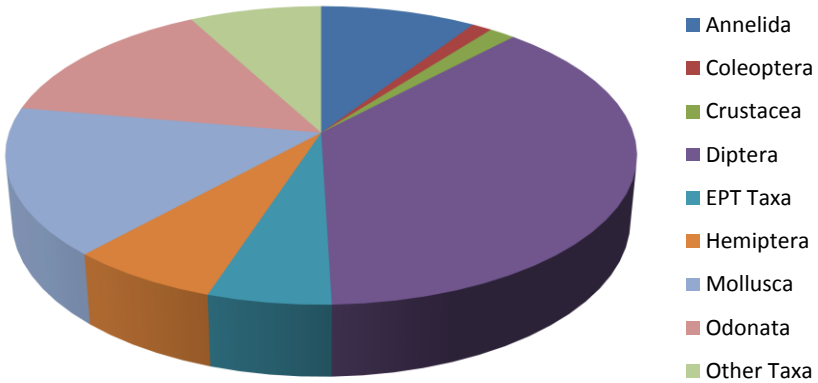



**Figure 16 Taxa group composition for Archers Creek, spring 2004 - spring 2013**

### 8.1.2 EPT taxa richness

> ***EPT taxa richness*** *shows the abundance of highly sensitive Ephemeroptera (mayfly), Plecoptera (stoneflly) and Trichoptera (caddisflly) orders. High EPT richness indicates increased water quality and a healthy creek system.*

The average EPT taxa richness collected during the spring 2013 survey are presented in Figure 17, including the historical average from previous surveys. Results indicate that EPT taxa are found sporadically and in very low numbers within the five creeks.

No EPT taxa were found during spring 2013 from Shrimptons or Buffalo creeks and Terrys, Porters and Archers creeks averaged less than 1 EPT taxa. Terrys Creek was the only creek to return a higher average in spring 2013 compared to the historical average, however this was a minimal difference.

Of the five creeks, Porters and Archers have historically the highest average EPT taxa however both creeks average less than 1. Since the program began in 2004 a total of only five EPT taxa families have been collected. Only one, the Hydroptilidae (Trichopteran), has been recorded regularly from all five creeks (Appendix 4).

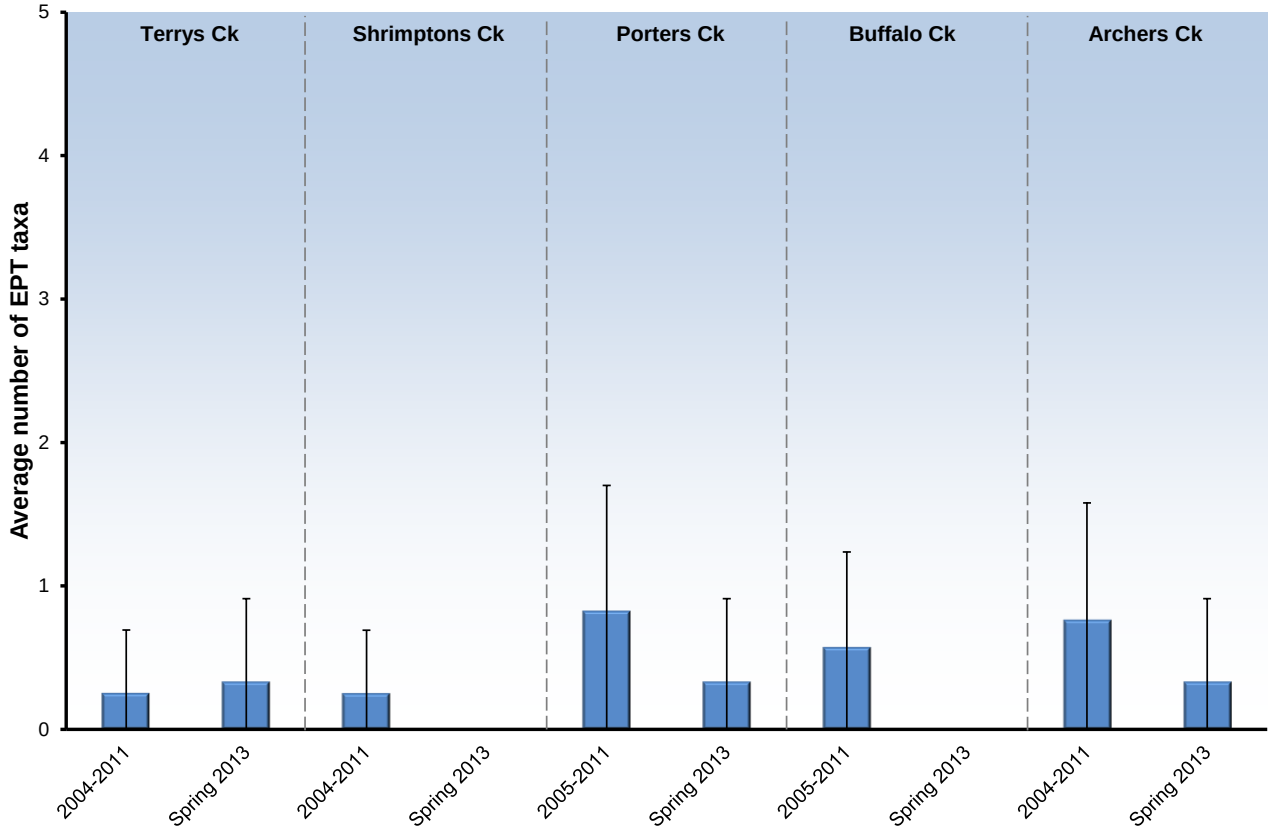



**Figure 17 Average EPT taxa for each creek**

## 8.2 Biological indices

### 8.2.1 SIGNAL2

***SIGNAL2*** *(Stream Invertebrate Grade Number Average Level) biotic index is a relatively simple method used to assess stream health. This index assigns 'sensitivity scores' to macroinvertebrate taxa. A final SIGNAL score combined with the total taxa then places a study creek within a quadrant based on potential pollution type.*

The average SIGNAL2 scores for the spring 2013 survey are presented in Figure 18 and the bi-plot placement for the five creeks are displayed in Figure 19. SIGNAL2 wasn't calculated in previous reports as such there are no historical averages.

Terrys Creek recorded the highest average SIGNAL2 score recording 3.6, the lowest average score was recorded in Shrimptons Creek with 2.6. Porters, Buffalo and Archers creeks all recorded similar average scores.

The five creeks are all placed in quadrat four in the bi-plot. Results in quadrat four are representative of urban, industrial or agricultural pollution (Figure 30), this placement is the result of samples having combined low SIGNAL2 scores and taxa counts.

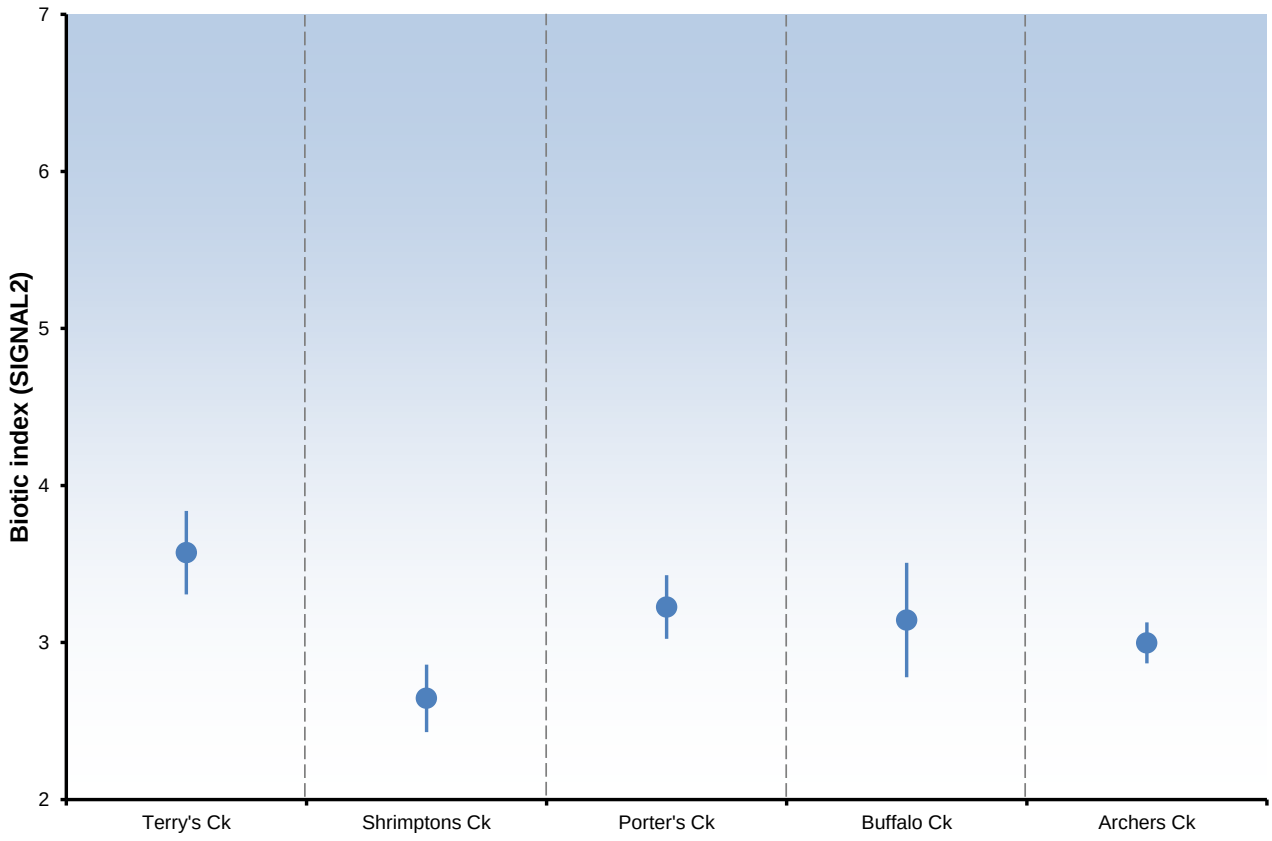



**Figure 18 Average SIGNAL2 scores for spring 2013**

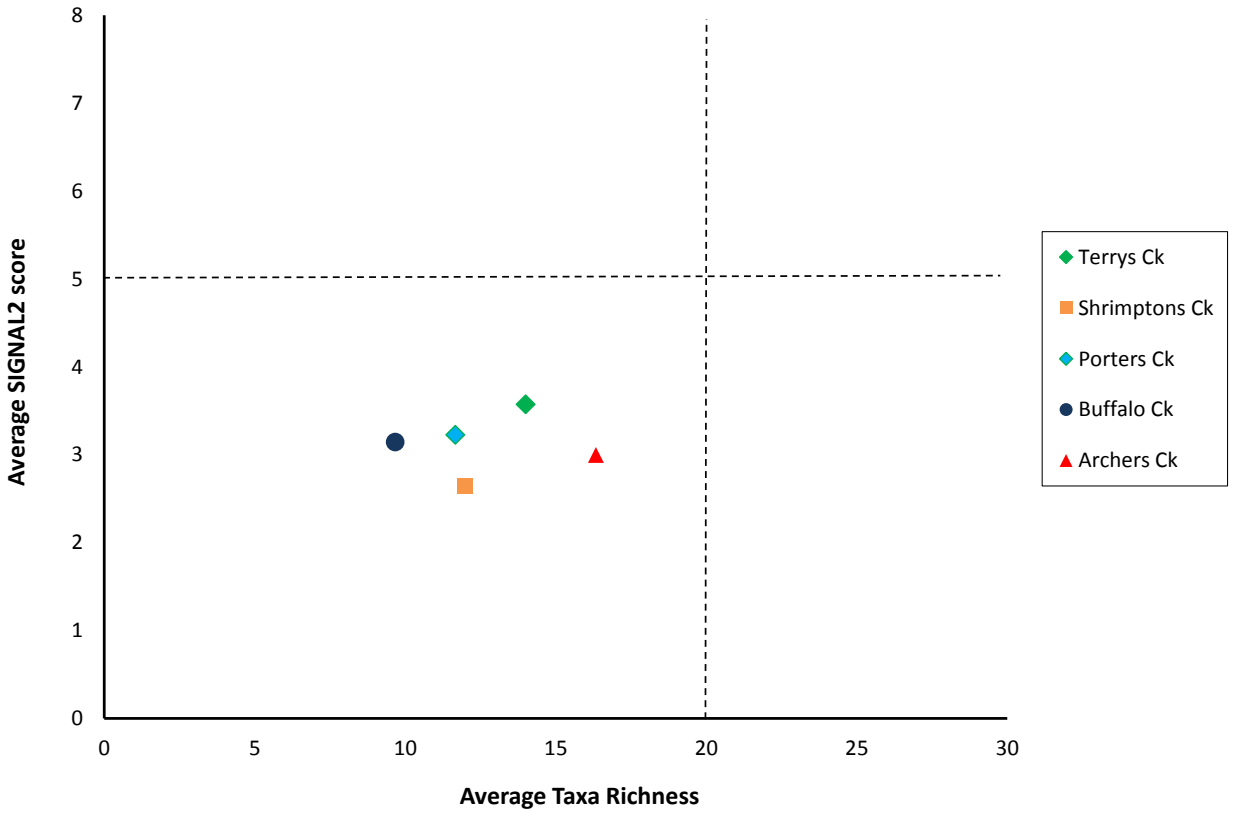



**Figure 19 SIGNAL2 bi-plot from spring 2013**

### 8.2.2 Signal-SF

***SIGNAL-SF 'Stream Invertebrate Grade Number Average Level - Sydney Family'*** *biotic index is a relatively simple method used to assess stream health. This index assigns 'sensitivity scores' from 1 being tolerant to 10 being very sensitive to each individual macroinvertebrate taxa.*

The average SIGNAL-SF biotic index scores for spring 2013 are presented in Figure 20, including the historical averages. The spring 2013 and historical average SIGNAL-SF scores for all five creeks are indicative of probable moderate organic pollution (Table 27).

Results in spring 2013 were reflective of what had been previously recorded with all average SIGNAL-SF scores falling within the range of the historical data for each respective creek. Archers Creek recorded the highest average SIGNAL-SF score in spring 2013 with 4.4 and Shrimptons recorded the lowest at 3.9. Archers and Terrys creeks average SIGNAL-SF scores increased slightly in spring 2013 compared to their respective historical averages whereas Shrimptons, Porters and Buffalo creeks slightly decreased.

Results indicate that Archers Creek is the healthiest of the five creeks of the program however results at Terrys, Porters and Buffalo creeks were only marginally lower. Results indicate that Shrimptons Creek is the least healthy creek of the program. While not dramatically lower than other creeks, results are significantly less than Terrys, Porters and Archers creeks particularly in the current survey.

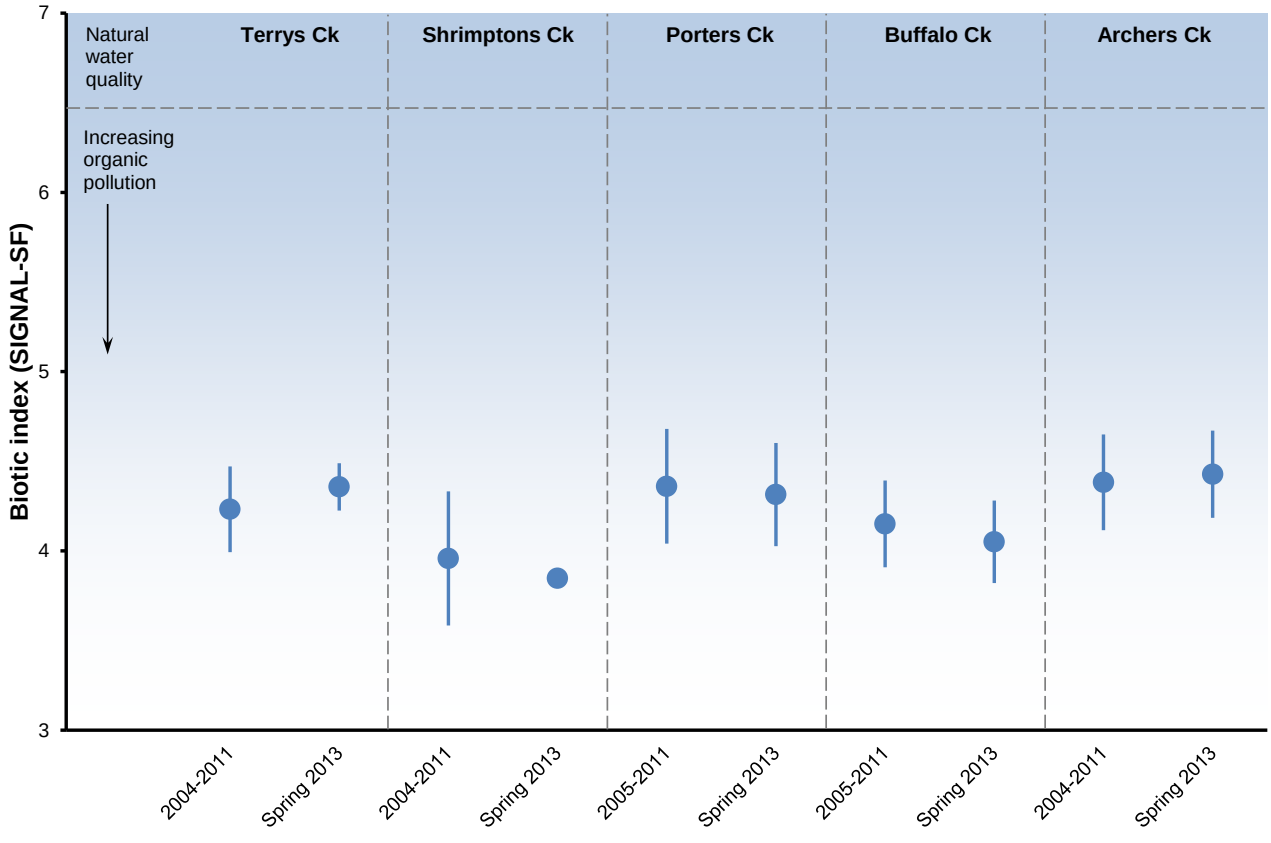



**Figure 20 Average SIGNAL-SF scores for each creek**

### 8.2.3 AUSRIVAS

#### AUSRIVAS OE50

***AUSRIVAS OE50*** *is an indice calculated from the AUSRIVAS predictive model, comparing the macroinvertebrates from a current assessment site to macroinvertebrate data previously collected from reference sites with similar physical and chemical characteristics. The OE50 indice compares only the macroinvertebrates from the assessment site with a greater than 50% chance of occurring at the reference site. This comparison can help determine the 'condition' or 'health' of the water body.*

The AUSRIVAS OE50 spring edge model scores, both the spring 2013 survey and historical averages are presented in Figure 21. The spring 2013 and historical average scores for Terrys, Shrimptons, Porters and Archers creeks were placed in Band C, which is indicative of severely impaired stream health. Buffalo Creek average historical score is placed in Band C, however spring 2013 it dropped into Band D which is indicative of extremely impaired stream health (Table 28)

Terrys, Shrimptons, Porters and Archers creeks average score range in spring 2013 overlapped with the historical average score range. The exception was Buffalo Creek where the spring 2013 average score dropped significantly below the historical average range.

Shrimptons and Porters creeks average scores in spring 2013 were slightly above the historical range. Terrys and Archers creeks average scores in spring 2013 were within the range of what had been previously recorded with Terrys Creek being slightly higher and Archers Creek lower than the historical average.

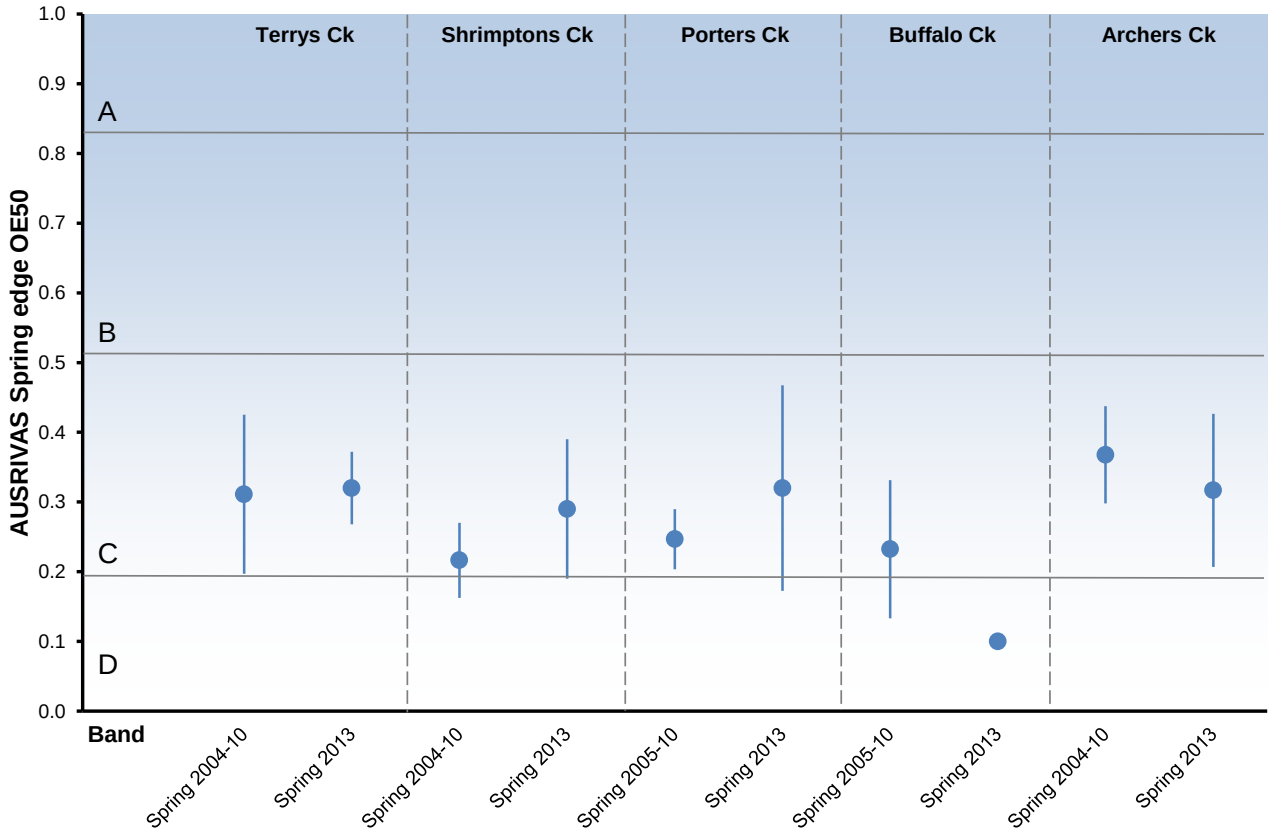



**Figure 21 Average AUSRIVAS OE50 spring edge model scores for each creek**

## AUSRIVAS OE0 SIGNAL

***AUSRIVAS OE0 SIGNAL*** *is an indice calculated from the AUSRIVAS predictive model, comparing the macroinvertebrates from a current assessment site to macroinvertebrate data previously collected from reference sites with similar physical and chemical characteristics. The OE0 SIGNAL indice is a ratio of the observed SIGNAL (Chessman, 1995)) values from the assessment site to the expected taxa from the reference sites. The ratio uses all (100%) of the observed and expected taxa in the calculation. This comparison can also help determine the 'condition' or 'health' of the water body.*

The AUSRIVAS OE0 SIGNAL Spring edge model scores, both the spring 2013 survey and historical averages are presented in Figure 22.

Terrys Creek recorded the highest average score of the five creeks in spring 2013 and was the only creeks to score higher than its historical average. Buffalo Creek had the next highest average score in spring 2013 which was reflective of historical results. Shrimptons, Porters and Archers creeks average scores were similar in spring 2013. Shrimptons and Archers creeks average scores were lower than the historical average score range, whilst Porters was within the historical range.

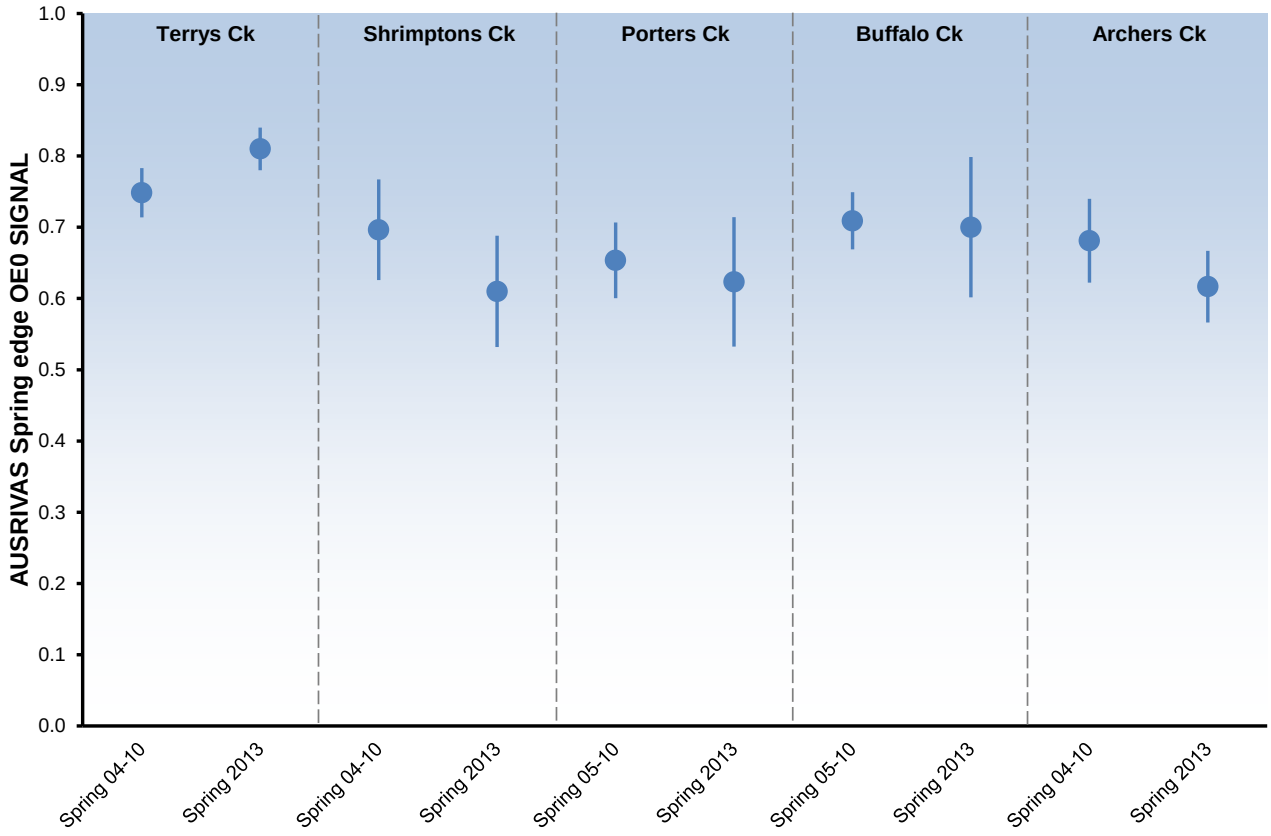



**Figure 22 Average AUSRIVAS OE0 SIGNAL spring edge model scores for each creek**

## AUSRIVAS missing taxa

***AUSRIVAS missing taxa*** *are the taxa that were missing from the assessment site but were predicted with a greater than 50% chance of occurring by the OE50 predictive model to occur at reference sites with similar physical and chemical characteristics.*

Taxa with a greater than 50% chance of occurring at reference sites that have been identified as missing from the survey sites according to the AUSRIVAS observed/expected analysis are listed in Table 23. Included is the SIGNAL scores for each taxa, these are the Chessman (1995) scores that are used by the NSW AUSRIVAS model.

The number of missing taxa range from 7 at Porters Creek (the least) to 12 at Buffalo Creek (the most). This was to be expected as there was only one expected taxa with a greater than 50% probability of occurring present in each of the spring 2013 samples (AUSRIVAS model output).

The missing taxa were relatively similar across the five sites and are a mix of tolerant (low SIGNAL scores) and sensitive (high SIGNAL scores).

**Table 23 AUSRIVAS missing taxa with >50% of occurring at test site with SIGNAL scores (Chessman 95)**

| Creek | Missing taxa | | |
|---|---|---|---|
| Terrys Creek | Acarina (6) | Scirtidae (6) | Hydrometridae (3) |
| | Atyidae (3) | Culicidae (1) | Gerridae (4) |
| | Dytiscidae (2) | Leptophlebidae (8) | Leptoceridae (6) |
| | Hydrophilidae (2) | | |
| Shrimptons Creek | Acarina (6) | Hydrophilidae (2) | Leptophlebidae (8) |
| | Atyidae (3) | Scirtidae (6) | Velidae (3) |
| | Dytiscidae (2) | Culicidae (1) | Leptoceridae (6) |
| | Gyrinidae (4) | | |
| Porters Creek | Gyrinidae (4) | Gerridae (4) | Aeshnidae (4) |
| | Leptophlebidae (8) | Synlestidae (7) | Leptoceridae (6) |
| | Velidae (3) | | |
| Buffalo Creek | Acarina (6) | Scirtidae (6) | Hydrometridae (3) |
| | Atyidae (3) | Culicidae (1) | Velidae (3) |
| | Dytiscidae (2) | Tanypodinae (4) | Gerridae (4) |
| | Hydrophilidae (2) | Leptophlebidae (8) | Leptoceridae (6) |
| Archers Creek | Dytiscidae (2) | Leptophlebidae (8) | Aeshnidae (4) |
| | Gyrinidae (4) | Gerridae (4) | Leptoceridae (6) |
| | Scirtidae (6) | Synlestidae (7) | |

## 8.3 Multivariate analyses

### 8.3.1 Spring 2013 analysis

*__Cluster analysis__ and __SIMPROF__ are multivariate tests which correlate and display the percent similarities between macroinvertebrate assemblages between each of the study creeks.*

*__MDS Ordinations__ attempt to place these assemblages using the similarities in a 2D or 3D space, with similar assemblages close together and those dissimilar further apart.*

Replicate data from the spring 2013 survey was analysed for all creeks and the resultant cluster analysis and SIMPROF permutation tests are presented in Figure 23. The cluster analysis lists each replicate in the output, potentially splitting all samples even when no real difference exists between them. The importance of this analysis lies within the grouping of replicates and the SIMPROF test complements the analysis by indicating if a real statistical difference actually exists between these groups.

The SIMPROF test indicates that there is no real statistical difference between any of the sample groups at varying levels of similarity. The cluster analysis separated the first sample group consisting of a single replicate from Terrys and Archers creeks at 47% similarity. The second group to split consists of two replicates from Porters Creek at 51% similarity. The remaining groups that split tend to include replicates from the same creek with a single replicate from another creek.

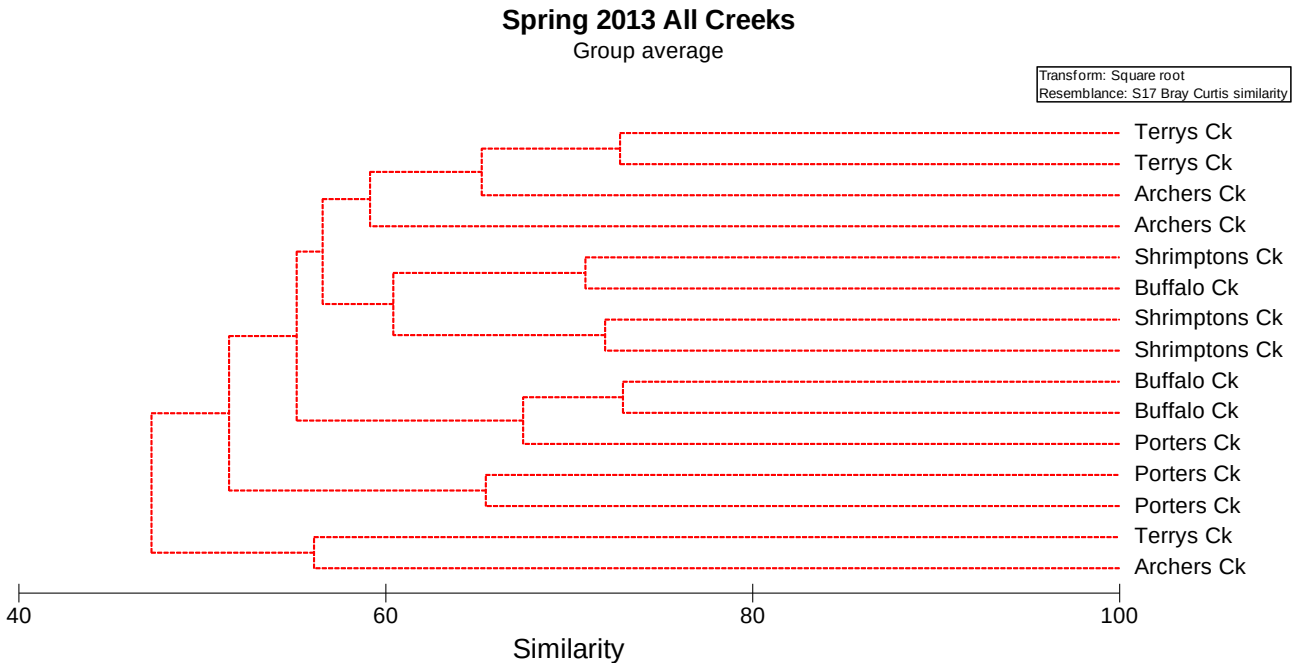



**Figure 23 All five creeks cluster analysis (SIMPROF), spring 2013**

The two dimensional mds ordination of the spring 2013 replicate data including 50% and 60% similarity clusters are presented in Figure 24. Except for the odd single replicate most of the creeks tended to group together, however sample groups as a whole were spread evenly and not grouped tightly. This suggests that there were not any significant differences in macroinvertebrate community assemblages.

The two-dimensional ordination is presented with a stress of 0.16. The relatively low sample numbers and results of the cluster (SIMPROF) indicate that while the samples and sample groups are all relatively similar the sporadic nature in community structure of some of the replicates has meant that there are not clear separation and clustering of sample groups.

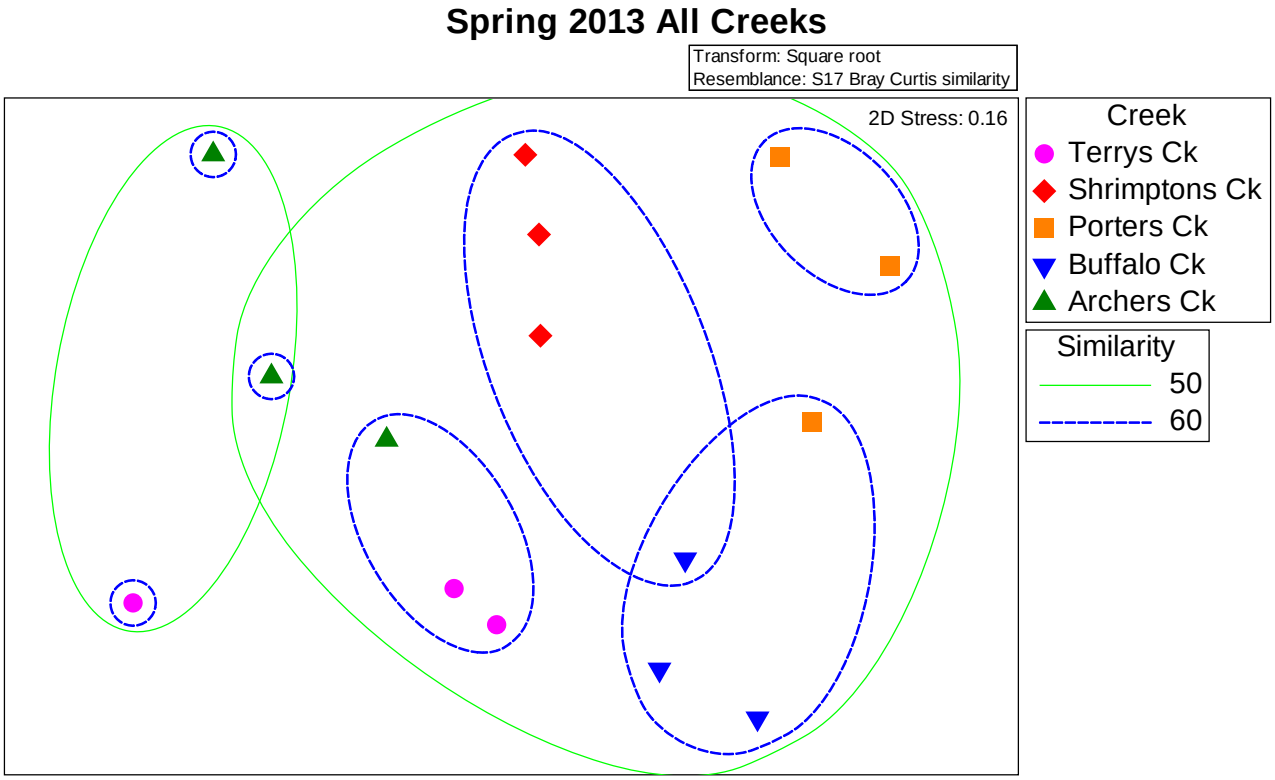



**Figure 24 All five creeks two dimensional mds ordination, including similarity clusters, spring 2013**

***SIMPER*** *uses the Bray Curtis analysis to explore the similarities and differences in macroinvertebrate community assemblages between and within study sites.*

Results of the SIMPER analysis looking at within site replicate similarity are presented in Table 24 and dissimilarity between sites in Table 25. Similarity between replicates at each site ranged from 68.7% at Buffalo Creek down to 61.3% at Archers Creek. The dissimilarity between sites ranged 54.2% between Porters and Archers creeks to 42.8% between Shrimptons and Archers creeks. Results from the SIMPER analysis suggested that there is slightly more variation in macroinverterbate community composition between different sites than there is between replicate samples of the same site at each of the five creeks.

SIMPER results indicated that all five creeks were dominated by relatively few taxa in spring 2013 (Appendix 5), notably Buffalo Creek with just four taxa contributing to over 90% of the total community composition. Clearly the most dominant taxa at all five creeks in spring 2013 was the Chironomidae sub-family, Chironominae, being the single most dominant taxa at all creeks except Archers Creek where it was still the second most dominant. The next most dominant taxa were the Mollusca, Tateidae (formerly Hydrobiidae).

**Table 24 SIMPER analysis for all five creeks, average similarity within sites, spring 2013**

| Season | Terrys | Shrimptons | Porters | Buffalo | Archers |
|---|---|---|---|---|---|
| **Spring 2013** | 62.3% | 68.6% | 64.14% | 68.7% | 61.3% |

**Table 25 SIMPER analysis for all five creeks, average dissimilarity between sites, spring 2013**

| Site | Dissimilarity | | | |
|---|---|---|---|---|
| **Terrys Creek** | 44.1% | | | |
| **Shrimptons Creek** | 42.8% | 48.1% | | |
| **Porters Creek** | 54.2% | 53.1% | 44.8% | |
| **Buffalo Creek** | 52.6% | 43.4% | 48.4% | 46.3% |
| | **Archers Creek** | **Terrys Creek** | **Shrimptons Creek** | **Porters Creek** |

### 8.3.2 Historical comparison

***ANOSIM*** *tests for real differences in data from within the same site replicates to replicates between different sites. The hypothesis being that all sites and replicates are the same. The complete dataset is essentially re-run numerous times to test if what was actually found in the data can randomly occur with comparative regularity. If this is the case then replicates within and between sites are proved to be statistically the same or very similar. If this doesn't occur then differences are presumed to occur. Further investigation is required to investigate where and why these differences occur.*

Spring 2013 data was compared to historical baseline data using ANOSIM to test for any significant differences between the two periods for each of the five creeks. ANOSIM tests the similarities of replicates within sites to the similarities between replicates from different sites, the null hypothesis being there is no difference between samples from spring 2013 and samples from the previous surveys between 2004 and 2011. The ANOSIM results are presented in Table 26, the R value is included along with the significance level presented as a *p* value.

The results of the ANOSIM analysis suggest that the samples collected from the spring 2013 survey reflect relatively closely what has been previously observed for Terrys (R = 0.273), Porters (R = 0.253) and Archers (R = 0.230) creeks and more closely what had previously been observed at Shrimptons Creek indicated by the lower R value of 0.139. All results, excluding Buffalo Creek were result non-significant with p values greater than 0.05. However the numbers of permutations run in the test combined with the strong R values suggest that the ANOSIM results hold weight for the analysis. ANOSIM results for Buffalo Creek were significant (Table 26) with an R value suggesting some community structure differences in between spring 2013 samples and the historical baseline samples.

**Table 26 One way ANOSIM results**

| Site | R value | *P* value |
|---|---|---|
| Terrys Creek | 0.273 | 0.062 |
| Shrimptons Creek | 0.139 | 0.168 |
| Porters Creek | 0.253 | 0.074 |
| Buffalo Creek | 0.350 | 0.006 |
| Archers Creek | 0.230 | 0.073 |

The two dimensional mds ordinations for the each of the creeks are presented with similarity cluster groupings and a trajectory showing sample group movement through time (Figure 25 - Figure 29). All ordinations provided suitable representations of the seasonal data as indicated by stress values of less than 0.2 (plots ranged from 0.05 to 0.14). Reference was made to the cluster analysis and in particular the permutation SIMPROF tests for the analysing the significance of these groupings (Appendix 5).

Spring 2013 distinctly separates from other seasons in all of the ordinations, except Archers Creek (Figure 29). Although this separation is at very high similarities of 60% to 70%, suggesting there were a lot of taxa in common as indicated by R values above (Table 26). Generally there were two clear groupings in the ordinations at around 60% similarity (Figure 26 Figure 29). The first sample group consists of spring 2004 to autumn 2006, the second, consisting of spring 2006 to autumn 2011. Terrys Creek has a similar grouping in the ordination except that four seasons (including spring 2013) separate by themselves (Figure 25).

Other than the groupings described above, another evident pattern in community assemblage data was the separation of autumn from spring seasons, particularly evident for Shrimptons and Buffalo creeks (Figure 26 and Figure 28). However, as with all of the sample groups for all of the creeks in the ordinations the splits were at similarity levels of 60 to 70%. This again suggests that while there are clear separations of the sample groups there is still a high degree of similarity between samples and seasons within each creek through time. It is important to understand that the purpose of the ordination is to always separate sample groups based on the similarity matrix, and the spread of samples in all of the ordinations suggest that many of the groupings are in fact quite similar.

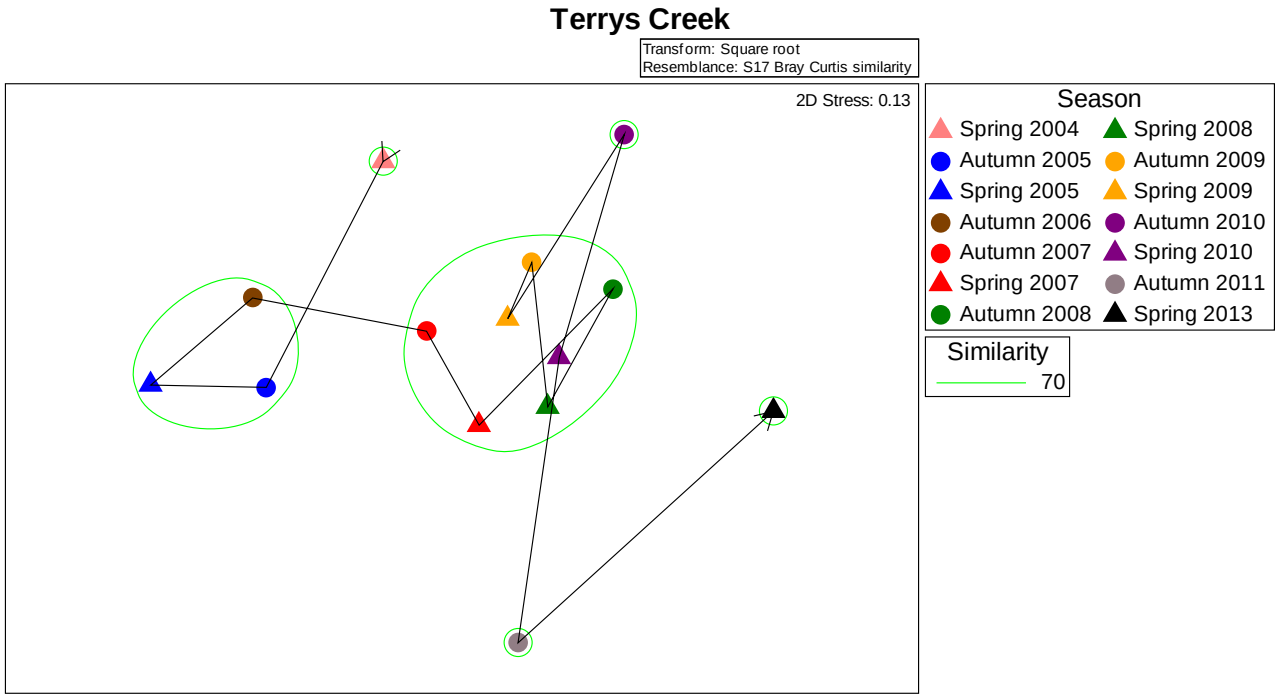



**Figure 25 Terrys Creek two dimensional mds ordination**

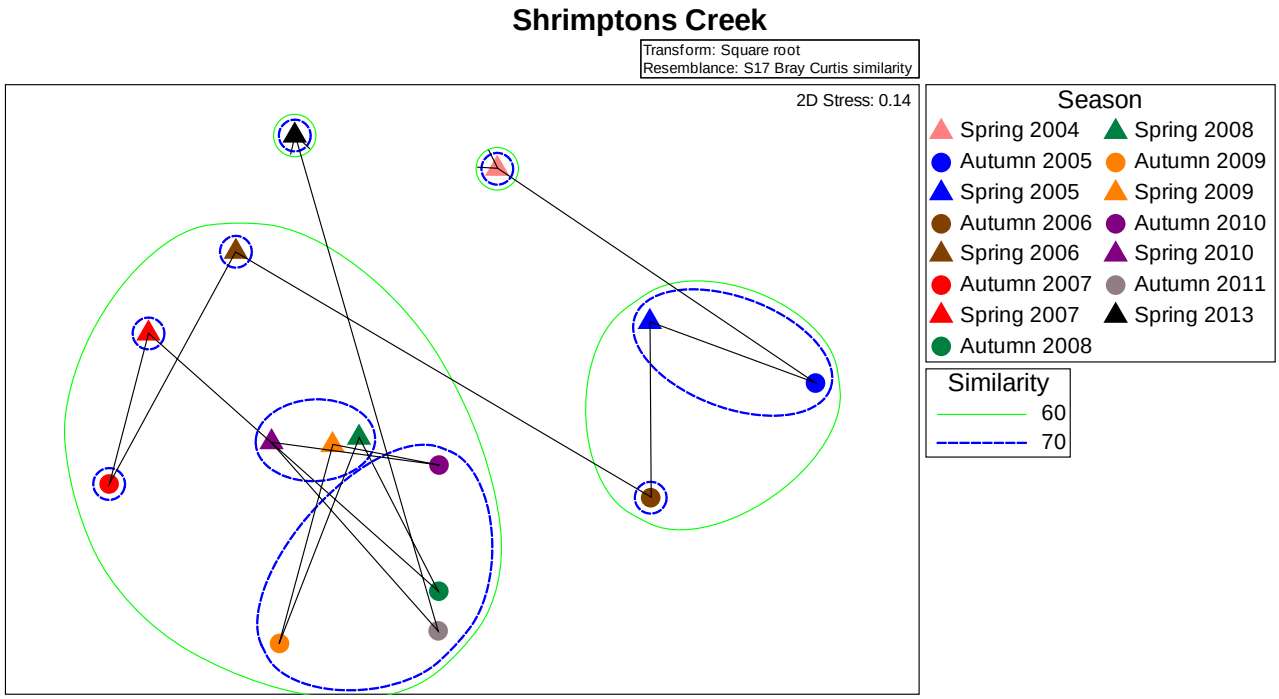



**Figure 26 Shrimptons Creek two dimensional mds ordination**

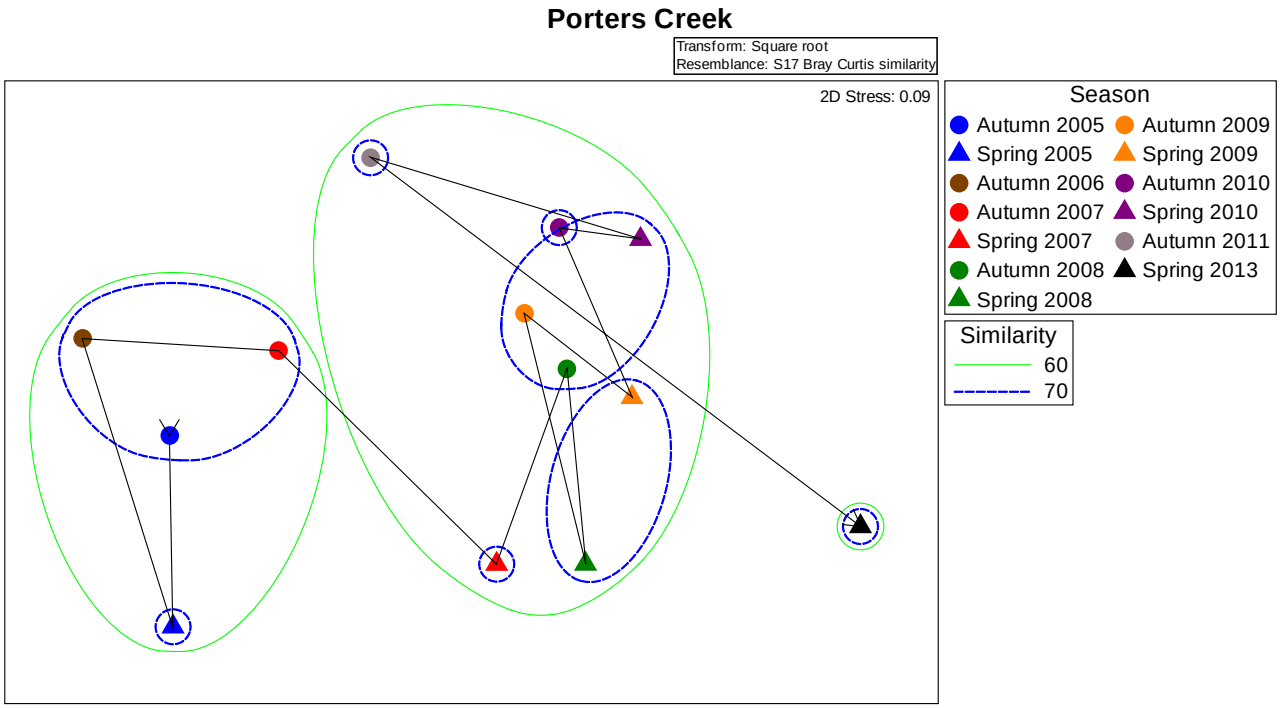



**Figure 27 Porters Creek two dimensional mds ordination**

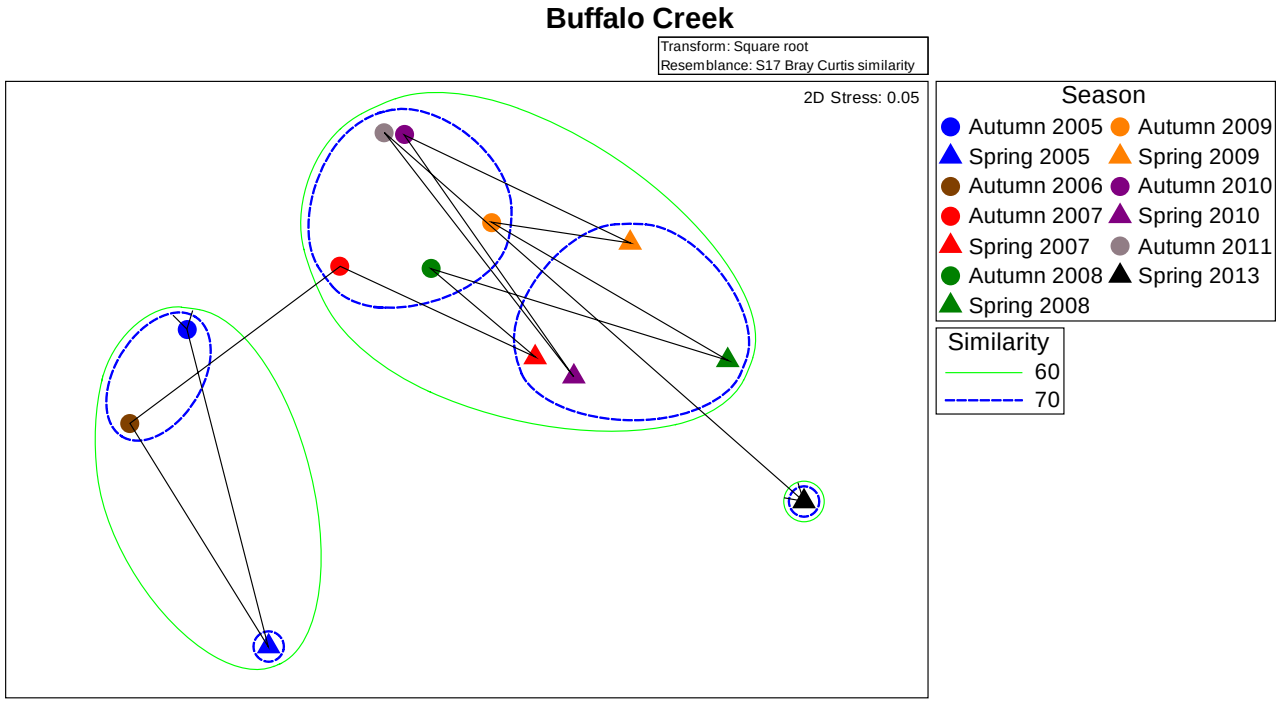



**Figure 28 Buffalo Creek two dimensional mds ordination**

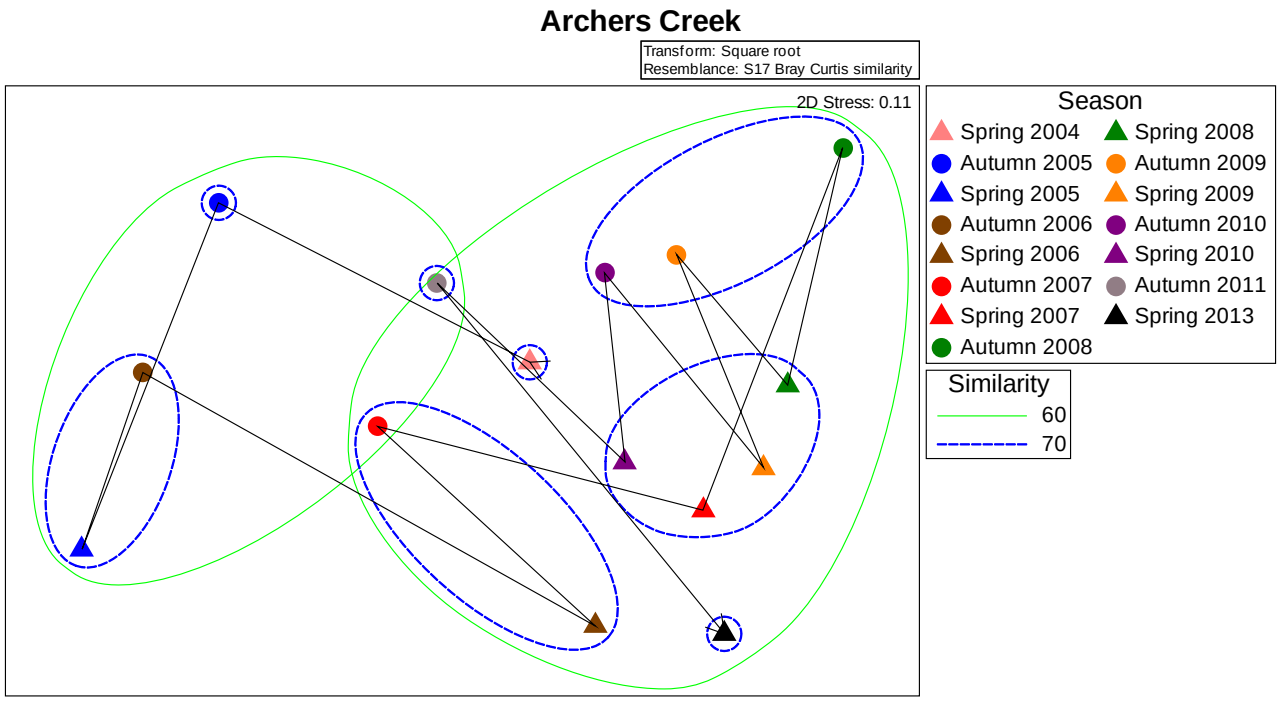



**Figure 29 Archers Creek two dimensional mds ordination**

# 9 Discussion

## 9.1 Water quality

Aquatic ecosystems comprise the animals, plants and micro-organisms that live in water, and the physical and chemical environment and climatic regime with which they interact. It is predominantly the physical components (eg light, temperature, mixing, flow and habitat) and chemical components (eg organic and inorganic carbon, oxygen, nutrients) of an ecosystem that determine what lives and breeds in it, and therefore the structure of the food web (ANZECC 2000).

Water quality results for this study, while not reflecting a sampling frequency suggested by ANZECC (2000), did allow for characterisation of water quality at each study creek against ANZECC (2000) guidelines for Aquatic Ecosystems (Lowland River SE Australia), Recreational Water Quality and Aesthetics (Secondary) and Toxicants (at 95% species protection level).

The streams in this study would be deemed highly disturbed systems as they are urban streams receiving road and stormwater runoff (ANZECC 2000). This said, they still retain ecological and conservation values, and the general objective might be to maintain present water quality to retain a functional, albeit modified, ecosystem that would support the management goals assigned to it.

Results of the spring 2013 water quality sampling for Shrimptons, Porters, Buffalo, Terrys and Archers creeks support results of previous studies, that have indicated that urban pollution transport is having an impact on instream water quality. This impact is indicated by low levels of dissolved oxygen and high concentrations of nutrients, especially nitrogen forms. The spatially variable pollutant concentrations indicate that they originate from varying locations over time.

Temperature in waterways generally varies with water depth, amount of shading and flow, and affects a number of other water quality parameters. Temperature fluctuations may affect: chemical and biochemical reaction rates; chemical solubility; growth and respiration rates of aquatic organisms; and reproduction and competitive interaction cues of aquatic organisms. Temperature results for November 2013 ranged from 17.1 $^{o}$C at Terrys Creek to 21.9 $^{o}$C at Porters Creek Main Branch. These results are consistent with the season and the environment of the stream, with Terrys Creek having a high degree of shading and the Porters Creek site being an open concrete channel.

Dissolved oxygen concentrations are an important water quality indicator for the survival of aquatic organisms and the control of many important physico-chemical processes. The oxygen balance in waters is dependent upon physical, chemical and biochemical conditions in the water body. Oxygen input is the result of diffusion from the atmosphere and photosynthesis by algae and other aquatic plants. Dissolved oxygen removal is due to respiration by aquatic organisms, decomposition of organic matter, oxidation of chemically reduced compounds and loss to the atmosphere. The solubility of oxygen in water decreases with increasing temperature but the respiratory rate of aquatic organisms increases with temperature (Connell, 1993).

Dissolved oxygen concentrations are often subject to large diurnal and seasonal fluctuations as a result of changes in temperature and photosynthetic rates. Therefore, a dissolved oxygen measurement taken at one time of the day may not truly represent the oxygen regime in the water body.

Dissolved oxygen saturation levels for eight of the twelve sites sampled in November 2013 were below the recommended ANZECC (2000) guideline, with the lowest reading of 9.6 % recorded from Archers Creek.

The optical clarity of a water body is one of its fundamental physical characteristics. Turbidity is determined by two groups of factors: particulate components which include suspended particles and algae, and dissolved components which affect water colour, particularly humic and fulvic acids. Both these groups of factors can be modified by a range of land use activities (Liston and Maher, 1997).

Turbidity can be caused by soil erosion, waste discharge, urban runoff, algal growth and other disturbances in the water channel. Particles can smother aquatic insects, can clog fish gills, prevent egg and larval development, reduce aquatic flora and fauna growth rates and generally decrease resistance to disease.

No sites on Terrys, Shrimptons, Buffalo, Porters or Archers creeks had elevated turbidity levels for November 2013. These results are consistent with the historical medians for these sites, none of which exceed the recommended guideline of 50 NTU.

pH influences many biological and chemical processes and is an important water quality parameter. It is the measure of the acid balance of a solution and is equated to the hydrogen ion activity. pH can change diurnally through photosynthetic and respiration rates. pH readings for all sites were within the recommended ANZECC (2000) guideline range in November 2013.

The indicator species used for faecal coliforms are naturally occurring and harmless inhabitants of the digestive tract of all warm-blooded animals (Boey 1993). The occurrence of large numbers of these bacteria signifies the presence of faecal pollution and, therefore, the possible presence of those pathogenic organisms that occur in faeces. A variety of factors including urban runoff, presence of waterfowl and other wildlife, waste depots, illegal dumping of waste and sewer overflows can influence faecal contamination of urban streams.

In November 2013, four sites had faecal coliform densities that exceeded the ANZECC (2000) guideline for secondary contact (1,000 CFU/100 mL). Porters Creek at Wicks Road and Archers Creek showed low levels of contamination with results of 7,700 CFU/100 mL and 2,100 CFU/100 mL, respectively.

The faecal coliform results from Buffalo Creek, however, showed high levels of contamination with levels of 1,300,000 CFU/100 mL upstream of Burrows Park and 320,000 CFU/100 mL downstream of Burrows Park. Sampling staff indicated that there were no visual signs of pollution at the time of sampling. The faecal coliform results for Buffalo Creek at Higginbotham Road were low at 270 CFU/100 mL indicating that the pollution had not reached this site at the time of sampling. Follow up sampling was conducted the week after, which included a visual assessment of the site and testing for ammonia. All evidence suggested that there was no longer an impact and that the previous pollution event was caused by the heavy rainfall preceding sampling which likely caused a sewer overflow.

Contamination was also evident in the nutrient results from Buffalo Creek upstream and downstream of Burrows Park with extremely high ammonia, total nitrogen, total kjeldahl nitrogen, oxidised nitrogen and total phosphorus concentrations.

Historical water quality results for Buffalo Creek show that a pollution event of this type has not previously been sampled, with the former maximum faecal coliform result being 10,000 CFU/100 mL (March 2008).

Sampling in November showed resultant total copper concentrations above the ANZECC (2000) guideline criteria at all sites, except three Shrimptons Creek sites (Kent Road, Bridge Street and Quarry Road). The highest concentration was from Porters Creek at Wicks Road (0.018 mg/L)

Copper is widely used in the manufacture of alloys with zinc, nickel and tin, in metal plating and in the production of copper wire and piping. Copper compounds are used in a range of industrial applications: copper nitrate in plating and textile dyeing processes; copper chloride in the manufacture of glass and ceramics and as a catalyst in the production of vinyl chloride. Copper compounds are also used as fungicides, in the manufacture of wood preserving agents, rayon and paint pigments. Increasingly, copper is also being used as a decorative cladding material (Beasley and Kneale 2002).

Zinc concentrations were above the ANZECC (2000) guideline at most sites in November; the exceptions were for Terrys Creek, Buffalo Creek at Higginbotham Road, and Shrimptons Creek at Kent Road and Quarry Street. The highest zinc concentration was from Archers Creek (0.161 mg/L)

The largest uses of zinc are in galvanizing iron and steel products, brass products and zinc-based alloys. It is also used in synthetic rubber, paints, cosmetics, ceramics, manufacturing and dyeing of textiles, wood preserves and the purification of fats (Beasley and Kneale 2002). In natural waters zinc occurs as a simple ion ($Zn^{2+}$), in inorganic complexes, organic complexes, and adsorbed to inorganic or organic colloids or particles. The $Zn^{2+}$ form of zinc is generally considered to be responsible for eliciting toxic responses in aquatic organisms. Inorganic and organic complexes reduce the uptake and toxicity of zinc by reducing the concentration of this form (ANZECC 2000). Zinc is essential for certain biological functions in minute quantities, but it is highly toxic beyond these requirements (Beasley and Kneale 2002).

Concentrations of arsenic, cadmium, lead and mercury were mostly below the analytical method detection limits or in low concentrations which were below the respective ANZECC (2000) guideline values. Total manganese concentrations were below the ANZECC (2000) guideline for all sites in November 2013.

## 9.2 Macroinvertebrates

Aquatic ecosystems comprise the animals, plants and micro-organisms that live in water, and the physical and chemical environment and climatic regime with which they interact. It is predominantly the physical components (such as light, temperature, mixing, flow, and habitat) and chemical components (such as organic and inorganic carbon, oxygen, nutrients) of an ecosystem that determine what lives and breeds in it, and therefore the structure of the food web (ANZECC 2000).

The condition or ‘health’ of aquatic ecosystems is assessed using a wide array of physical and chemical variables. Increasingly the use of biological indicators has been utilised as a measure of aquatic ecosystem health. Macroinvertebrates, in particular, indicators using macroinvertebrate community composition (Walsh 2006), have been widely accepted and utilised globally.

Macroinvertebrates are widely recognised as key indicators because their presence or absence is a result of their exposure to changing water quality over periods of time. They also reflect changes in physical habitats, including sediment deposition and altered hydrology, as well as changes in biological interaction such as the introduction of pest plant and animal species. Macroinvertebrates are also ubiquitous, they are found in almost all water bodies and as such, the type and diversity of macroinvertebrates present can indicate what stressors may be acting upon a given aquatic system.

The taxa richness observed in spring 2013 was relatively similar to what has been previously observed at most of the creeks. The exception was Buffalo Creek which had a lower number of average taxa compared to the historical range. The dominant taxa that comprise a significant proportion of the total community assemblages have historically been within the Mollusca (snails & mussells), Diptera (true flies) and Odonata (dragonflies & damselflies) taxa groups. In spring 2013, the Mollusca and Dipterans have again heavily dominated the community assemblage's at all five creeks. The significant absentee was the Odonata, which had no significant presence at Archers, Porters, Shrimptons and Terrys creeks. The only exception was the family Isostictidae which moderately contributed to the community assemblage at Buffalo Creek.

EPT taxa richness was again very low in spring 2013, a typical result from the previous surveys. Two creeks, Shrimptons and Buffalo, did not register a single EPT specimen. Historically no creek in the survey had an average of one EPT taxa (collected from each replicate). The usefulness of this measure for the survey and City of Ryde has been questioned in previous reports (Sydney Water 2011) and the current results reflect this is likely to continue. The environmental conditions required to support healthy populations of even relatively tolerant EPT taxa is likely not possible within the catchments of the City of Ryde. EPT taxa generally require freely available high oxygen levels, relatively natural flowing clear water bodies and they are also very susceptible to toxicants and other pollutants.

SIGNAL2 was calculated and included in this report, which is an addition to the historical reporting for City of Ryde. The recommended approach for displaying this measure is using the quadrat bi-plot. This resulted in all five creeks being placed in quadrat 4, representative of urban, industrial or agricultural pollution. Placement in this quadrat is due to a combination of samples low SIGNAL2 scores and low taxa counts. However, the placement of the quadrat boundaries is arbitrary and preferably with the aid of reference sites. This is not possible for the City of Ryde, and the boundaries were placed with data from reference sites from the Sydney region located in relatively natural catchments. Returning the creeks and catchments to a natural and reference like condition is highly unlikely in the City of Ryde locale. Whilst this helps to represent the conditions present, the measure in this format is limited in its usefulness for ongoing monitoring and site assessment for City of Ryde.

The SIGNAL-SF results in spring 2013 were reflective of what had been previously recorded for all five creeks. Terry's Creek average score increased slightly on the historical average in spring 2013 and the remaining creeks average scores deviated very little from the historical average. Historically the SIGNAL-SF average scores have had a lower variability through time compared to the other univariate and biological indices, however shifts in creek health have been evident. Shrimptons Creek has historically had the biggest variation through time, and a clear impact was evident at Buffalo Creek in spring 2008 (Sydney Water 2011).

SIGNAL-SF was calculated using extensive reference baseline data from and for specific use in the greater Sydney region, it was last calculated in 2007 (Chessman *et al.* 2007).

This index has shown lower sample variability through time and has allowed for a clear tracking of ongoing changes in the creeks within the context of the naturally occurring variation in the macroinvertebrate communities. This biological index is likely the best option for tracking the health of the five creeks and for monitoring impacts or improvements within the catchments.

The AUSRIVAS OE50 scores are calculated by comparing the observed taxa at a site to the expected taxa. The expected taxa are derived from reference site taxa lists matched to physical/chemical data from the survey creeks. The reference taxa list consists of the animals that are expected to those with a greater than 50% chance of occurring. Buffalo Creek had the most taxa listed as missing, and the OE50 score was calculated using just the one observed taxa (Chironomidae: S.F Chironominae). All other taxa that were observed at the site were ignored by the AUSRIVAS analysis. The other four creeks OE50 scores were generally calculated using just two to four of the total taxa observed.

The AUSRIVAS spring edge OE50 results indicated several significant changes from the historical averages. Shrimptons and Porters creeks spring 2013 average scores were above the historical average scores and Buffalo Creek average score was significantly below the historical average score. The spring 2013 average score placed Buffalo Creek in Band D, representing an extremely impaired creek condition. All other spring 2013 and historical average scores place the other four creeks in the Band C, representing severely impaired creek conditions. The OE50 scores have high sample variation both historically and in spring 2013, this complicates the tracking and assessment of clear changes in stream health.

The AUSRIVAS spring edge OE0 SIGNAL average scores from spring 2013 were above the historical average at Terrys Creek and below the historical average at Shrimptons and Archers creeks. Porters and Buffalo averages scores were very similar to the historical average scores. The OE0 SIGNAL index has lees sample variation both historically and in spring 2013 compared to the OE50 index.

The reference sites used by AUSRIVAS are very limited in the Sydney region. Given this and the creeks being within a heavily urbanised environment, the ability for AUSRIVAS to track creek health through time is potentially limited.

The multivariate analyses indicate that spring 2013 data from all five creeks showed slightly more similarity within creeks than when comparing between creeks. The cluster and SIMPROF analysis indicated no ‘real significance’ in the sample groupings from spring 2013, and the samples were spread out and there were no tight groupings of samples in the ordinations. This suggests that all of the creeks had quite similar macroinvertebrate community assemblages, reflective of what had been previously observed during the past surveys (Sydney Water 2011).

Multivariate analyses were used to assess how spring 2013 data compared to historical baseline data of previous surveys (2004 - 2011). Results indicated that spring 2013 results were placed slightly different to previous surveys for all of the five creeks. However, it is likely that this difference wasn’t significant. The cluster analysis did show a separation of the spring 2013 data as indicated by the SIMRPOF test, this was also evident in the ordinations. However the samples were all separating at very high similarities of 60-70%, which indicates that the historical samples and the spring 2013 samples are all very similar within creeks across seasons. It is important to understand that the clustering and ordinations will always group and ultimately split all of the samples. It is therefore essential to analyse the other multivariate tests in order to contextualise and interpret what is being observed in the data.

The ANOSIM analysis does this by testing the spring 2013 against the historical data set. Results indicate that the creeks spring 2013 data was similar to what had been previously observed for all creeks. R values ranged from 0.139 to 0.350, with 0 being identical and 1 being significantly different. The significance values were in the 'non-significant' bracket being $p$ = >0.05 (except at Buffalo Creek). However not too much weight should be given to this as the R values were low and the permutations possible with the data were more than adequate.

The R value of 0.350 at Buffalo Creek was significant with a $p$ value of 0.006, indicating that while similar to the historical data there was still a change in the community assemblage in spring 2013. When looking at taxa richness and the SIMPER analyses together it is clear that there were low taxa numbers present in the current survey, in fact SIMPER indicated that there were just four taxa comprising 90% of the overall assemblages. It is likely that the drop in taxa and shift in abundances was the driver for spring 2013 samples being moderately dissimilar to the historical data.

The same trend is likely the cause of the slight separation of spring 2013 samples from the historical samples for the four other creeks. Looking at taxa richness, taxa abundance composition and SIMPER analysis it would appear that some 'key' taxa were absent and shifts in taxa abundance occured in samples from the current survey. A clear indicator of this was the taxa group Odonata (dragonflies & damselflies), which had a minimal presence in the samples from spring 2013, however historically this was one of the dominant taxa groups. This would explain the slight difference between the two periods.

The cause of these taxa shifts could be linked to increased rainfall that occurred before and during the sampling period, with November experiencing a very high 190mm of rainfall. The increased flow could have washed taxa from their usual habitats in the survey creeks. Stormwater may have introduced increased pollutants and concentrations to the creeks and modified the benthic conditions of the creek resulting in taxa not being able to survive. Likewise this can then allow for the increased dominance of taxa more tolerant of these conditions. At Buffalo Creek the rainfall would likely have been the cause of the highly elevated faecal and nutrient concentrations that contaminated the creek.

Sampling was carried out as close to baseline flows as possible, the constraints of following the required sampling protocols and project timelines resulted in sampling occurring closer to rainfall events than what would've been preferred. As such the analysis of spring 2013 data and the overall implications of the results need to be done within the context of these limitations. That being said, results of the current analyses indicate taxa and abundance shifts have occurred from comparison to historical data not necessarily a decline in creek health. Buffalo Creek has had a slight decline in taxa richness and creek health, but this was only significant in the AUSRIVAS OE50 analysis, of which, results were likely exaggerated due to the analysis processing. SIGNAL-SF indicated only a slight decline in the average score in spring 2013, and it is suggested that SIGNAL-SF is likely a more robust and suitable indice for tracking the conditions of creek health for the City of Ryde monitoring strategy.

The spring 2013 survey was the first survey for the recommencement of the monitoring program. As such further sampling and data collection is necessary for a thorough analysis of the current conditions of the creeks and catchments. The spring 2013 survey was completed during a 'peak' rainfall period and the addition of the autumn 2014 data will help to assess the implications of this.

# 10 Conclusions and recommendations

The following conclusions and recommendations are based on the spring 2013 results, with consideration given to the historical dataset. The inclusion of autumn 2014 results will enable a more decisive conclusion and complete set of recommendations.

Key findings of the report are presented below:

- Survey results using macroinvertebrates indicate that the surveyed creeks have degraded health and are adversely impacted from anthropogenic influences in their respective catchments.
- Water quality results indicated that the surveyed creeks have significant problems with dissolved oxygen, faecal and nutrient concentrations, and total copper and zinc.
- EPT taxa richness and abundance are very low at all of the surveyed creeks of the monitoring program.
- The spring 2013 results from SIGNAL-SF and AUSRIVAS were reflective of what had been previously observed for the five creeks.
- Multivariate analyses indicated that the spring 2013 data set was slightly different to what had been previously observed. This indicated a slight shift in macroinvertebrate community assemblages, possibly due to the elevated rainfall that occurred during the survey period.

Recommendations for improvements and alternative approaches to future monitoring and reporting are included below:

- Ongoing reference to EPT taxa richness in future monitoring plans will be very limited in applicability. It is highly likely the creeks surveyed will never be returned to conditions that allow for diverse EPT taxa, despite any concerted effort by City of Ryde. Concentration on overall taxa composition and alternative indicator taxa may be a more appropriate approach.
- City of Ryde should consider investigating impervious surface percentages in specific catchments and link this to any development and/or programs that could lead to a reduction or more efficient stormwater system in the Ryde LGA.
- City of Ryde has a baseline data set spanning 9 years that has captured climatic and seasonal changes that any continuing monitoring can be compared to. This will allow a more flexible approach to further monitoring. Concentration on specific catchments/hotspots and furthering spatial sampling along catchment lines are some options.
- City of Ryde could look at more efficiencies and cost-effective monitoring in future programs. A reduction in analyses and sites (based on future project requirements), concentration on key analyses and base reporting options could all be looked at.
- The extensive data set and findings will compliment community education and information projects involving catchment and environment subject matter.

# 11 Glossary

| | |
|---|---|
| Abundance | The total number of individual specimens; in a sample, community, ecosystem etc. |
| Algae | Comparatively simple chlorophyll-bearing plants, most of which are aquatic and microscopic in size. |
| Alkalinity | The ability of a solution to neutralise acid (or buffer). |
| Aquatic ecosystem | Community of aquatic plants and animals together with the physical and chemical environment in which they live. |
| Ammonia | Is a colourless gas; In the aquatic environment it exists in the relatively harmless form ammonium (NH4) and the toxic form ammonia (NH3). |
| Analyte | The physical and chemical parameters (indicators) to be measured. |
| Anthropogenic | Impacts on an environment that are produced or caused by humans |
| ANZECC | ANZECC was a forum for member governments to develop coordinated policies about national and international environment and conservation issues. Operating from 1991 to 2001. |
| AUSRIVAS | AUSRIVAS is a rapid prediction system used to assess the biological health of Australian rivers. |
| Baseline Data | Is prior collected data that allows comparison to subsequently collected data, enabling comparison to 'normal' background levels. |
| Benthic | Refers to the lowest area of a water body; the sediment layer; referring to the organisms that live within this area |
| Catchment | The area that is drained by a river, lake or other water body. |
| Community | Assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another. |
| Concentration | The quantifiable amount of a chemical divided by the total volume of a mixture. |
| Conductivity | The measure of salt content in soil or water; it refers to the ability of the substance to transfer an electrical charge. |
| Correlation | Refers to a quantifiable statistical relationship between two variables. |
| Detection limit | The smallest concentration or amount of a substance that can be defined by an analytical process for reporting with a specific degree of certainty. |
| Detritus | Pieces of dead and decomposing plants and organisms (generally in the form of small pieces) found in a water body. |
| Dissolved Oxygen | The measurement of the concentration of oxygen that is dissolved in a water body. |
| Diversity (Biological) | The measure of the number and/or degree of available organisms in an environment. |
| Edge habitat | The edge habitat is an area of unbroken water surface that is within 2 m of the bank. |
| Effluent | A waste product that is discharged to the environment, usually in reference to waste water discharged from sewage treatment plants. |
| Ethanol | Alcohol used to preserve macroinvertebrates for long-term reference and identification. |
| Eutrophic | Refers to the presence of high levels of nutrients in a water body. |
| Faecal Coliforms | Bacteria which inhabit the intestines of humans and other vertebrates and are present in faeces. Used as a primary indicator of sewage pollution in the environment. |
| Guideline (water quality) | Concentration limit or narrative statement recommended to support and maintain a designated water use. |
| Habitat | The place where a population lives and its surroundings, both living and non-living. |
| Indicator | A parameter (chemical, biological or geological) that can be used to provide a measure of the quality of water or the condition of an ecosystem. |
| Invertebrate | Animal lacking a dorsal column of vertebrae (backbone) or a notochord. |
| Lentic | Refers to standing water, such as lakes, ponds and swamps. |

| | |
|---|---|
| Lotic | Refers to flowing waters, such as creeks, rivers and rivulets. |
| Macroinvertebrate (Aquatic) | Animals without backbones that when mature are greater than 1 millimetre; live in the water column, on the water surface or on the bottom of a waterway. |
| Macrophyte | Plant species that are adapted to growing in or on permanent water and has a definite life form related to the aquatic environment. |
| Morphotype | A classification of a specimen based solely on morphological characteristics. |
| Multivariate Analysis | The statistical analysis of data containing more than one variable. |
| Nitrogen (Aquatic) | Is an element that is essential for plant and animal growth, it occurs in three forms Nitrate, Nitrite and ammonium. |
| Nutrients | Compounds required for growth by plants and other organisms. Major plant nutrients are phosphorus and nitrogen. |
| Organic Pollution (Aquatic) | Organic compounds in the form of contaminants (pollution) in a water body that in time can be oxidised by microorganisms (biodegrade). |
| pH | A measure of the degree of acidity or alkalinity; expressed on a logarithmic scale of 1 to 14 (1 is most acid, 7 neutral and 14 most alkaline). |
| Phosphorus | Is an element that is essential for plant and animal growth, excess concentrations can lead to eutrophication. |
| Photosynthesis | The conversion of carbon dioxide to carbohydrates in the presence of chlorophyll using light energy. |
| Physico-Chemical (Aquatic) | The measure and relationship between the physical and chemical identities of a water body. |
| Point source pollution | A single identifiable source of pollution such as a stormwater outlet or Industrial drain. |
| PRIMER | Analysis program that consists of a wide range of univariate and multivariate routines used to analyse ecological data. |
| Rapid Assessment | Sampling method that involves semi-quantitative techniques for collection of a restricted number of specimens. A time and cost effective method. |
| Receiving water | A stream, river, pond, lake or ocean that receives stormwater or effluent discharges. |
| Reference Site | A sampling site that occurs in a catchment largely void of human related impacts. |
| Sensitive organism | Is an organism that's survival is highly susceptible to shifts in environmental conditions. |
| Sewage | The waste water from homes, offices, shops, factories and other premises discharged to the sewer. Is usually 99% water. |
| SIGNAL | SIGNAL (Stream Invertebrate Grade Number Average Level) is a biotic index using aquatic macroinvertebrates to assess stream health. |
| Stormwater | Rainwater that runs off the land, frequently carrying various forms of pollution such as litter and detritus, animal droppings and dissolved chemicals. This untreated water is carried in stormwater channels and discharged directly into water bodies. |
| Stormwater system | The system of pipes, canals and other channels used to carry stormwater to bodies of water, such as rivers or oceans. The system does not usually involve any significant form of treatment. |
| Taxon | Is the definite entity and classification formally recognized by taxonomists of any given organism. |
| Taxonomic Level | Refers to the classification type of an organism; species, genus, family, order, class, phylum, kingdom. |
| Tolerant organism | An organism that can survive in highly variable environmental conditions. |
| Turbidity | A measure of the amount of suspended solids (usually fine clay or silt particles) in water and thus the degree of scattering or absorption of light in the water. |
| Univariate Analyses | Refers to the statistical analysis of data containing one variable. |

# 12 Acronyms and abbreviations

| | |
|---|---|
| ANZECC | Australian and New Zealand Environment and Conservation Council |
| AUSRIVAS | Australian River Assessment System |
| cfu | colony forming unit |
| DO | dissolved oxygen |
| EPT | Ephemeroptera, Plecoptera, Trichoptera |
| mg/L | milligrams per litre |
| MDS | Multi-dimensional scaling |
| NATA | National Association of Testing Authorities of Australia |
| NTU | Nephelometric Turbidity Units |
| PRIMER | Plymouth Routines In Multivariate Ecological Research |
| RBA | Rapid biological assessment |
| SIGNAL-SF | Stream Invertebrate Grade Number Average Level – Sydney Family |
| SIGNAL-SG | Stream Invertebrate Grade Number Average Level – Sydney Genus |
| SIGNAL2 | Stream Invertebrate Grade Number Average Level – National scores (2003) |
| SIMPER | Similarity percentages routine |
| SIMPROF | Similarity profile routine |
| STP | Sewage treatment plant |
| µg/L | micrograms per litre |
| µS/cm | micro-siemens per centimetre (unit of conductivity) |

# 13 References

*ANZECC (2000). Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters. Australian and New Zealand Environment and Conservation Council.*

*Boey, A., Chessman, B., McEvoy, P. & Rae, D. (1993). Stream water quality and Biota in the Picton Region 1992. AWT Science & Environment Report 93/2.*

*Chessman, B.C. (1995). Rapid assessment of rivers using macroinvertebrates: a procedure based on habitat-specific sampling, family-level identification and a biotic index. Australian Journal of Ecology, 20, 122-129.*

*Chessman, B.C. (2003a). New sensitivity grades for Australian river macroinvertebrates. Marine and Freshwater Research, 2003, 54, 95-103.*

*Chessman, B.C. (2003b). SIGNAL2.iv – A Scoring System for Macroinvertebrates ('Water Bugs') in Australian Rivers. User Manual. National Heritage Trust. Report No.31.*

*Chessman, B.C, Kotlash, A. and Growns, J. (1997) Objective derivation of macroinvertebrate family sensitivity grade numbers for the SIGNAL-HU97B biotic index: application to the Hunter River system, New South Wales. Marine and Freshwater Research, 48, 159-172.*

*Chessman, B.C., Trayler, K.M., and Davis, J.A. (2002) Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research, 53, 919-930.*

*Chessman B.C., Williams S.A. & Besley C.H. (2007) Bioassessment of streams with macroinvertebrates: effect of sampled habitat and taxonomic resolution. Journal of the North American Benthological Society. 26 (3), (546-563).*

*City of Ryde, (2014) Online: http://www.ryde.nsw.gov.au/About+Ryde/Profile/City+Profile. Last updated 30th October 2012.*

*Connell, D.W. (1993). Water Pollution. Causes and effects in Australia and New Zealand. University of Queensland Press.*

*Coysh, J., Nichols, S., Ransom, G., Simpson, J., Norris, R. Barmuta, L., & Chessman, B. (2000) AUSRIVAS Predictive Modelling Manual. Available online at: http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/Man/Pred/.*

*Growns, J.E, Chessman, B.C., McEvoy, P.K. & Wright, I.A. (1995) Rapid assessment of rivers using macroinvertebrates: Case studies in the Nepean River and Blue Mountains, NSW. Australian Journal of Ecology, 20, 130-141.*

*Growns, J.E., Chessman, B.C., Jackson, J.E., & Ross, D.G. (1997) Rapid assessment of Australian rivers using macroinvertebrates: cost efficiency of 6 methods of sample processing. Journal of North American Benthological Society, 16, 682-693.*

*Lenat, D.R. (1998). Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of North American Benthological Society, 7, 222-223.*

*Liston, P. and Maher, W (1997). Water quality for maintenance of aquatic ecosystems: Appropriate indicators and analysis, Australia: State of the Environment Technical Paper Series (Inland Waters). Department of the Environment, Sport and Territories, Canberra*

*Metzeling, L., Chessman, B. Hardwick, R. & Wong, V. (2003) Rapid assessment of rivers using macroinvertebrates: the role of experience, and comparisons with quantitative methods. Hydrobiologia, 510, 39-52.*

*Ransom, G., Coysh, J. & Nichols, S. (2004) 'AUSRIVAS Macroinvertebrate Bioassessment Predicitve Modelling Software V3.1.1 User Manual'. Available online at http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/Man/User/.*

*Sydney Water Corporation. (2011) Biological & Water Quality Monitoring Autumn 2011 for City of Ryde. Available on-line at http://www.ryde.nsw.gov.au/Environment/Water+Quality+and+Pollution/Water+Quality+Monitoring+Strategy*

*Turak, E., Waddell, N. & Johnstone, G. (2004) New South Wales (NSW) Australian Assessment System (AUSRIVAS) Sample Processing Manual. Online available at http://ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/.*

*WMO (1996) Guide to Meteorological Instruments and Methods of Observations. World Meteorological Organization No 8, sixth edition, 1996.*

*Wright, J.R. (1995). Development of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology, 20, 181-197.*

# Appendix 1: Quality assurance

AS/NZS IS Sydney Water is a quality business organisation certified to AS/NZS ISO 9001 and ISO 14001. All investigations performed for the production of this report, as with all business operations of the organisation, were conducted to the requirements of this standard including project management, macroinvertebrate sampling, water quality sampling and interpretive reporting.

The Sydney Water laboratories, located in West Ryde, are National Association of Testing Authorities (NATA) accredited to ISO 17025 for a broad range of analytical testing that includes water, sediments, microbiologic, biologic and pathogenic. The laboratories have been accredited for chemical testing since 1952, for biological testing since 1966 and for the identification of aquatic macroinvertebrates to species, genus and family levels since 1997.

Sydney Water maintains a permanent aquatic macroinvertebrate laboratory with high-resolution microscopes, a systematically organised, fully catalogued macroinvertebrate voucher reference collection of over 1300 species and associated detailed keys and descriptions.

The collection is one of the largest freshwater macroinvertebrate reference collections in Australia and the largest species-level macroinvertebrate collection in New South Wales. Specimens are collected from the Sydney basin and the Hawkesbury-Nepean catchment and are regularly sent to Australian taxonomic specialists for verification. Specimens are loaned to biological, particularly taxonomic, researchers throughout Australia and the laboratory is visited and inspected by recognised taxonomists. Through the reference collection, Sydney Water actively contributes to the international aquatic macroinvertebrate taxonomic knowledge base while maintaining a repository of natural history information.

The laboratory also has a tailored Leica Montage Digital Database for storage of digital images of the freshwater macroinvertebrate voucher collection. The Montage software and camera provide an additional tool in the identification of macroinvertebrates and are used in conjunction with other identification methods set out in this document. The benefit of electronic imaging lies in the time efficiencies it brings to the identification process. The Montage tool creates tailored photographic archives of freshwater macroinvertebrates. It enables comparison of sample specimens with stored images and provides measurement and labelling functions. Electronic images are sent to international and national experts for confirmation of identification, which avoids potential loss or damage to a physical specimen.

Macroinvertebrates were identified and enumerated for this study to the family or morphospecies taxonomic level. The method used, SSWI433 *In-house test method Macroinvertebrate Cataloguing, Identification and Counting* is in compliance with the requirements of AS ISO/IEC 17025 *General Requirements for the Competence of Testing and Calibration Laboratories*, under technical accreditation number 610 issued by NATA. Macroinvertebrate identification was performed using appropriate and current published keys and identification tools, Sydney Water internal keys specific to the laboratory's collection, unpublished descriptions and voucher specimens.

Quality assurance was conducted as per SSWI434 *In-house test method Quality Control of Macroinvertebrate Identification, Counting and Archiving of Collections*, in compliance with the requirements of AS ISO/IEC 17025 *General Requirements for the Competence of Testing and Calibration Laboratories* under technical accreditation number 610. Quality assurance was conducted on at least 5% of samples collected for this study.

# Appendix 2: Water chemistry parameters and their method of collection

| Analyte | Units | Field Instrument / Bottle |
|---|---|---|
| Sample clarity | NA | NA |
| Algae present | | |
| Recent rain | | |
| Visual pollution | | |
| Flow Rate (visual assessment) | | |
| Dissolved Oxygen | mg/L | WTW Multiliner Universal Meter |
| Dissolved Oxygen Percent | % saturation | |
| Conductivity Low Range | µS/cm | |
| pH | pH units | |
| Water Temperature | Degrees C | Digital Thermometer |
| Turbidity (white light) | NTU | HACH Turbidimeter |
| Oxidised Nitorgen Nox-N Low Level | mg/L | 1 x 200mL PET |
| Nitrite Nitrogen NO2-N | mg/L | |
| Nitrate Nitrogen NO3-N | mg/L | |
| Soluble Reactive Phosphorus | mg/L | |
| Total Nitrogen | mg/L | |
| Total Phosphorus | mg/L | |
| Alkalinity | mg $CaCO_3$/L | 1 x 500mL PET |
| Total Hardness | mg $CaCO_3$/L | |
| Metals | mg/L | 1 x 200mL PET |
| Faecal Coliform | CFU/100 mL | 1 x 500mL PET sterile (red cap) |

# Appendix 3: Macroinvertebrate analyses

## Univariate analyses (diversity indices)

Univariate analyses test hypotheses with only one variable. Univariate analyses were performed on macroinvertebrate data using the following diversity indices:

### Taxa richness

Taxa richness is the overall variety (total taxa) of macroinvertebrates in a given community assemblage. It is an indicator of stream health that can be measured at any specific taxonomic level and operates under the assumption that taxa richness will be higher in healthy streams and lower in streams of poor health.

The composition of macroinvertebrate abundances within taxa groups was included in this report. Taxa were for the most part placed into Class and Order groups. The composition of macroinvertebrate abundance at the basic level is limited in its ability to indicate water body health. However it can give an indication of the habitat and biological holding capacity of the water-bodies being studied.

Taxa richness can be a useful tool for indicating the general health of a water body. However, it should be used with caution, as taxa numbers may be attributable to factors other than stream health and/or anthropogenic impacts. For example, taxa richness may increase with elevated levels of organic pollution and may not be a good indication that stream health is better than areas with lower levels of organic pollution.

### EPT taxa richness

EPT taxa richness is a diversity index that measures the total number of families of Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trichoptera (Caddisflies) in a given community assemblage. These taxonomic Orders of macroinvertebrates are highly sensitivity to changes in water quality condition (Lenat 1998). The number of EPT taxa found at a site can generally be used as an indicator of stream biological health. An absence of these taxa may be attributable to anthropogenic disturbances within a catchment.

Many EPT taxa are sensitive to natural factors and changes in streams, such as altitude and environmental flows. While EPT taxa tend to favour higher altitude streams, Sydney Water has observed a diverse range of these taxa at altitudes as low as ten metres at reference sites in the greater Sydney region and on the Clyde River.

Some caution must be applied when interpreting patterns based on EPT taxa. Some EPT taxa are relatively tolerant and are commonly found in streams with moderate to mild levels of pollution. A decline or absence of EPT taxa may be attributable to natural changes in a catchment, such as a decline in flow.

## Biological indices (models)

Various models have been developed to help add meaning to macroinvertebrate data. They have been developed to help represent realistic processes in ecosystems and predict system response using minimal data collected. Results are presented with a measure of variation (plus and minus one standard deviation of the average score), as recommended by Australian and New Zealand Water Quality Guidelines for Fresh and Marine Waters (2000). This allows stream health comparison between sampling occasions for each creek

and between creeks through time. Two useful macroinvertebrate models used in this report include:

## SIGNAL

The SIGNAL (Stream Invertebrate Grade Number Average Level) biotic index is a relatively simple and inexpensive method to assess stream health. This index assigns 'sensitivity scores' to macroinvertebrate taxa that are collected using the rapid assessment sampling method. The original version was developed for Sydney Water, assessing the Hawkesbury-Nepean catchment and required identifications to the Family taxonomic level (Chessman, 1995).

The original SIGNAL index was refined to include the response of SIGNAL to natural and anthropogenic environmental factors (Growns *et al*. 1995), variations in sampling and sample processing methods (Growns *et al*. 1997;) and the objective setting of sensitivity grades of the taxa (Chessman et al. 1997; Chessman *et al*. 2002).

### *SIGNAL2*

Chessman (2003a) revised SIGNAL for national application and produced a complete set of revised scores using reference data from around Australia. Known as SIGNAL2 (Chessman 2003b), this index is applicable to the greater community and scientists alike and can be applied to the Order-Class-Phylum taxonomic level as well as Family. Refer to Chessman (2003b) for the variants for the calculation of SIGNAL2 scores.

A bi-plot of the sensitivity scores can be used to help interpret results (Figure 30). This requires the placement of arbitrary boundaries to indicate the condition of and likely impacts experienced by a water body. However, this largely relies on the inclusion in a study of reference sites to guide the placement of boundaries. The bi-plot should be used purely as an indicator of likely impacts and caution should be taken when interpreting results, particularly when reference sites are unavailable for a study. The arbitrary boundaries for this report have been based on a SIGNAL2 score of 5 and total taxa count of 20. These figures are based on comparable data from sites within the Sydney region that could be considered to be of a 'healthier' condition.

SIGNAL2 can be calculated with or without abundance weighting (Chessman 2003b). Calculations for this report were completed using data treated with abundance weighted scores.

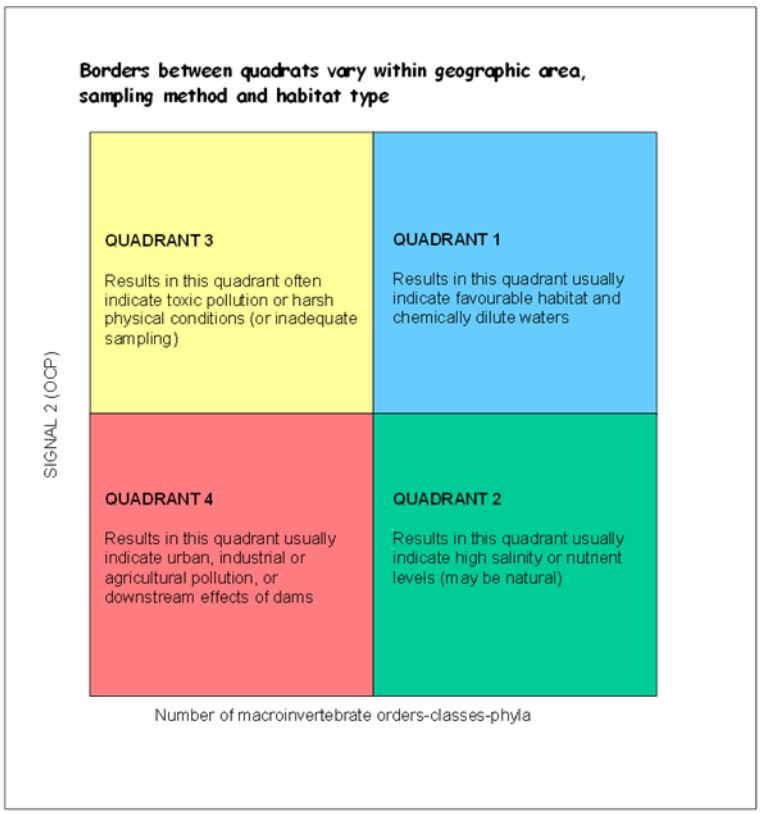



**Figure 30 Quadrant diagram for family version of SIGNAL2 (Chessman 2003b)**

## *SIGNAL-SF*

Chessman *et al*. (2007) saw the development of a Sydney-specific SIGNAL biotic index that drew on family and genus level macroinvertebrate data from the greater Sydney region. The water quality status of 'clean water' was established using data from near pristine reference sites in the bushland fringes of Sydney and determining the 10th percentile of the average score of those sites (Table 27).

SIGNAL-SF allows a direct measure of test site condition and incorporates abundance information gathered from the rapid assessment sampling. 'S' indicates the Sydney region version and 'F' indicates that the taxonomy is at the family level.

The first step in calculating a SIGNAL-SF score is to apply predetermined sensitivity grade numbers (from 1, tolerant to 10, highly sensitive) to each family count for a given habitat sample. Families without a grade score that are present in a sample are removed from the SIGNAL-SF calculation. This occurs for very few animals that, generally, are not 'true' aquatic invertebrates.

The square root transformed count (treated to remove bias of taxa with high abundance counts) of each family is then multiplied by the sensitivity grade. The products are summed and then divided by the total square root transformed number of individuals in all families. A location-specific average is then calculated for each sampling site.

**Table 27 Interpretation of SIGNAL-SF scores (Chessman *et al*., 2007)**

| SIGNAL-SF score | Water quality status |
|---|---|
| > 6.5 | Clean water |
| 5.2-6.5 | Possible mild organic pollution |
| 3.8-5.2 | Probable moderate organic pollution |
| < 3.8 | Probable severe organic pollution |

## AUSRIVAS

AUSRIVAS (AUStralian RIVers Assessment System) is an interactive software package that uses data based on predictive models of macroinvertebrate distribution to assess river health. It grew out of the British program RIVPACS (River Invertebrate Prediction and Classification System; Wright 1995), which was modified to suit Australian environmental conditions (Turak *et al*. 2004).

AUSRIVAS models were developed using biological, physical and chemical data collected from reference sites in all states and territories of Australia. Models and methodologies were calibrated to the specific area from which the data underlying them were collected.

The sampled macroinvertebrate families are imported into the chosen model as presence/absence (1 or 0) or binary data. The physical and chemical data (predictor variables) from the project site is then used to determine a predicted macroinvertebrate community assemblage (Expected). The macroinvertebrates collected at a project site (Observed) are then compared to the predicted assemblage (Expected), given that the expected assemblage would occur at an undisturbed/reference site (Turak *et al*. 2004).

Data from pool edge and riffle habitats sampled in single spring and autumn seasons, or in combined seasons forms the basis of NSW AUSRIVAS models. Ransom *et al*. (2004) describes the combined season model as preferable, as it maximizes the family list for a project site being examined. Each model output includes a variety of analyses or 'scores'. Those used in this report are described below.

### *Predicted/Collected data*

The AUSRIVAS output includes a datasheet that presents the predicted, expected and observed number of taxa at a test site. These indices are used to produce a score called the 'OE50 ratio', which provides a measure of biological impairment at a test site (Ransom *et al*., 2004). OE50 compares the number of observed invertebrate families at a site and those expected to occur with a greater than 50% probability of finding them at any one sampling occasion (Coysh *et al*. 2000).

The OE50 ratio of each test sample also corresponds to a band representing different levels of biological condition. This helps to categorise each test site, allowing a comparison with reference sites from rivers of the same type. This comparison assists in interpretation of the data with a view to aid in environmental management decision making (Coysh *et al*. 2000). Interpretation of the five possible bands of river condition is detailed in Table 28 (Coysh *et al.* 2000). Thresholds that correspond to these bands of each respective model are detailed in Table 29.

The predicted/collected data includes results that incorporate SIGNAL tolerance grades (Chessman, 1995). SIGNAL scores are used to produce an OE0-SIGNAL value, which is the ratio of observed taxa with those expected to occur with a greater than 0% probability.

No bands have been developed for SIGNAL (Coysh *et al*. 2000). However, values of around 1 would be similar to reference condition (Chessman pers comm.).

**Table 28 Interpretation of bands associated with AUSRIVAS OE50 model output (Coysh *et al*., 2000)**

| Band | Description | O/E taxa | O/E taxa interpretations |
|---|---|---|---|
| X | More biologically diverse than reference | ▪ O/E greater than 90th percentile of reference sites used to create the model | ▪ More families found than expected<br>▪ Potential biodiversity 'hot spot' or mild organic enrichment<br>▪ Continuous irrigation flow in a normally intermittent stream |
| A | Similar to reference | ▪ O/E within range of central 80% of reference sites used to create the model | ▪ Expected number of families within the range found at 80% of the reference sites |
| B | Significantly impaired | ▪ O/E below 10th percentile of reference sites used to create the model<br>▪ Same width as band A | ▪ Fewer families than expected<br>▪ Potential impact either on water and/or habitat quality resulting in a loss of families |
| C | Severely impaired | ▪ O/E below band B<br>▪ Same width as band A | ▪ Many fewer families than expected<br>▪ Loss of families from substantial impairment of expected biota caused by water and/or habitat quality |
| D | Extremely impaired | ▪ O/E below band C down to zero | ▪ Few of the expected families and only the hardy, pollution tolerant families remain<br>▪ Severe impairment |

**Table 29 Upper thresholds for bands of impairment (OE50 taxa) for AUSRIVAS models developed for NSW (Turak and Waddell, 2001)**

| Model | Threshold | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Combined edge (East) | 1.17 | 0.82 | 0.48 | 0.14 |
| Autumn edge | 1.17 | 0.81 | 0.46 | 0.11 |
| Spring edge | 1.16 | 0.83 | 0.51 | 0.19 |

## Multivariate analyses

Multivariate statistical analyses were performed using the PRIMERv6 software package (Clarke and Warwick, 2006) and involve the analysis of more than one variable. Multivariate analysis using macroinvertebrates, water quality, rainfall and other physical attributes of the site allow comparisons to be made of macroinvertebrate community composition within sites, between sites and of patterns that emerge through time.

## Clustering and SIMPROF test

Cluster analysis uses a matrix of correlations to look for patterns of structure within samples. Samples that are highly correlated and thus more similar will be grouped together closer than samples that are least similar. The output is a tree diagram (dendrogram) displaying the groupings of samples into successively smaller numbers of clusters.

A SIMPROF permutation test on a cluster analysis helps to see which (if any) clusters are significantly different. Samples connected by red lines cannot be significantly differentiated. SIMPROF test groups can be checked against the complementary ordination results.

## Ordination

Ordination produces a plot of samples on two (2D) or three (3D) axes such that samples with similar taxa lie closer together than samples with differing taxon composition. When ordination and SIMPROF test results produce similar patterns the analysis can be considered reliable, but should also be verified by a test of variance, such as ANOSIM

Macroinvertebrate samples were ordinated on the Bray-Curtis similarity matrix between samples using the non-metric Multi-Dimensional Scaling (MDS) technique. The success of the ordination is measured by a stress value, which indicates the degree of distortion imposed. In PRIMER v6 a stress value of below 0.2 indicates an acceptable representation of the original data, although lower values are desirable.

Environmental samples were ordinated on the normalised Euclidean distances between samples using the Principal Components Analysis (PCA) technique.

## SIMPER

The SIMPER routine was employed to investigate community structure between and within groups of sites as detailed above. This routine employs Bray Curtis similarities to examine the contribution of individual taxa to the average similarity between groups and also within groups. This is an exploratory rather than a statistical analysis. Results from the SIMPER procedure can be superimposed on an MDS (or PCA) plot, as circles whose varying diameters reflect the abundance changes for that species across samples (bubble plots).

## ANOSIM

ANOSIM is used to test the hypothesis that there is no difference in community structure between site groups. This is tested by comparing the similarity between sample groups within sites to the similarity of sample groups between sites (Clarke and Warwick, 2006). ANOSIM is employed to investigate the potential spatial or temporal differences that exist both within and between site sample groups.

ANOSIM works by using a randomisation process, whereby an R-value is originally calculated from the data set and then each randomisation compares a newly calculated R-value with the original. This randomisation compares all sample groups resulting in an R-value for all site groups, known as a global R-value, and an R-value for all site group comparisons. An R-value is a number between -1 and 1, and the higher the number (further from 0) the bigger the difference or lack of similarity between groups.

# Appendix 4: Water quality results

| Site Code | Site Location | Survey Season | Total Phosphorus TP µg/L | Total Nitrogen TN µg/L | Total Kjeldahl Nitrogen TKN µg/L | Oxidised Nitrogen NOx µg/L | Ammonia µg/L | Conductivity µS/cm | Dissolved Oxygen mg/L | Dissolved Oxygen %Sat | Temperature $^{o}C$ | pH | Faecal Coliform CFU/100mL | Alkalinity mg CaCO3/L | Turbidity NTU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | Terrys Creek @ Somerset Park | Spring 2013 | 49 | 1020 | 640 | 380 | 10 | 522 | 6.2 | 64.1 | 17.1 | 7.22 | 150 | 76.7 | 3.82 |
| S2 | Shrimpton's Creek @ Wilga Park | Spring 2013 | 58 | 1250 | 810 | 440 | 40 | 428 | 4.8 | 52.8 | 19.1 | 7.25 | 260 | 57.2 | 4.65 |
| CR1SA | Shrimpton's Creek @ Kent Rd | Spring 2013 | 45 | 790 | 720 | 70 | 10 | 408 | 4.2 | 44.5 | 18.7 | 7.08 | 590 | 52.3 | 4.6 |
| CR1SB | Shrimpton's Creek @ Bridge St | Spring 2013 | 41 | 680 | 670 | 10 | 10 | 522 | 2.2 | 24.3 | 19.2 | 7.09 | 220 | 69.8 | 5.58 |
| CR1SC | Shrimpton's Creek @ Quarry Rd | Spring 2013 | 25 | 1320 | 660 | 660 | 80 | 546 | 8.8 | 95.1 | 19.2 | 7.23 | 250 | 52.1 | 1.69 |
| S3 | Porters Creek @ Ryde Depot | Spring 2013 | 98 | 2730 | 1370 | 1360 | 320 | 512 | 7.8 | 78.9 | 19 | 7.53 | 210 | 118 | 4.96 |
| CR5PA | Porters Creek @ Main Branch | Spring 2013 | 63 | 900 | 670 | 230 | 30 | 140 | 8.3 | 94.8 | 21.9 | 7.45 | 420 | 33.2 | 14.8 |
| CR5PB | Porters Creek @ Spur Branch | Spring 2013 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| CR5PC | Porters Creek @ Wicks Rd | Spring 2013 | 276 | 3360 | 1450 | 1910 | 210 | 438 | 7.4 | 84 | 18.4 | 7.3 | 7700 | 77.9 | 16 |
| S4 | Buffalo Creek @ Higginbotham Rd | Spring 2013 | 58 | 1080 | 690 | 390 | 10 | 472 | 7.3 | 80.3 | 19.6 | 7.43 | 270 | 58.1 | 3.33 |
| CR4BA | Buffalo Creek d/s Burrows Park | Spring 2013 | 214 | 3430 | 2580 | 850 | 1070 | 620 | 5.2 | 56.4 | 18.7 | 7.48 | 320000 | 82.8 | 6.59 |
| CR4BB | Buffalo Creek u/s Burrows Park | Spring 2013 | 820 | 12200 | 10900 | 1250 | 6600 | 547 | 5.2 | 56.3 | 18.6 | 7.55 | 1300000 | 107 | 9.05 |
| S5 | Archers Creek @ Maze Park | Spring 2013 | 80 | 900 | 900 | 5 | 10 | 499 | 0.8 | 9.6 | 21.5 | 7.15 | 2100 | 67.1 | 3.16 |

| Site Code | Site Location | Survey Season | Total Chromium mg/L | Total Manganese mg/L | Total Iron mg/L | Total Copper mg/L | Total Zinc mg/L | Total Arsenic mg/L | Total Cadmium mg/L | Total Lead mg/L | Total Mercury mg/L | Total Calcium mg/L | Total Magnesium mg/L | Total Hardness mg CaCO3/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | Terrys Creek @ Somerset Park | Spring 2013 | 0.0005 | 0.033 | 0.653 | 0.005 | 0.016 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 30.3 | 7.7 | 107 |
| S2 | Shrimpton's Creek @ Wilga Park | Spring 2013 | 0.0005 | 0.043 | 0.836 | 0.006 | 0.033 | 0.001 | 0.0005 | 0.002 | 0.00015 | 21.1 | 4.66 | 71.9 |
| CR1SA | Shrimpton's Creek @ Kent Rd | Spring 2013 | 0.0005 | 0.063 | 1.3 | 0.002 | 0.015 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 20.9 | 6.04 | 77.1 |
| CR1SB | Shrimpton's Creek @ Bridge St | Spring 2013 | 0.0005 | 0.132 | 2.56 | 0.002 | 0.022 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 27 | 7.69 | 99.2 |
| CR1SC | Shrimpton's Creek @ Quarry Rd | Spring 2013 | 0.0005 | 0.045 | 0.381 | 0.002 | 0.014 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 21.5 | 8.34 | 88.1 |
| S3 | Porters Creek @ Ryde Depot | Spring 2013 | 0.0005 | 0.055 | 1.1 | 0.004 | 0.023 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 36 | 8.76 | 126 |
| CR5PA | Porters Creek @ Main Branch | Spring 2013 | 0.001 | 0.011 | 0.491 | 0.005 | 0.027 | 0.0005 | 0.0005 | 0.002 | 0.00015 | 10.8 | 2.21 | 36.1 |
| CR5PB | Porters Creek @ Spur Branch | Spring 2013 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| CR5PC | Porters Creek @ Wicks Rd | Spring 2013 | 0.001 | 0.026 | 2.29 | 0.018 | 0.099 | 0.0005 | 0.0005 | 0.002 | 0.00015 | 28.7 | 7.19 | 101 |
| S4 | Buffalo Creek @ Higginbotham Rd | Spring 2013 | 0.0005 | 0.04 | 1.17 | 0.004 | 0.016 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 22.9 | 7.62 | 88.6 |
| CR4BA | Buffalo Creek d/s Burrows Park | Spring 2013 | 0.0005 | 0.094 | 1.29 | 0.006 | 0.027 | 0.0005 | 0.0005 | 0.001 | 0.00015 | 25.6 | 9.56 | 103 |
| CR4BB | Buffalo Creek u/s Burrows Park | Spring 2013 | 0.0005 | 0.042 | 0.513 | 0.014 | 0.034 | 0.001 | 0.0005 | 0.0005 | 0.00015 | 23.1 | 7.36 | 88.1 |
| S5 | Archers Creek @ Maze Park | Spring 2013 | 0.0005 | 0.903 | 0.828 | 0.005 | 0.161 | 0.0005 | 0.0005 | 0.0005 | 0.00015 | 24.4 | 8.7 | 96.8 |

# Appendix 5: Macroinvertebrate raw data

| Site Location | | Archers Ck | Archers Ck | Archers Ck | Buffalo Ck | Buffalo Ck | Buffalo Ck | Porters Ck | Porters Ck | Porters Ck | Shrimptons Ck | Shrimptons Ck | Shrimptons Ck | Terrys Ck | Terrys Ck | Terrys Ck |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey Season | | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 |
| Site Code | | S5 | S5 | S5 | S4 | S4 | S4 | S3 | S3 | S3 | S2 | S2 | S2 | S1 | S1 | S1 |
| Acarina | Acarina | | 2 | | | | | | 1 | | | | | | | |
| Bivalvia | Sphaeriidae | 4 | 3 | | | | | | | | | 1 | | | | 1 |
| Coleoptera | Dytiscidae | | | | | | | 1 | | | | | | | | |
| Coleoptera | Elmidae | | 1 | | | | | | | | | | | | | 1 |
| Coleoptera | Hydraenidae | | 2 | | | | | | | | | | | | | |
| Coleoptera | Hydrophilidae | | | 2 | | | | 1 | | | | | | | | |
| Coleoptera | Psephenidae | 5 | 9 | 12 | | 2 | 1 | | | | 2 | | 1 | 1 | 5 | 6 |
| Coleoptera | Scirtidae | | | | | | | 1 | | | | | | | | |
| Decapoda | Parastacidae | | | | | | | | | | | 1 | | | | |
| Diptera | Culicidae | 4 | 11 | 4 | | | | | | | | | | | | |
| Diptera | Dolichopodidae | | | | | | | | | | | | | | | 2 |
| Diptera | s-f Chironominae | 7 | 12 | 26 | 13 | 15 | 13 | 22 | 10 | 15 | 16 | 10 | 10 | 6 | 8 | 5 |
| Diptera | s-f Orthocladiinae | | | | | | | | 1 | 2 | | 1 | 1 | | | |
| Diptera | s-f Tanypodinae | | 6 | | | | | 1 | 1 | | | | | 1 | 3 | 3 |
| Diptera | Simuliidae | | | | | | | | | | | | | | 2 | |
| Diptera | Stratiomyidae | 1 | 4 | 2 | | | 1 | 1 | 1 | 2 | 2 | 1 | 1 | | | 1 |
| Gastropoda | Tateidae | 10 | 12 | 11 | 13 | 11 | 9 | 13 | 2 | 16 | 1 | 9 | 7 | 10 | 13 | 2 |
| Gastropoda | Lymnaeidae | | 1 | | | | 1 | 1 | | | | | | | | |
| Gastropoda | Physidae | 4 | 12 | 9 | | 1 | 4 | 1 | 2 | 1 | 10 | 10 | 9 | 5 | 2 | 12 |
| Gastropoda | Planorbidae | | | | 1 | 2 | 2 | | | 1 | | | | | | 1 |
| Hemiptera | Corixidae | | 1 | | | | | 4 | 3 | 1 | 2 | 3 | | | | |
| Hemiptera | Gerridae | | | | | | | | | | | | 1 | | | |
| Hemiptera | Notonectidae | 8 | 6 | 1 | 2 | | | | | 1 | 1 | 1 | 1 | 2 | 3 | 4 |
| Hemiptera | Pleidae | | | | | | | 1 | | 1 | | | | | | |
| Hemiptera | Veliidae | | | 9 | | | | | | | | | | | | 1 |
| Isopoda | Scyphacidae | | | | | | | | | | | 1 | | | | |
| Odonata | Aeshnidae | | | | | | | | | | | | | 1 | | |
| Odonata | Coenagrionidae | | 1 | | | | | | | | | 3 | | | | 1 |
| Odonata | Hemicorduliidae | | 5 | | | | | | | | | | | | | 1 |
| Odonata | Isostictidae | | | | 2 | 1 | 4 | | | | | | | 1 | 1 | 1 |
| Odonata | Libellulidae | | 2 | | | | | | | | | | | | | |
| Odonata | Megapodagrionidae | | | 2 | | 2 | | | | | | | | 1 | | 9 |

| Site Location | | Archers Ck | Archers Ck | Archers Ck | Buffalo Ck | Buffalo Ck | Buffalo Ck | Porters Ck | Porters Ck | Porters Ck | Shrimptons Ck | Shrimptons Ck | Shrimptons Ck | Terrys Ck | Terrys Ck | Terrys Ck |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey Season | | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 | Spring 2013 |
| Site Code | | S5 | S5 | S5 | S4 | S4 | S4 | S3 | S3 | S3 | S2 | S2 | S2 | S1 | S1 | S1 |
| Odonata | Synlestidae | | | | | | | | | | | | | | | 1 |
| Oligochaeta | Oligochaeta | 2 | 10 | 5 | 1 | 3 | | 6 | 6 | 1 | 7 | 7 | | 3 | 5 | 3 |
| Rhynchobdellida | Glossiphoniidae | | 5 | | | | | | | | 1 | 1 | | | | |
| Trichoptera | Antipodoecidae | | | | | | | 1 | | | | | | | | |
| Trichoptera | Hydroptilidae | | | 2 | | | | | | | | | | 1 | | |
| Turbellaria | Dugesiidae | 1 | 3 | 4 | | | 2 | | | | 2 | 9 | 2 | 1 | | |

# Appendix 6: Multivariate raw data

## SIMPER raw results spring 2013

SIMPER
Similarity Percentages - species contributions

One-Way Analysis
*Data worksheet*
Name: Data1
Data type: Abundance
Sample selection: All
Variable selection: All

*Parameters*
Resemblance: S17 Bray Curtis similarity
Cut off for low contributions: 90.00%

*Factor Groups*

| Sample | Creek |
|---|---|
| ArchersSp13a | Archers Ck |
| ArchersSp13b | Archers Ck |
| ArchersSp13c | Archers Ck |
| BuffaloSp13a | Buffalo Ck |
| BuffaloSp13b | Buffalo Ck |
| BuffaloSp13c | Buffalo Ck |
| PortersSp13a | Porters Ck |
| PortersSp13b | Porters Ck |
| PortersSp13c | Porters Ck |
| ShrimptonsSp13a | Shrimptons Ck |
| ShrimptonsSp13b | Shrimptons Ck |
| ShrimptonsSp13c | Shrimptons Ck |
| TerrysSp13a | Terrys Ck |
| TerrysSp13b | Terrys Ck |
| TerrysSp13c | Terrys Ck |

*Group Archers Ck*
Average similarity: 61.33

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| Tateidae | 3.31 | 10.46 | 6.01 | 17.06 | 17.06 |
| s-f Chironominae | 3.74 | 9.38 | 9.40 | 15.29 | 32.35 |
| Psephenidae | 2.90 | 7.99 | 9.37 | 13.03 | 45.37 |
| Physidae | 2.82 | 7.43 | 7.66 | 12.12 | 57.49 |
| Culicidae | 2.44 | 6.53 | 5.37 | 10.64 | 68.14 |
| Oligochaeta | 2.27 | 5.36 | 6.60 | 8.74 | 76.87 |
| Notonectidae | 2.09 | 4.79 | 1.82 | 7.81 | 84.69 |
| Dugesiidae | 1.58 | 3.93 | 5.11 | 6.40 | 91.09 |

*Group Buffalo Ck*
Average similarity: 68.68

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| s-f Chironominae | 3.69 | 24.88 | 13.22 | 36.23 | 36.23 |
| Tateidae | 3.31 | 21.48 | 7.90 | 31.28 | 67.51 |
| Isostictidae | 1.47 | 7.87 | 4.24 | 11.46 | 78.97 |
| Planorbidae | 1.28 | 7.78 | 7.54 | 11.32 | 90.29 |

*Group Porters Ck*
Average similarity: 64.14

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| s-f Chironominae | 3.91 | 19.41 | 12.35 | 30.27 | 30.27 |
| Tateidae | 3.01 | 11.93 | 2.01 | 18.60 | 48.87 |
| Oligochaeta | 1.97 | 8.44 | 1.86 | 13.16 | 62.03 |
| Corixidae | 1.58 | 7.11 | 3.11 | 11.08 | 73.11 |
| Stratiomyidae | 1.14 | 5.75 | 8.75 | 8.96 | 82.07 |
| Physidae | 1.14 | 5.75 | 8.75 | 8.96 | 91.04 |

*Group Shrimptons Ck*
Average similarity: 68.58

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| s-f Chironominae | 3.44 | 16.25 | 7.18 | 23.69 | 23.69 |
| Physidae | 3.11 | 15.66 | 8.36 | 22.83 | 46.52 |
| Tateidae | 2.22 | 7.84 | 1.73 | 11.43 | 57.94 |
| Dugesiidae | 1.94 | 7.27 | 7.18 | 10.59 | 68.54 |
| Stratiomyidae | 1.14 | 5.14 | 7.18 | 7.49 | 76.03 |
| Notonectidae | 1.00 | 5.14 | 7.18 | 7.49 | 83.52 |
| Oligochaeta | 1.76 | 4.02 | 0.58 | 5.86 | 89.38 |
| Corixidae | 1.05 | 2.15 | 0.58 | 3.13 | 92.51 |

*Group Terrys Ck*
Average similarity: 62.27

| Species | Av.Abund | Av.Sim | Sim/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|
| s-f Chironominae | 2.50 | 10.92 | 4.82 | 17.54 | 17.54 |
| Tateidae | 2.73 | 9.88 | 1.50 | 15.86 | 33.40 |
| Oligochaeta | 1.90 | 8.15 | 6.64 | 13.09 | 46.49 |
| Physidae | 2.37 | 7.84 | 4.39 | 12.59 | 59.08 |
| Notonectidae | 1.72 | 7.11 | 7.86 | 11.42 | 70.50 |
| Psephenidae | 1.90 | 6.47 | 2.34 | 10.40 | 80.89 |
| s-f Tanypodinae | 1.49 | 5.75 | 3.66 | 9.24 | 90.13 |

*Groups Archers Ck & Buffalo Ck*
Average dissimilarity = 52.63

| | Group Archers Ck | Group Buffalo Ck | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| Culicidae | 2.44 | 0.00 | 5.32 | 7.41 | 10.10 | 10.10 |
| Psephenidae | 2.90 | 0.80 | 4.66 | 2.39 | 8.85 | 18.95 |
| Notonectidae | 2.09 | 0.47 | 3.95 | 1.58 | 7.50 | 26.46 |
| Physidae | 2.82 | 1.00 | 3.94 | 1.71 | 7.49 | 33.95 |
| Isostictidae | 0.00 | 1.47 | 3.34 | 2.83 | 6.34 | 40.29 |
| Oligochaeta | 2.27 | 0.91 | 2.94 | 1.80 | 5.59 | 45.87 |
| Sphaeriidae | 1.24 | 0.00 | 2.92 | 1.17 | 5.56 | 51.43 |
| Planorbidae | 0.00 | 1.28 | 2.89 | 4.01 | 5.48 | 56.91 |
| Dugesiidae | 1.58 | 0.47 | 2.66 | 1.86 | 5.06 | 61.98 |
| Stratiomyidae | 1.47 | 0.33 | 2.44 | 1.90 | 4.63 | 66.61 |
| Veliidae | 1.00 | 0.00 | 2.21 | 0.67 | 4.20 | 70.81 |
| s-f Chironominae | 3.74 | 3.69 | 2.17 | 1.59 | 4.13 | 74.94 |
| s-f Tanypodinae | 0.82 | 0.00 | 1.42 | 0.67 | 2.70 | 77.64 |
| Megapodagrionidae | 0.47 | 0.47 | 1.41 | 0.82 | 2.69 | 80.32 |
| Hemicorduliidae | 0.75 | 0.00 | 1.30 | 0.67 | 2.47 | 82.79 |
| Glossiphoniidae | 0.75 | 0.00 | 1.30 | 0.67 | 2.47 | 85.25 |
| Hydrophilidae | 0.47 | 0.00 | 1.04 | 0.67 | 1.98 | 87.23 |
| Hydroptilidae | 0.47 | 0.00 | 1.04 | 0.67 | 1.98 | 89.21 |
| Lymnaeidae | 0.33 | 0.33 | 0.93 | 0.82 | 1.77 | 90.98 |

*Groups Archers Ck & Porters Ck*
Average dissimilarity = 54.17

| | Group Archers Ck | Group Porters Ck | | | | |
|---|---|---|---|---|---|---|
| Species | Av.Abund | Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
| Psephenidae | 2.90 | 0.00 | 6.04 | 5.70 | 11.15 | 11.15 |
| Culicidae | 2.44 | 0.00 | 4.99 | 6.90 | 9.22 | 20.37 |
| Notonectidae | 2.09 | 0.33 | 3.83 | 1.51 | 7.08 | 27.45 |
| Physidae | 2.82 | 1.14 | 3.32 | 3.85 | 6.12 | 33.57 |
| Dugesiidae | 1.58 | 0.00 | 3.23 | 4.38 | 5.96 | 39.54 |
| Corixidae | 0.33 | 1.58 | 2.79 | 1.64 | 5.15 | 44.68 |
| Sphaeriidae | 1.24 | 0.00 | 2.73 | 1.18 | 5.04 | 49.72 |
| s-f Chironominae | 3.74 | 3.91 | 2.27 | 1.42 | 4.20 | 53.92 |
| Tateidae | 3.31 | 3.01 | 2.15 | 1.23 | 3.96 | 57.88 |
| Veliidae | 1.00 | 0.00 | 2.08 | 0.66 | 3.84 | 61.72 |
| s-f Tanypodinae | 0.82 | 0.67 | 2.03 | 1.55 | 3.75 | 65.47 |
| s-f Orthocladiinae | 0.00 | 0.80 | 1.78 | 1.23 | 3.29 | 68.76 |
| Oligochaeta | 2.27 | 1.97 | 1.78 | 1.53 | 3.29 | 72.06 |
| Pleidae | 0.00 | 0.67 | 1.37 | 1.26 | 2.53 | 74.58 |
| Hemicorduliidae | 0.75 | 0.00 | 1.24 | 0.67 | 2.28 | 76.86 |
| Glossiphoniidae | 0.75 | 0.00 | 1.24 | 0.67 | 2.28 | 79.14 |
| Hydrophilidae | 0.47 | 0.33 | 1.20 | 0.90 | 2.22 | 81.37 |
| Acarina | 0.47 | 0.33 | 1.16 | 0.93 | 2.13 | 83.50 |
| Megapodagrionidae | 0.47 | 0.00 | 0.98 | 0.66 | 1.81 | 85.31 |
| Hydroptilidae | 0.47 | 0.00 | 0.98 | 0.66 | 1.81 | 87.12 |
| Lymnaeidae | 0.33 | 0.33 | 0.86 | 0.83 | 1.58 | 88.70 |
| Stratiomyidae | 1.47 | 1.14 | 0.79 | 1.19 | 1.46 | 90.16 |

*Groups Buffalo Ck & Porters Ck*
Average dissimilarity = 46.25

| Species | Group Buffalo Ck Av.Abund | Group Porters Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Corixidae | 0.00 | 1.58 | 4.93 | 3.65 | 10.66 | 10.66 |
| Isostictidae | 1.47 | 0.00 | 4.62 | 3.46 | 9.99 | 20.65 |
| Oligochaeta | 0.91 | 1.97 | 3.77 | 1.50 | 8.15 | 28.80 |
| Tateidae | 3.31 | 3.01 | 3.21 | 1.13 | 6.95 | 35.75 |
| Planorbidae | 1.28 | 0.33 | 2.92 | 1.74 | 6.32 | 42.07 |
| s-f Orthocladiinae | 0.00 | 0.80 | 2.68 | 1.29 | 5.79 | 47.86 |
| Stratiomyidae | 0.33 | 1.14 | 2.61 | 1.44 | 5.65 | 53.51 |
| Psephenidae | 0.80 | 0.00 | 2.44 | 1.25 | 5.28 | 58.79 |
| Physidae | 1.00 | 1.14 | 2.31 | 1.35 | 5.00 | 63.79 |
| s-f Tanypodinae | 0.00 | 0.67 | 2.09 | 1.30 | 4.51 | 68.30 |
| Pleidae | 0.00 | 0.67 | 1.99 | 1.32 | 4.31 | 72.61 |
| Notonectidae | 0.47 | 0.33 | 1.91 | 0.91 | 4.13 | 76.73 |
| s-f Chironominae | 3.69 | 3.91 | 1.73 | 1.66 | 3.74 | 80.47 |
| Megapodagrionidae | 0.47 | 0.00 | 1.45 | 0.66 | 3.14 | 83.62 |
| Dugesiidae | 0.47 | 0.00 | 1.40 | 0.66 | 3.03 | 86.64 |
| Lymnaeidae | 0.33 | 0.33 | 1.33 | 0.84 | 2.87 | 89.52 |
| Acarina | 0.00 | 0.33 | 1.17 | 0.66 | 2.52 | 92.04 |

*Groups Archers Ck & Shrimptons Ck*
Average dissimilarity = 42.75

| Species | Group Archers Ck Av.Abund | Group Shrimptons Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Culicidae | 2.44 | 0.00 | 4.79 | 6.41 | 11.20 | 11.20 |
| Psephenidae | 2.90 | 0.80 | 4.06 | 3.12 | 9.51 | 20.71 |
| Oligochaeta | 2.27 | 1.76 | 2.59 | 1.37 | 6.06 | 26.76 |
| Sphaeriidae | 1.24 | 0.33 | 2.40 | 1.20 | 5.62 | 32.39 |
| Notonectidae | 2.09 | 1.00 | 2.32 | 1.14 | 5.42 | 37.80 |
| Tateidae | 3.31 | 2.22 | 2.25 | 1.14 | 5.25 | 43.05 |
| Veliidae | 1.00 | 0.00 | 1.99 | 0.66 | 4.67 | 47.72 |
| s-f Chironominae | 3.74 | 3.44 | 1.98 | 1.39 | 4.63 | 52.35 |
| Corixidae | 0.33 | 1.05 | 1.87 | 1.23 | 4.38 | 56.73 |
| Glossiphoniidae | 0.75 | 0.67 | 1.80 | 1.50 | 4.22 | 60.95 |
| Dugesiidae | 1.58 | 1.94 | 1.53 | 1.32 | 3.58 | 64.53 |
| s-f Orthocladiinae | 0.00 | 0.67 | 1.35 | 1.25 | 3.15 | 67.68 |
| s-f Tanypodinae | 0.82 | 0.00 | 1.31 | 0.66 | 3.06 | 70.74 |
| Coenagrionidae | 0.33 | 0.58 | 1.25 | 0.87 | 2.93 | 73.68 |
| Hemicorduliidae | 0.75 | 0.00 | 1.19 | 0.66 | 2.80 | 76.47 |
| Physidae | 2.82 | 3.11 | 1.19 | 0.97 | 2.78 | 79.25 |
| Hydrophilidae | 0.47 | 0.00 | 0.94 | 0.66 | 2.20 | 81.45 |
| Megapodagrionidae | 0.47 | 0.00 | 0.94 | 0.66 | 2.20 | 83.65 |
| Hydroptilidae | 0.47 | 0.00 | 0.94 | 0.66 | 2.20 | 85.85 |
| Stratiomyidae | 1.47 | 1.14 | 0.76 | 1.18 | 1.78 | 87.63 |
| Acarina | 0.47 | 0.00 | 0.76 | 0.66 | 1.77 | 89.40 |
| Hydraenidae | 0.47 | 0.00 | 0.76 | 0.66 | 1.77 | 91.17 |

*Groups Buffalo Ck & Shrimptons Ck*
Average dissimilarity = 48.39

| Species | Group Buffalo Ck Av.Abund | Group Shrimptons Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Physidae | 1.00 | 3.11 | 6.38 | 2.08 | 13.18 | 13.18 |
| Isostictidae | 1.47 | 0.00 | 4.35 | 3.33 | 8.99 | 22.17 |
| Oligochaeta | 0.91 | 1.76 | 4.22 | 1.81 | 8.73 | 30.90 |
| Dugesiidae | 0.47 | 1.94 | 4.21 | 1.52 | 8.69 | 39.60 |
| Planorbidae | 1.28 | 0.00 | 3.76 | 5.91 | 7.77 | 47.37 |
| Tateidae | 3.31 | 2.22 | 3.38 | 1.12 | 6.98 | 54.36 |
| Corixidae | 0.00 | 1.05 | 2.88 | 1.33 | 5.95 | 60.31 |
| Stratiomyidae | 0.33 | 1.14 | 2.46 | 1.43 | 5.08 | 65.39 |
| Notonectidae | 0.47 | 1.00 | 2.35 | 2.85 | 4.85 | 70.24 |
| s-f Orthocladiinae | 0.00 | 0.67 | 1.96 | 1.29 | 4.05 | 74.29 |
| Psephenidae | 0.80 | 0.80 | 1.86 | 1.05 | 3.84 | 78.13 |
| Glossiphoniidae | 0.00 | 0.67 | 1.85 | 1.31 | 3.82 | 81.95 |
| Coenagrionidae | 0.00 | 0.58 | 1.45 | 0.67 | 2.99 | 84.94 |
| Megapodagrionidae | 0.47 | 0.00 | 1.37 | 0.66 | 2.83 | 87.77 |
| s-f Chironominae | 3.69 | 3.44 | 1.35 | 2.51 | 2.79 | 90.56 |

*Groups Porters Ck & Shrimptons Ck*
Average dissimilarity = 43.77

| Species | Group Porters Ck Av.Abund | Group Shrimptons Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Physidae | 1.14 | 3.11 | 5.34 | 8.73 | 12.21 | 12.21 |
| Dugesiidae | 0.00 | 1.94 | 5.11 | 3.39 | 11.68 | 23.88 |
| Tateidae | 3.01 | 2.22 | 3.89 | 1.62 | 8.88 | 32.76 |
| Oligochaeta | 1.97 | 1.76 | 3.19 | 1.08 | 7.28 | 40.04 |
| Psephenidae | 0.00 | 0.80 | 2.35 | 1.29 | 5.36 | 45.40 |
| Corixidae | 1.58 | 1.05 | 2.26 | 1.07 | 5.17 | 50.57 |
| s-f Tanypodinae | 0.67 | 0.00 | 1.81 | 1.29 | 4.14 | 54.70 |
| Notonectidae | 0.33 | 1.00 | 1.81 | 1.29 | 4.14 | 58.84 |
| s-f Chironominae | 3.91 | 3.44 | 1.77 | 1.22 | 4.04 | 62.89 |
| Pleidae | 0.67 | 0.00 | 1.74 | 1.30 | 3.98 | 66.86 |
| Glossiphoniidae | 0.00 | 0.67 | 1.71 | 1.31 | 3.91 | 70.78 |
| s-f Orthocladiinae | 0.80 | 0.67 | 1.58 | 1.06 | 3.60 | 74.38 |
| Coenagrionidae | 0.00 | 0.58 | 1.35 | 0.66 | 3.09 | 77.46 |
| Gerridae | 0.00 | 0.33 | 1.03 | 0.66 | 2.35 | 79.81 |
| Acarina | 0.33 | 0.00 | 1.00 | 0.66 | 2.28 | 82.09 |
| Planorbidae | 0.33 | 0.00 | 0.93 | 0.66 | 2.12 | 84.21 |
| Dytiscidae | 0.33 | 0.00 | 0.81 | 0.66 | 1.86 | 86.07 |
| Hydrophilidae | 0.33 | 0.00 | 0.81 | 0.66 | 1.86 | 87.92 |
| Scirtidae | 0.33 | 0.00 | 0.81 | 0.66 | 1.86 | 89.78 |
| Lymnaeidae | 0.33 | 0.00 | 0.81 | 0.66 | 1.86 | 91.64 |

*Groups Archers Ck & Terrys Ck*
Average dissimilarity = 44.13

| Species | Group Archers Ck Av.Abund | Group Terrys Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Culicidae | 2.44 | 0.00 | 4.62 | 6.24 | 10.47 | 10.47 |
| s-f Tanypodinae | 0.82 | 1.49 | 2.64 | 2.31 | 5.98 | 16.45 |
| s-f Chironominae | 3.74 | 2.50 | 2.35 | 1.16 | 5.33 | 21.78 |
| Megapodagrionidae | 0.47 | 1.33 | 2.34 | 1.16 | 5.29 | 27.07 |
| Sphaeriidae | 1.24 | 0.33 | 2.32 | 1.19 | 5.25 | 32.32 |
| Dugesiidae | 1.58 | 0.33 | 2.29 | 1.92 | 5.19 | 37.51 |
| Stratiomyidae | 1.47 | 0.33 | 2.18 | 1.83 | 4.95 | 42.46 |
| Veliidae | 1.00 | 0.33 | 2.12 | 0.83 | 4.81 | 47.27 |
| Psephenidae | 2.90 | 1.90 | 2.03 | 1.24 | 4.59 | 51.86 |
| Isostictidae | 0.00 | 1.00 | 1.97 | 4.63 | 4.46 | 56.33 |
| Physidae | 2.82 | 2.37 | 1.79 | 1.47 | 4.05 | 60.38 |
| Notonectidae | 2.09 | 1.72 | 1.75 | 1.82 | 3.97 | 64.35 |
| Hemicorduliidae | 0.75 | 0.33 | 1.42 | 0.93 | 3.22 | 67.57 |
| Tateidae | 3.31 | 2.73 | 1.38 | 0.97 | 3.14 | 70.71 |
| Oligochaeta | 2.27 | 1.90 | 1.26 | 1.61 | 2.86 | 73.57 |
| Glossiphoniidae | 0.75 | 0.00 | 1.16 | 0.66 | 2.63 | 76.20 |
| Hydroptilidae | 0.47 | 0.33 | 1.15 | 0.93 | 2.61 | 78.82 |
| Simuliidae | 0.00 | 0.47 | 0.99 | 0.65 | 2.23 | 81.05 |
| Hydrophilidae | 0.47 | 0.00 | 0.91 | 0.66 | 2.06 | 83.11 |
| Dolichopodidae | 0.00 | 0.47 | 0.81 | 0.65 | 1.83 | 84.94 |
| Elmidae | 0.33 | 0.33 | 0.78 | 0.84 | 1.77 | 86.71 |
| Coenagrionidae | 0.33 | 0.33 | 0.78 | 0.84 | 1.77 | 88.47 |
| Acarina | 0.47 | 0.00 | 0.73 | 0.66 | 1.67 | 90.14 |

*Groups Buffalo Ck & Terrys Ck*
Average dissimilarity = 43.37

| Species | Group Buffalo Ck Av.Abund | Group Terrys Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| s-f Tanypodinae | 0.00 | 1.49 | 4.14 | 4.16 | 9.55 | 9.55 |
| Physidae | 1.00 | 2.37 | 4.10 | 1.50 | 9.46 | 19.02 |
| Notonectidae | 0.47 | 1.72 | 3.35 | 1.72 | 7.71 | 26.73 |
| Psephenidae | 0.80 | 1.90 | 3.30 | 1.45 | 7.60 | 34.33 |
| s-f Chironominae | 3.69 | 2.50 | 3.29 | 5.17 | 7.59 | 41.92 |
| Megapodagrionidae | 0.47 | 1.33 | 3.27 | 1.24 | 7.55 | 49.47 |
| Planorbidae | 1.28 | 0.33 | 2.80 | 1.66 | 6.46 | 55.93 |
| Oligochaeta | 0.91 | 1.90 | 2.80 | 1.26 | 6.45 | 62.38 |
| Tateidae | 3.31 | 2.73 | 2.04 | 1.05 | 4.70 | 67.08 |
| Dugesiidae | 0.47 | 0.33 | 1.64 | 0.95 | 3.79 | 70.87 |
| Simuliidae | 0.00 | 0.47 | 1.44 | 0.66 | 3.33 | 74.20 |
| Isostictidae | 1.47 | 1.00 | 1.31 | 1.11 | 3.02 | 77.22 |
| Stratiomyidae | 0.33 | 0.33 | 1.17 | 0.84 | 2.70 | 79.92 |
| Dolichopodidae | 0.00 | 0.47 | 1.10 | 0.67 | 2.53 | 82.46 |
| Aeshnidae | 0.00 | 0.33 | 1.03 | 0.66 | 2.37 | 84.83 |
| Hydroptilidae | 0.00 | 0.33 | 1.03 | 0.66 | 2.37 | 87.20 |
| Lymnaeidae | 0.33 | 0.00 | 0.89 | 0.66 | 2.05 | 89.25 |
| Sphaeriidae | 0.00 | 0.33 | 0.78 | 0.67 | 1.79 | 91.04 |

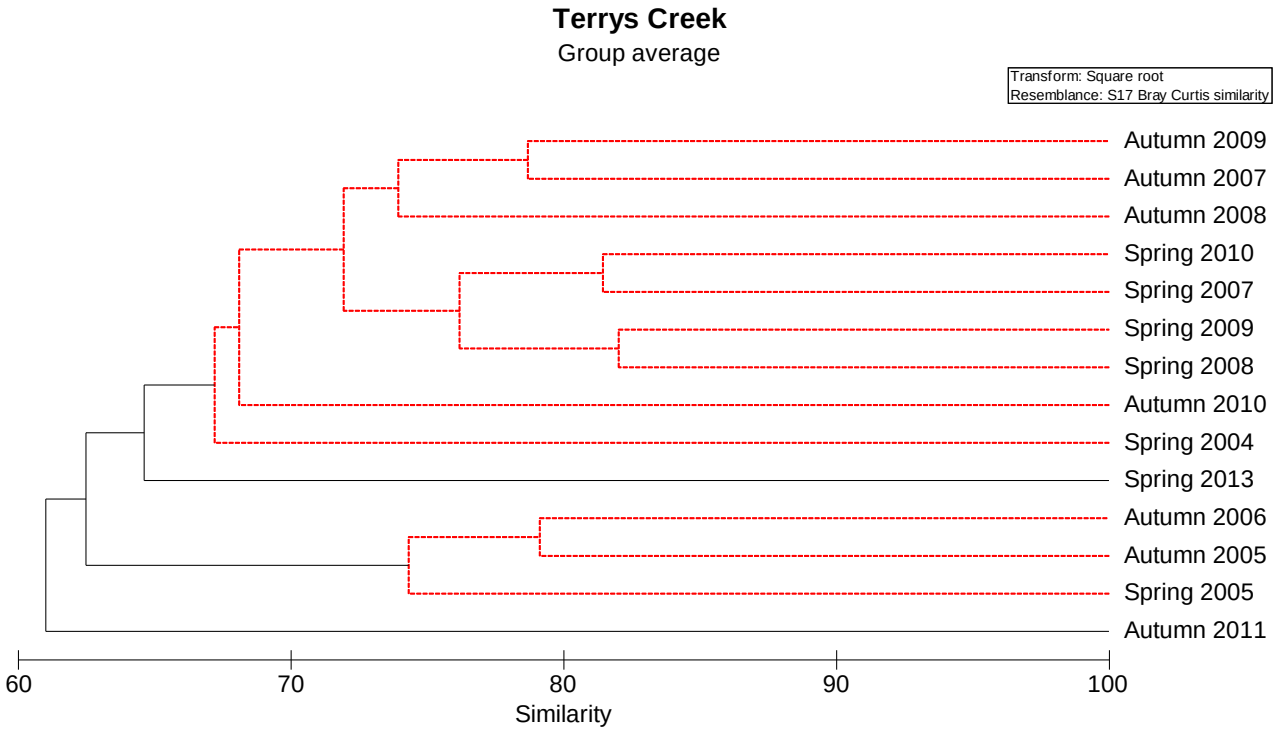
*Groups Porters Ck & Terrys Ck*
Average dissimilarity = 53.12

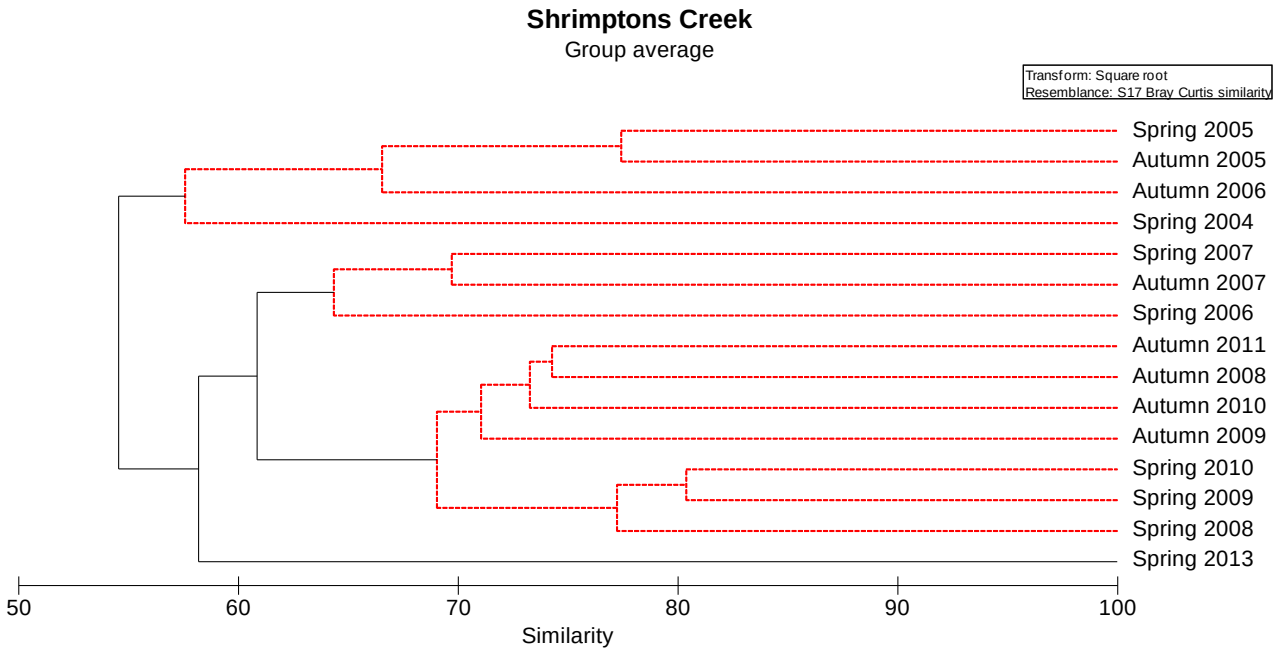
| Species | Group Porters Ck Av.Abund | Group Terrys Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Psephenidae | 0.00 | 1.90 | 4.83 | 3.00 | 9.09 | 9.09 |
| Corixidae | 1.58 | 0.00 | 4.09 | 3.41 | 7.69 | 16.79 |
| Notonectidae | 0.33 | 1.72 | 3.54 | 2.54 | 6.66 | 23.45 |
| s-f Chironominae | 3.91 | 2.50 | 3.48 | 2.32 | 6.55 | 30.00 |
| Megapodagrionidae | 0.00 | 1.33 | 3.13 | 1.09 | 5.89 | 35.89 |
| Tateidae | 3.01 | 2.73 | 3.00 | 1.14 | 5.64 | 41.53 |
| Physidae | 1.14 | 2.37 | 2.96 | 1.54 | 5.57 | 47.10 |
| Isostictidae | 0.00 | 1.00 | 2.61 | 6.63 | 4.92 | 52.02 |
| Stratiomyidae | 1.14 | 0.33 | 2.25 | 1.42 | 4.24 | 56.26 |
| s-f Orthocladiinae | 0.80 | 0.00 | 2.20 | 1.27 | 4.14 | 60.40 |
| s-f Tanypodinae | 0.67 | 1.49 | 2.11 | 1.29 | 3.96 | 64.37 |
| Oligochaeta | 1.97 | 1.90 | 1.74 | 1.95 | 3.27 | 67.63 |
| Pleidae | 0.67 | 0.00 | 1.66 | 1.30 | 3.13 | 70.76 |
| Simuliidae | 0.00 | 0.47 | 1.33 | 0.66 | 2.50 | 73.27 |
| Planorbidae | 0.33 | 0.33 | 1.12 | 0.83 | 2.11 | 75.38 |
| Dolichopodidae | 0.00 | 0.47 | 1.03 | 0.66 | 1.94 | 77.31 |
| Acarina | 0.33 | 0.00 | 0.95 | 0.66 | 1.79 | 79.10 |
| Aeshnidae | 0.00 | 0.33 | 0.95 | 0.66 | 1.78 | 80.88 |
| Hydroptilidae | 0.00 | 0.33 | 0.95 | 0.66 | 1.78 | 82.66 |
| Dugesiidae | 0.00 | 0.33 | 0.95 | 0.66 | 1.78 | 84.44 |
| Dytiscidae | 0.33 | 0.00 | 0.78 | 0.66 | 1.47 | 85.91 |
| Hydrophilidae | 0.33 | 0.00 | 0.78 | 0.66 | 1.47 | 87.37 |
| Scirtidae | 0.33 | 0.00 | 0.78 | 0.66 | 1.47 | 88.84 |
| Lymnaeidae | 0.33 | 0.00 | 0.78 | 0.66 | 1.47 | 90.31 |

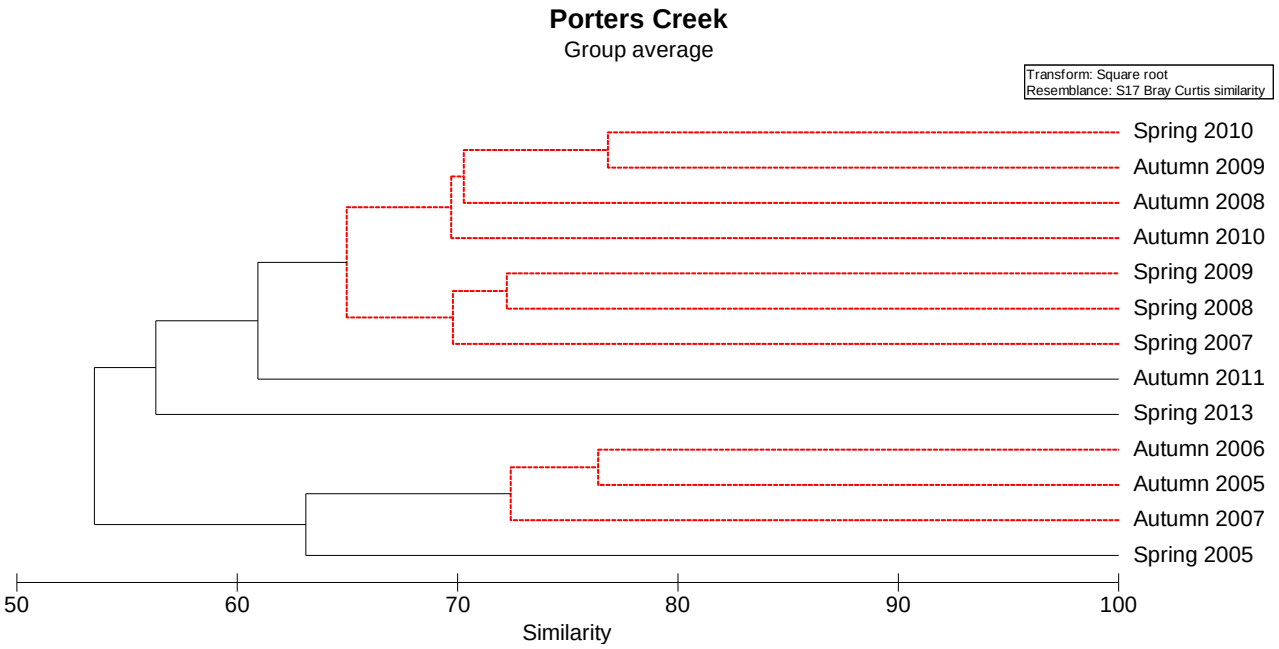
*Groups Shrimptons Ck & Terrys Ck*
Average dissimilarity = 48.10

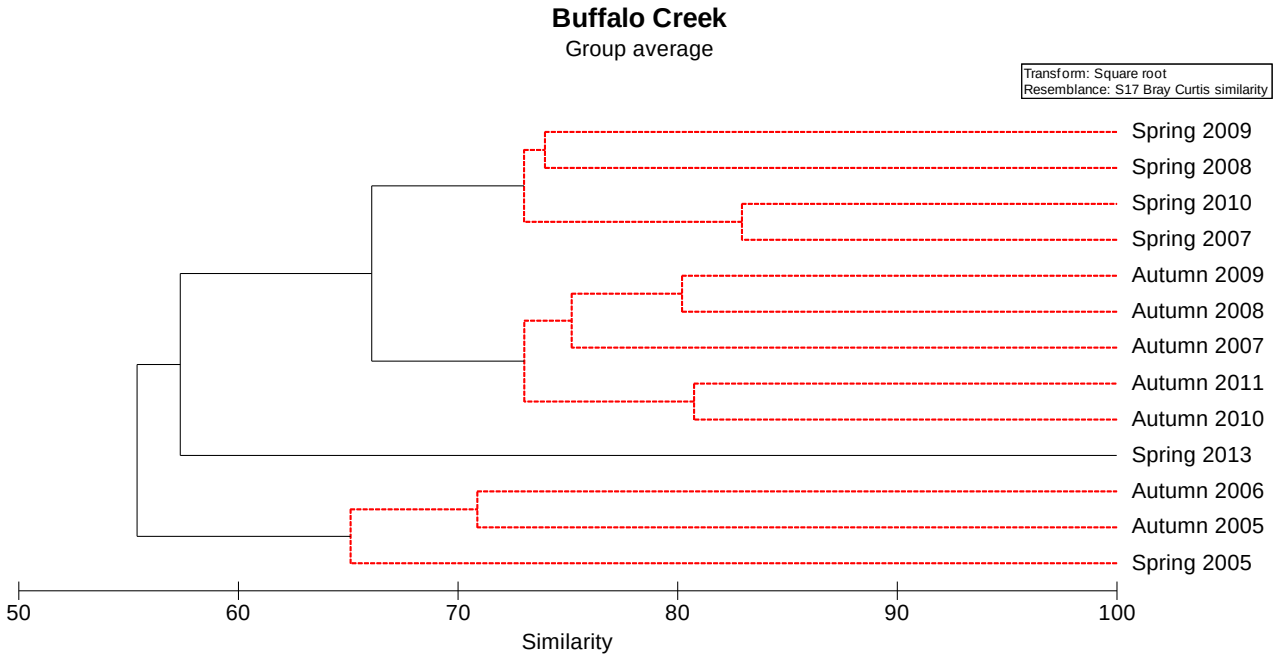
| Species | Group Shrimptons Ck Av.Abund | Group Terrys Ck Av.Abund | Av.Diss | Diss/SD | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| Dugesiidae | 1.94 | 0.33 | 3.75 | 2.01 | 7.80 | 7.80 |
| s-f Tanypodinae | 0.00 | 1.49 | 3.65 | 3.91 | 7.58 | 15.38 |
| Megapodagrionidae | 0.00 | 1.33 | 2.99 | 1.09 | 6.21 | 21.59 |
| Oligochaeta | 1.76 | 1.90 | 2.91 | 1.48 | 6.05 | 27.64 |
| Tateidae | 2.22 | 2.73 | 2.87 | 1.26 | 5.98 | 33.62 |
| Psephenidae | 0.80 | 1.90 | 2.73 | 1.69 | 5.68 | 39.30 |
| Physidae | 3.11 | 2.37 | 2.53 | 1.53 | 5.26 | 44.55 |
| Isostictidae | 0.00 | 1.00 | 2.48 | 6.19 | 5.16 | 49.71 |
| Corixidae | 1.05 | 0.00 | 2.44 | 1.31 | 5.06 | 54.78 |
| s-f Chironominae | 3.44 | 2.50 | 2.29 | 1.90 | 4.76 | 59.54 |
| Stratiomyidae | 1.14 | 0.33 | 2.14 | 1.41 | 4.44 | 63.98 |
| Notonectidae | 1.00 | 1.72 | 1.72 | 3.47 | 3.58 | 67.55 |
| s-f Orthocladiinae | 0.67 | 0.00 | 1.64 | 1.28 | 3.41 | 70.96 |
| Glossiphoniidae | 0.67 | 0.00 | 1.56 | 1.30 | 3.25 | 74.21 |
| Coenagrionidae | 0.58 | 0.33 | 1.53 | 0.91 | 3.17 | 77.38 |
| Simuliidae | 0.00 | 0.47 | 1.26 | 0.66 | 2.62 | 80.00 |
| Sphaeriidae | 0.33 | 0.33 | 1.00 | 0.84 | 2.08 | 82.08 |
| Dolichopodidae | 0.00 | 0.47 | 0.99 | 0.66 | 2.05 | 84.13 |
| Gerridae | 0.33 | 0.00 | 0.92 | 0.66 | 1.92 | 86.05 |
| Aeshnidae | 0.00 | 0.33 | 0.90 | 0.66 | 1.86 | 87.91 |
| Hydroptilidae | 0.00 | 0.33 | 0.90 | 0.66 | 1.86 | 89.77 |
| Parastacidae | 0.33 | 0.00 | 0.72 | 0.66 | 1.49 | 91.26 |

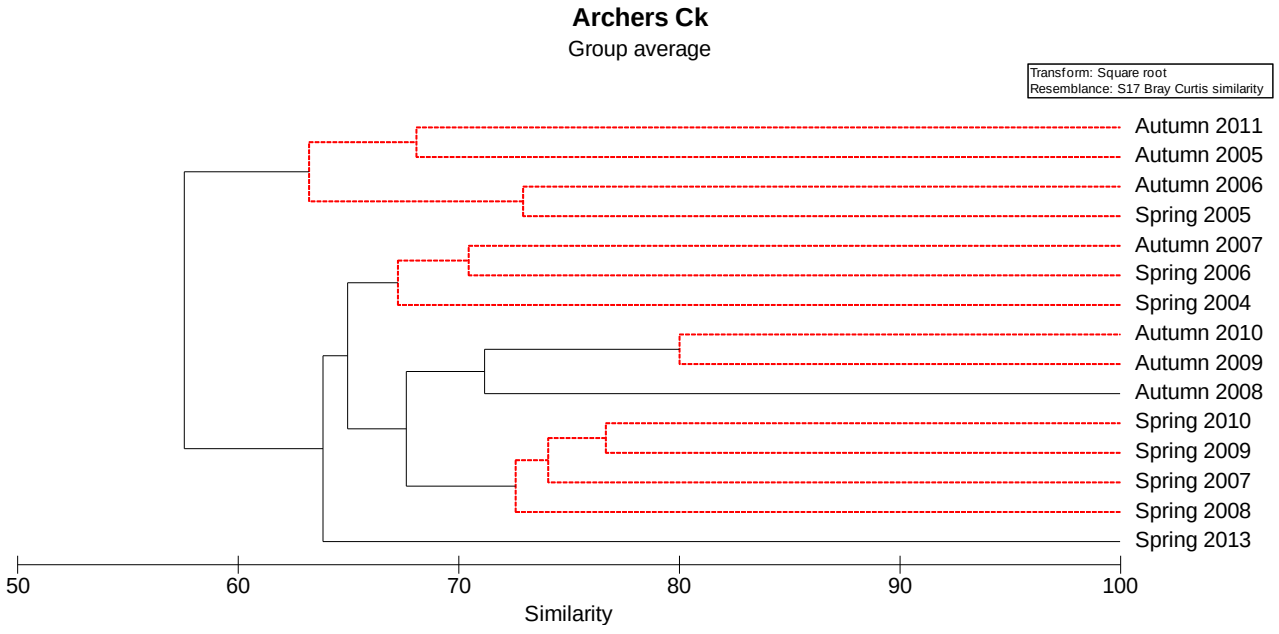
# Cluster and SIMPROF of each creek




Porters Creek
Group average
Transform: Square root
Resemblance: S17 Bray Curtis similarity
Spring 2010
Autumn 2009
Autumn 2008
Autumn 2010
Spring 2009
Spring 2008
Spring 2007
Autumn 2011
Spring 2013
Autumn 2006
Autumn 2005
Autumn 2007
Spring 2005
50
60
70
80
90
100
Similarity


Buffalo Creek
Group average
Transform: Square root
Resemblance: S17 Bray Curtis similarity
Spring 2009
Spring 2008
Spring 2010
Spring 2007
Autumn 2009
Autumn 2008
Autumn 2007
Autumn 2011
Autumn 2010
Spring 2013
Autumn 2006
Autumn 2005
Spring 2005
50
60
70
80
90
100
Similarity


Archers Ck
Group average
Transform: Square root
Resemblance: S17 Bray Curtis similarity
Autumn 2011
Autumn 2005
Autumn 2006
Spring 2005
Autumn 2007
Spring 2006
Spring 2004
Autumn 2010
Autumn 2009
Autumn 2008
Spring 2010
Spring 2009
Spring 2007
Spring 2008
Spring 2013
50
60
70
80
90
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Similarity