# Ku-ring-gai Council Water Quality and Aquatic Macroinvertebrate Sampling


## Background Report 2016
## Updated Jan 2024

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# 1. Introduction

Ku-ring-gai Council is responsible for managing urban waterways within its Local Government Area (LGA). Population growth and increased urban development continue to exert pressures on local waterways. Due to the location of historical sewerage infrastructure near watercourses, and an increase in built impervious surfaces, creeks within Ku-ring-gai are increasingly at risk of becoming substitute transport pathways for wastes such as stormwater runoff and sewerage effluent (Findlay *et al*. 2005). Moreover, many urban waterways have been engineered into pipes or culverts to help minimise flood risk (Findlay *et al*. 2005). As a result, these developmental pressures have impacted and altered the hydrological and ecological conditions of local aquatic ecosystems.

Since 1998, Council has conducted water quality monitoring and macroinvertebrate sampling across the LGA, at monitoring sites representative of Ku-ring-gai's aquatic ecosystems.

Regular monitoring of stream health and analysis of the data helps to identify changes in water quality and ecological condition of local waterways. Trends in the data will help identify areas where:

- high biodiversity should be protected,
- on-ground works have been effective,
- remediation works could be carried out in the future, and
- further investigation may be required.

This report provides technical information to accompany Council's annual Water Quality Report Cards as well as the processes involved in conducting annual water quality and aquatic macroinvertebrate sampling.

# 2. The Catchments

Ku-ring-gai is situated on the Hornsby Plateau and its geomorphology is characterised by three connected, flat-topped ridges which have been eroded to form deeply-incised gullies. Water flows from ridge tops to major waterways through a network of streams and creeks, forming the three major catchments (Figure 1) of Lane Cove River, Middle Harbour and Cowan Creek.

Most streams are protected to some extent by their incised, bedrock-confined setting, along with associated bushland corridors and connected formal reserves and national park areas (Findlay *et al*. 2005). While many of the waterways still possess intact, natural channels as well as well-vegetated riparian zones, weed infestation has become a significant environmental issue (Lake and Leishman 2004).

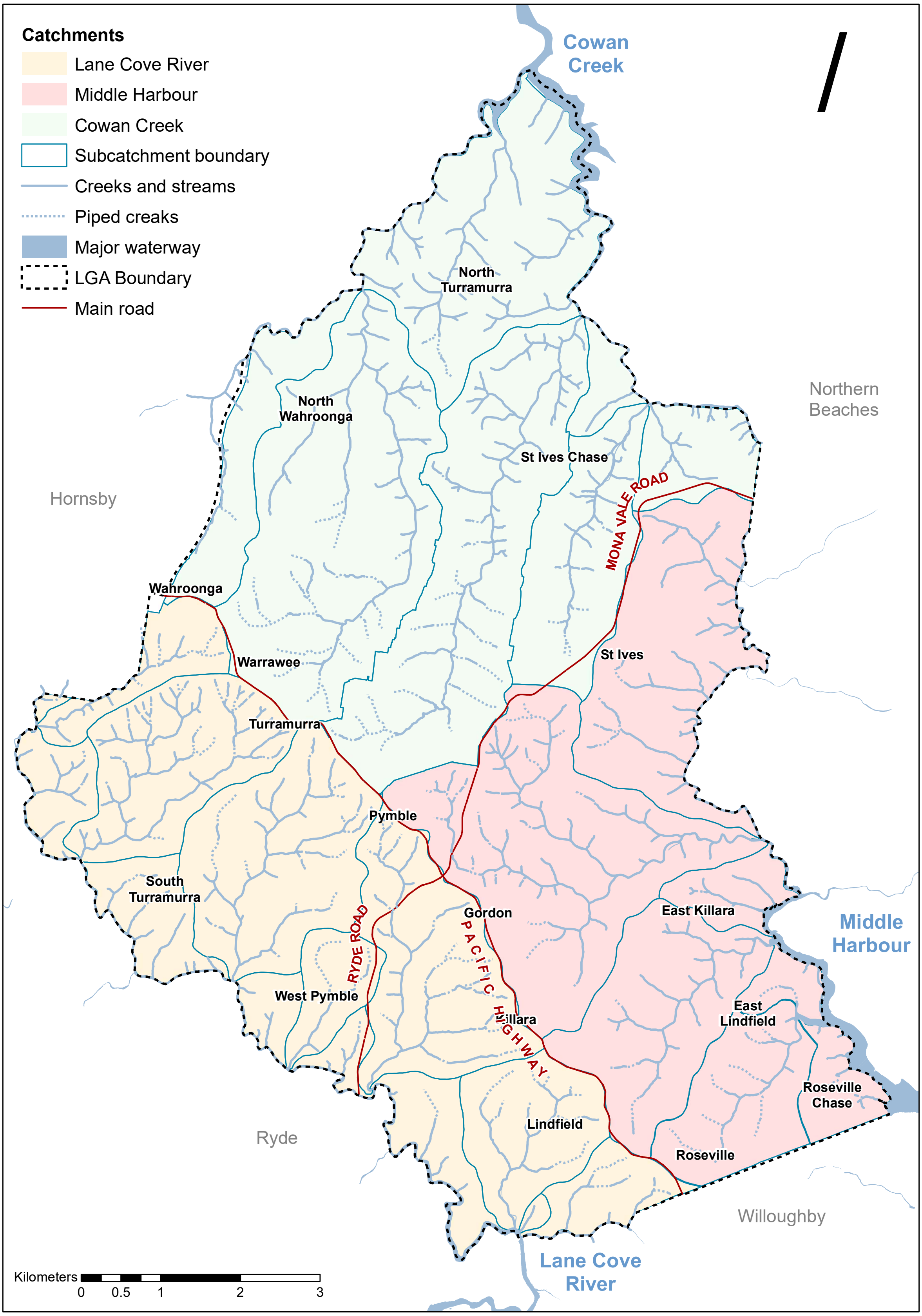


**Figure 1. Map of Ku-ring-gai Local Government Area and its three major catchments**

This is partly because the headwaters of many streams and creeks are located along areas with the most accessible terrain, which have received the greatest impacts from urban development over the past 200 years (Australian Water Technologies [AWT] 1998, Wright *et al*. 2007). Urban runoff, coupled with historical practices of treating streams as extensions to drainage infrastructure (Taylor *et al*. 2004), has resulted in disturbed riparian habitats. Typically, stream and creek beds are lined with a mix of rocks, cobbles, boulders and even bedrock of mainly Hawkesbury sandstone, as well as Wiannamatta shale outcrops (AWT 1998, Wright *et al*. 2007). The soils in the area are primarily shallow lithosols, siliceous sands, yellow earths and yellow podzolics and sand, silt, clay and gravel are present in most riparian habitats (Chapman & Murphy 1989, as cited by AWT 1998, Wright *et al*. 2007).

A brief description of each major catchment is provided below.

## 2.1 Lane Cove River Catchment

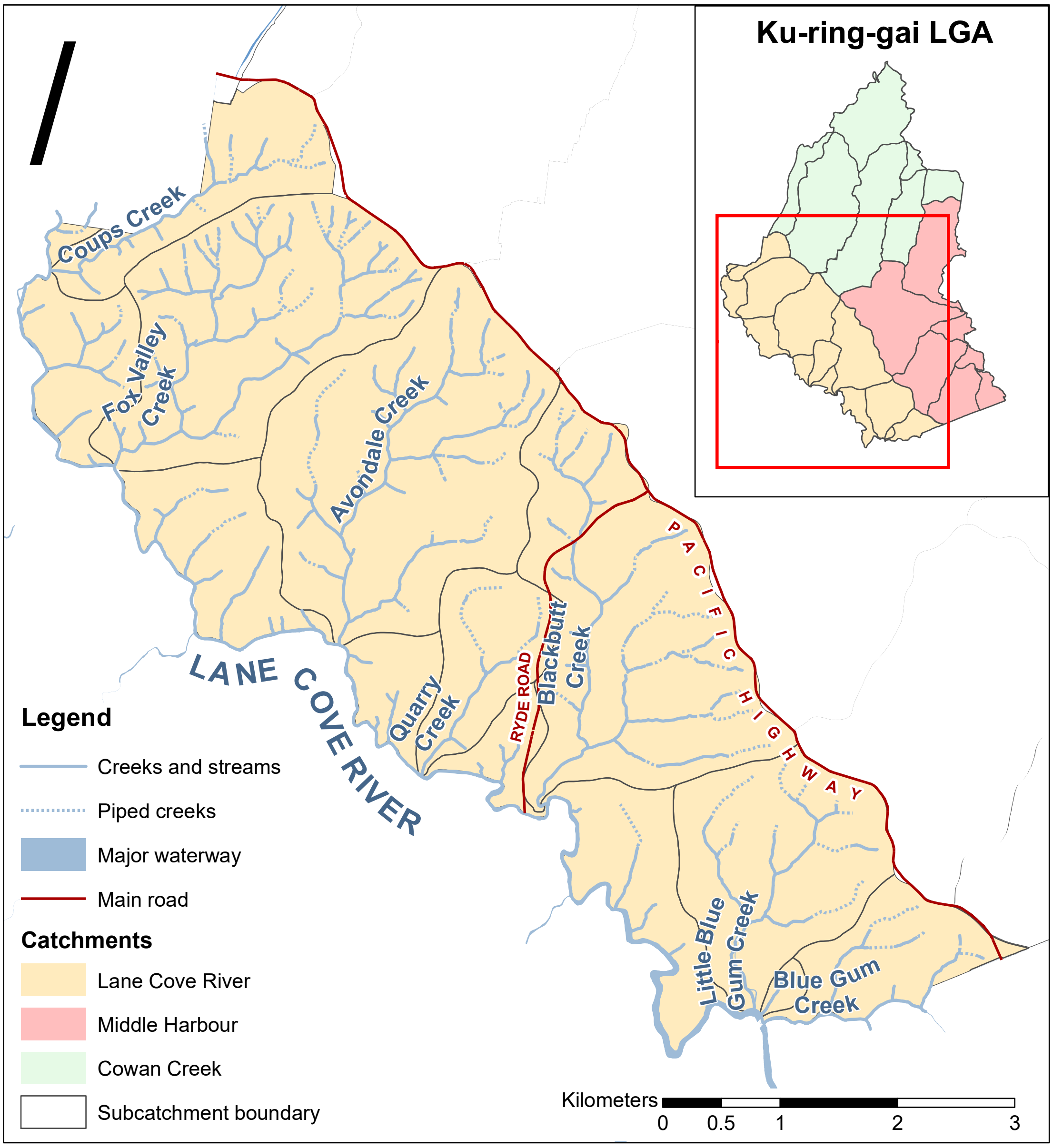


**Figure 1A**. Map of Lane Cove River Catchment within Ku-ring-gai

In Ku-ring-gai the Lane Cove River catchment is bounded to the north by Coups Creek, to the east by Pacific Highway, to the south by Blue Gum Creek and to the west by Lane Cove River. There are key habitats for endangered and vulnerable flora and fauna in Lane Cove National Park on the western extent of the catchment, as well as in connected bushland in Sheldon Forest and Rofe Park Natural Areas (KC 2013). Land use in the catchment is primarily residential with light commercial use. Known impairments to water quality are mainly the result of stormwater runoff from urban areas on both sides of Lane Cove Valley and from industrial sources outside Ku-ring-gai (NP&WS 1998).

## 2.2 Middle Harbour Catchment

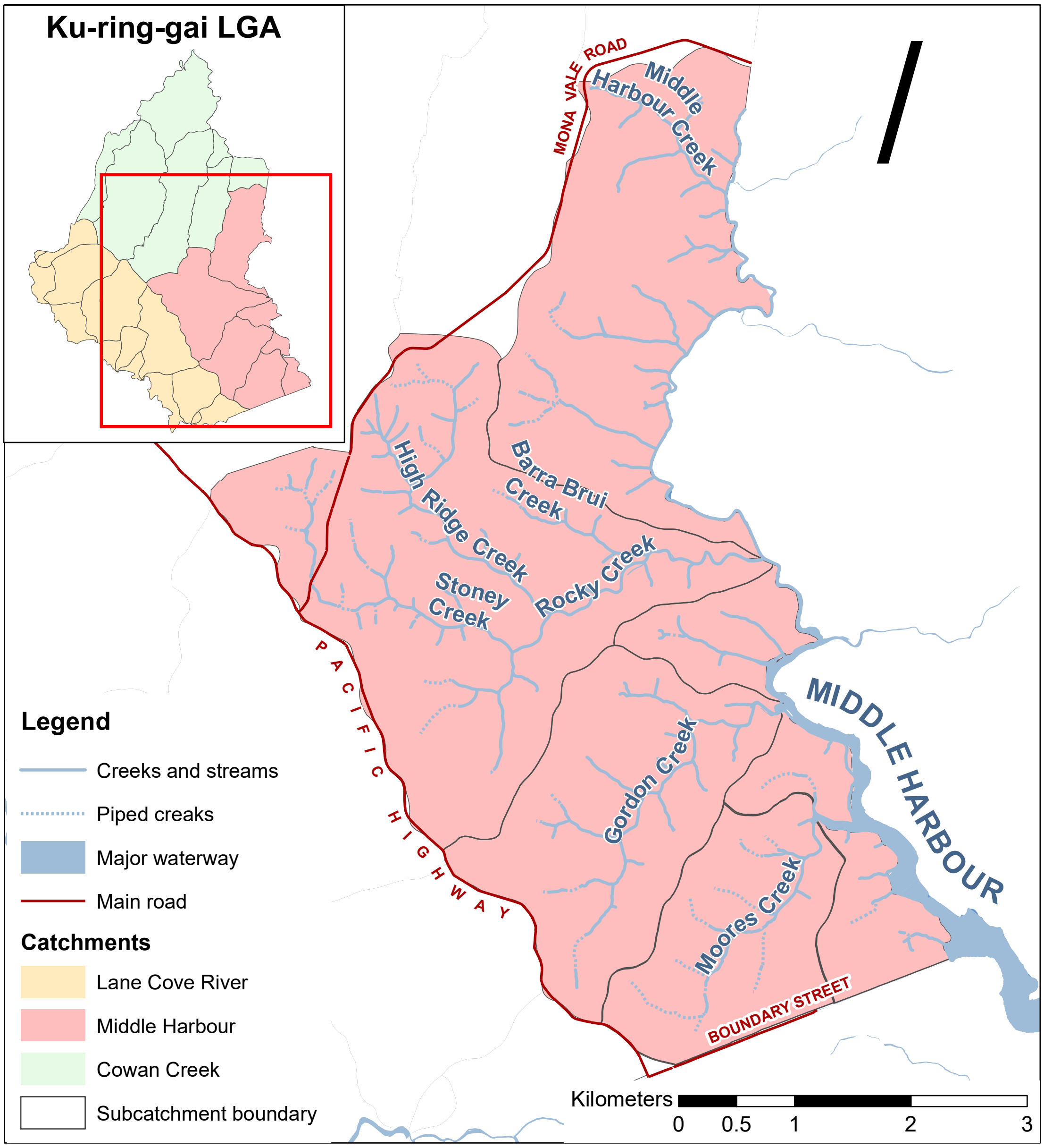


**Figure 1B**. Map of Middle Harbour Catchment within Ku-ring-gai

In Ku-ring-gai the Middle Harbour catchment is approximately bounded by Mona Vale Road to the north, Pacific Highway to the west, Boundary Street to the south, and

Middle Harbour to the east. On the eastern side of the catchment there are large tracts of bushland habitat supporting endangered and vulnerable flora and fauna, including parts of Garigal National Park, the connected Ku-ring-gai Flying-Fox Reserve (KFFR), as well as Browns Forest (Dalrymple-Hay Nature Reserve) (KC 2013). Land use in the catchment is primarily residential with light commercial use. Due to a number of popular swimming spots in Middle Harbour, faecal coliforms and enterococci levels are closely monitored to safeguard public health (OEH 2015); refer to the NSW Office of Environment and Heritage 'Beachwatch' webpage for daily forecasts:
[https://beachwatch.nsw.gov.au/home](https://beachwatch.nsw.gov.au/home) (January 2024)

### 2.3 Cowan Creek Catchment

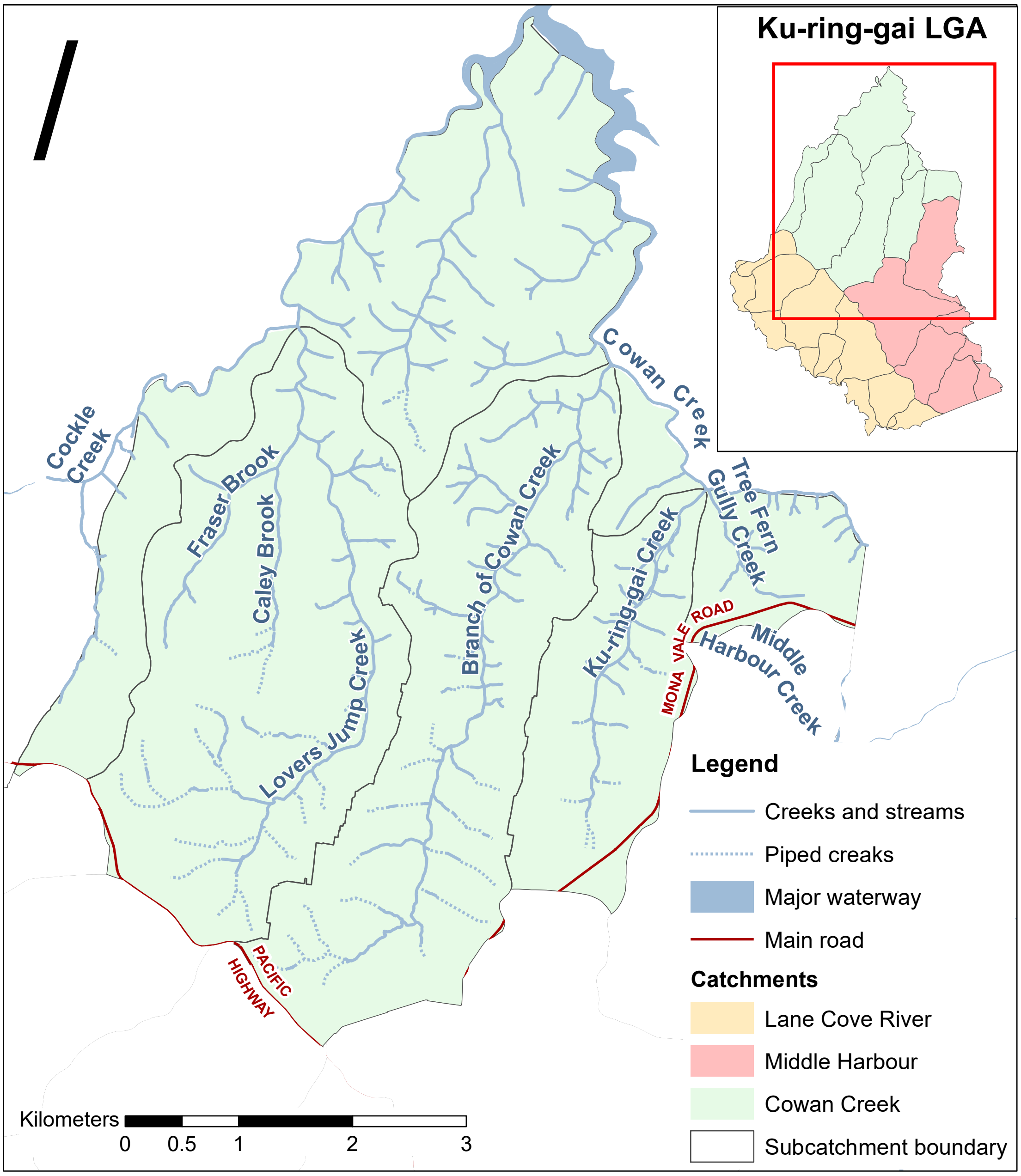


**Figure 1C**. Map of Cowan Creek Catchment within Ku-ring-gai

In Ku-ring-gai the southern boundary of Cowan Creek catchment roughly adjoins Lane Cove River catchment at Pacific Highway and Middle Harbour catchment at Mona Vale Road. The northern half of the catchment is bounded by M1 Pacific Motorway and Cockle Creek to the west, and by Cowan Creek to the east. Most of the northern half of the catchment consists of bushland within Ku-ring-gai Chase National Park. Consequently, Cowan Creek catchment contains the highest native species biodiversity of the three major catchments in Ku-ring-gai, and is home to numerous threatened species (KC 2013). Land use in the catchment is primarily residential with light commercial use.

## 3. Monitoring Water Quality

The quality of surface and groundwater can be adversely impacted by urban development and human activities. Regular monitoring and analyses of urban waterways may provide early detection of and warning against potential contamination threats, and help inform decision-making in maintaining aquatic ecosystem health and public safety.

By measuring and analysing the physical and chemical parameters of water, specific stressors which are detrimental to water quality and ecological health may be identified. This encompasses those stressors that are:

- directly toxic to living things (e.g. heavy metals),
- not toxic but directly and adversely affect aquatic ecosystems (e.g. excessive nutrients causing eutrophication), and
- those that have an indirect effect by modifying other stressors (e.g. dissolved organic carbon influencing the bioavailability of heavy metals) (ANZECC/ARMCANZ 2000c).

Generally, the specific concentrations at which various elements and compounds become toxic to living things are known from laboratory studies (ANZECC/ARMCANZ 2000c). Consequently, it is relatively quick and easy to determine many aspects of water quality at any particular moment in time, with the use of measurement technologies in the field and in the laboratory. Some common examples are given in Table 1 below.

**Table 1.** General measurement parameters used for assessing aquatic system health: Excerpt from the Australian guidelines for water quality monitoring and reporting (ANZECC/AMRCANZ 2000c)

| Measurement parameter | Input(s) | Potential effects |
|---|---|---|
| Electrical conductivity | Salt | Loss of sensitive biota |
| Total phosphorus | Phosphorous | Eutrophication |
| Total phosphorous: Total nitrogen | Phosphorous, nitrogen | Cyanobacterial blooms |
| pH | Acid drainage | Loss of sensitive biota |
| Suspended solids | Sediment | Changes in ecosystem habitat, loss of sensitive species |
| Turbidity | Sediment | Altered light climate that affects productivity and predator-prey relationships |

Other advantages of measuring physical and chemical parameters include (ANZECC/ARMCANZ 2000c):

- conceptual simplicity;
- established technology;
- explicit numerical objectives;
- comparatively low costs; and
- the ability to acquire meaningful quantities of data relatively quickly.

However, there are limitations to information on ecological health attained through physical and chemical assessments. The use of biological assessment is recommended to complement physical and chemical assessments for a holistic, integrated approach to water quality monitoring and assessing aquatic ecosystem health (ANZECC/ARMCANZ 2000c). Biological assessment includes ecotoxicological and ecological measurements, both of which integrate the effects of contaminants over time to provide an indication of the health of an aquatic ecosystem (ANZECC/AMRCANZ 2000c). As the next section illustrates, macroinvertebrate sampling is one of the relatively common and inexpensive methods of conducting rapid biological assessment.

# 4. Monitoring Macroinvertebrates

Aquatic macroinvertebrates – commonly known as 'water bugs' – are animals without a backbone that live all or part of their lives in water (Chessman 2003). They are usually small but can be seen without the use of a magnifying glass or microscope (Chessman 2003). There are many types of macroinvertebrates, including insects, mites, crustaceans, molluscs, sponges and worms (Chessman 2003).

## 4.1 Macroinvertebrate habitats and microhabitats

Macroinvertebrate communities have adapted to live in different types of freshwater habitats. These include still water habitats like wetlands and lakes, as well as flowing water habitats, such as riffles, pools, runs and edgewater (Environment Australia 2002, Department of Environment and Conservation [DEC] 2004). Within these habitats macroinvertebrates may dwell in the bottom substratum (e.g. underneath mud, gravel, rocks), near the water surface, or amongst aquatic plants throughout the water column, as well as within terrestrial vegetation overhanging from the banks (DEC 2004).

## 4.2 Ecological role of macroinvertebrates

Macroinvertebrates are crucial to maintaining a healthy freshwater ecosystem as many species are detritivores that consume, and therefore remove, leaf litter, woody debris and dead organisms (Gooderham and Tsyrlin 2002, Chessman 2003). In addition, many macroinvertebrates are food for other macroinvertebrate and vertebrate species; thus they play a significant role in maintaining key linkages in the aquatic food web (AWT 1998, ANZECC/ARMCANZ 2000b, Gooderham and Tsyrlin 2002, Chessman 2003).

### 4.3 Macroinvertebrates as indicators of water quality and ecosystem health

Macroinvertebrates are useful indicators of the ecological health of freshwater habitats due to the diversity of species and the known, particular environmental conditions required by each species (ANZECC/ARMCANZ 2000b, Gooderham and Tsyrlin 2002, Chessman 2003). For water quality monitoring purposes, they are useful because sampling is relatively easy and there will almost always be some macroinvertebrates in any freshwater habitat (Chessman 2003). Because some species are sensitive to certain pollutants while others are more tolerant, the presence and abundance of different species convey information about water quality and environmental conditions (ANZECC/ARMCANZ 2000b, Chessman 2003).

Usually, healthy aquatic ecosystems contain high species diversity for macroinvertebrates and relatively low species abundance; in contrast, stressed aquatic ecosystems tend to contain a high abundance of pollution-tolerant species and lower species diversity (LCRCC 2003).

Because macroinvertebrate populations require time to recover after impact events (e.g. pollution incidents), changes to community assemblages between monitoring events can reflect changes to water quality and environmental conditions that have occurred in the intervening period (AWT 1998, Chessman 2003). This provides a more holistic understanding of the state of water quality and aquatic ecosystem health over time (i.e. stable, improving, or deteriorating), rather than a snapshot of that particular moment in time, which is typically achieved through tests of physical and chemical characteristics (AWT 1998, Chessman 2003, LCRCC 2003).

## 5. Sampling Periods and Monitoring Sites

### 5.1 Sampling Periods

Since 1998 Council has conducted water and macroinvertebrate sampling at monitoring sites throughout the LGA. Sampling occurs twice a year in autumn (15$^{th}$ March – 15$^{th}$ June) and spring (15$^{th}$ September – 15$^{th}$ December) in accordance with NSW WaterWatch and Australian River Assessment System (AUSRIVAS) guidelines for New South Wales. These guidelines were originally created due to perceived seasonal influences in regional rainfall, vegetation and macroinvertebrate lifecycles (Environment Australia 2002, DEC 2004). For example, in eastern New South Wales, the combination of low flows and high temperature during autumn months better highlight the effects of pollution impacts (Environment Australia 2002). Meanwhile in springtime, macroinvertebrates hatched in the previous summer are easier to identify, as they are larger and have reached visually more distinctive mature lifecycle stages (Environment Australia 2002). However, recent studies have found limited support for seasonality influence on macroinvertebrate communities within the Sydney Basin, including Ku-ring-gai (Wright 2011, Tippler *et al*. 2014). One of the main reasons suggested was that the temperate climate of the Sydney Basin did not subject macroinvertebrates to distinct wet and dry seasons (Tippler *et al*. 2014). A general increase in monitoring frequency was also recommended (Tippler *et al*. 2014). While noting the lack of distinct wet/dry seasonality, and the advantages to sampling regularly (e.g. monthly) throughout the year (HSC 2014), Council has maintained a biannual sampling frequency, due to limited resources and to ensure consistency in data collection and interpretation.

Sampling during and immediately after rain events has generally been avoided. This is because physical and chemical water quality parameters (e.g. turbidity) may be substantially confounded by the ‘first flush’ of new flows after a prolonged dry period, which often contains elevated levels of contaminants from urban runoff (ANZECC/ARMCANZ 2000c, HSC 2014), and known issues with sewage overflows (Wright *et al*. 2007). Macroinvertebrate communities may also be flushed from the aquatic habitats where they were dwelling in prior to such rain events, with no guarantee that the species diversity and/or abundance from sampling is representative of the community assemblage at the monitoring site. On the other hand, as much of the aquatic ecological health impairment occurs during wet weather flow conditions, investigation into wet weather water quality may be informative (Wright 2011) and could be undertaken if necessary. As a general guide, water sampling will not take place if there has been greater than 10mls of rain in the previous 24 hrs.

Over time six reference monitoring sites (four of which lie outside the LGA) and 23 urban monitoring sites have been established across the three major catchments of Ku-ring-gai (Figure 2). Each financial year, 1 reference site and 9 urban sites will be monitored consecutively in spring and summer. The historical legacy of extensive urban and agricultural development precludes the use of Before/After Control/Impact studies (BACI), making the comparison of urban streams with multiple reference streams the most practical way of monitoring water quality and aquatic ecosystem conditions (Wright *et al*. 2007).

### 5.2 Reference monitoring sites

A reference site represents the least impacted freshwater habitat in the region with the best water quality, thus providing a baseline of natural variability in water quality to compare with the more impacted urban sites (HSC 2014). Reference sites were selected in freshwater habitats bearing the closest ecological resemblance to natural conditions, which likely existed prior to European settlement in Ku-ring-gai. Because of historical agricultural and urban development in Ku-ring-gai, few streams resemble near-natural conditions with minimal human impact (Findlay *et al*. 2005). As a result, only two of the six reference sites are located within the LGA (near the northern boundary of Ku-ring-gai Wildflower Garden in St Ives); the remaining four reference sites are located north of the LGA in national parks (Garigal National Park, Ku-ring-gai Chase National Park). Four reference sites are no longer being routinely monitored due to declining ecosystem health. However, historic data is still available for these sites (refer to Appendix C for the complete listing of all monitoring sites).

### 5.3 Urban monitoring sites

Urban sites were selected to be as representative as possible of major creeks in Ku-ring-gai in terms of aquatic and riparian habitat features; with considerations to site access, nearby land use, and environmental issues specific to the surrounding area.

Generally, an urban site is located in the lowest possible reach[1] of the waterway that satisfies the above considerations. This is based on the assumption that cumulative impacts on water quality in the sub-catchment are best assessed at their most integrated point, (i.e. the reach furthest downstream but immediately before the point of entry into a major waterway) (AWT 1998).

[1] Defined as a homogenous section of a channel with uniform channel morphology and sufficiently consistent hydrological, geological, and adjacent watershed surface conditions (Kellerhals *et al*. 1976, as cited by Taylor *et al*. 2004)

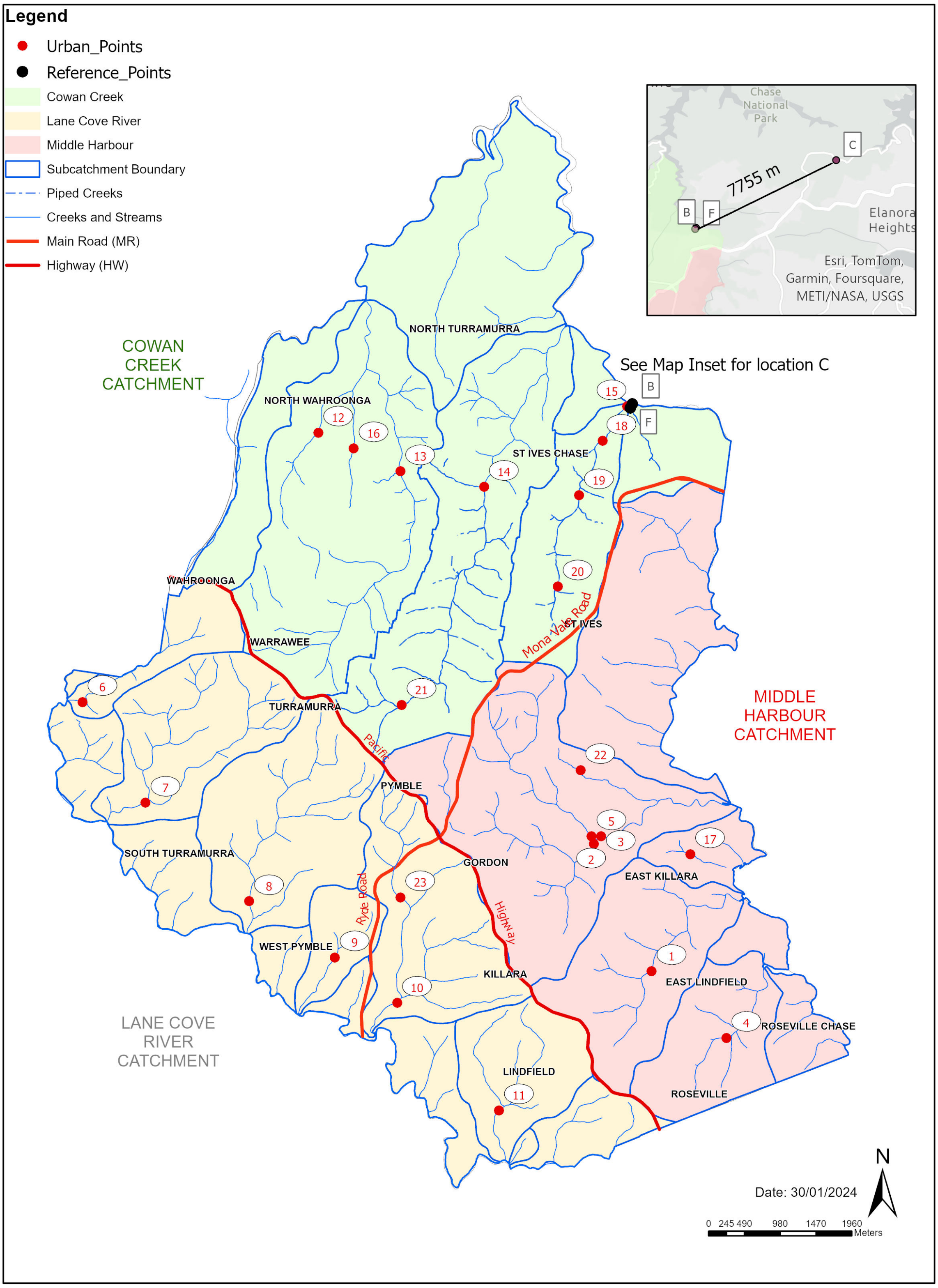


Figure 2. Water quality monitoring sites in Ku-ring-gai
(each site is identified by its Site ID; refer to Appendix C for the complete list of all sites)

## 5.4 Site characteristics

Consistent with Waterwatch and AUSRIVAS guidelines, ideally sampling should be conducted in both riffle and edge habitats. Riffles are segments of streams with rapid current and broken water over a cobble and boulder substratum (Environment Australia 2002, DEC 2004). Depending on the variety of rock sizes, riffles potentially contain the most diverse habitats for macroinvertebrates, which may seek shelter under rocks or have adaptations to fast-flowing currents (Environment Australia 2002, Chessman 2003). Edgewater, or edge habitats, are segments along stream banks with slow current or no flow (DEC 2004). Macroinvertebrates tend to occur in microhabitats such as benthic leaf litter, macrophyte beds, silt beds, trailing or overhanging vegetation from the banks, as well as submerged logs and rocks (DEC 2004). Typically, edge habitats support species that are more mobile than those found in riffles (Environment Australia 2002).

## 5.5 Changes to monitoring sites over time

Historically, Council and consultants engaged by Council regularly attempted to sample riffle as well as edge habitats at monitoring sites (AWT 1998; 2000, Lane Cove River Catchment Councils 2002; 2003; 2004). However, in recent years sampling in riffle habitats has become infrequent (Wright *et al*. 2007). Local waterways appear to be experiencing lower flows and therefore lack the fast currents necessary for appropriate riffle habitat (as defined by AUSRIVAS), except during and after periods of prolonged and/or intense rainfall. The change in flow regime may be attributable to several factors, most notably the increase in connected impervious surfaces as a result of land use changes and increased urban development (AWT 1998, KC 2013). Impervious surfaces prevent infiltration of water into the ground, thereby reducing groundwater recharge and the steady baseflow of groundwater into waterways (Arnold and Gibbons 1996, KC 2013). Connected impervious surfaces also alter and channelise the flow paths of urban runoff, and in the process concentrate and increase runoff volume and velocity (Arnold and Gibbons 1996, Walsh *et al*. 2012, KC 2013, HSC 2014). As a result, waterways are increasingly characterised by long periods of low flows interrupted by short bouts of intense ‘flash’ flows during and after rain events. Apart from scouring stream beds and increasing the risk of bank erosion, the changed hydrology can potentially lead to ecological processes that impair water quality and ecological health (Wright *et al*. 2007), for example, increased nutrient pollution and removal of instream habitat (LCRCC 2003).

# 6. Materials and Methods

## 6.1 Assessing riparian characteristics

For each monitoring site, the following attributes are assessed in accordance with AUSRIVAS guidelines and recorded onto a field datasheet (AUSRIVAS NSW field data sheet):

- topography of surrounding riparian habitat
- water level
- level of shading of the stream
- absence or presence of riparian trees taller than 10 metres
- minimum, maximum and modal stream width in metres

## 6.2 Measuring physical characteristics of water

To measure physical and chemical characteristics of water, a segment near the middle of the stream is selected, away from the edges and free of floating debris, with constant flow of water. Next, a portable multi-sensor probe (YeoKal YK611 Water Quality Analyser) is placed below water surface, at a depth about midway in the water column, to measure the following characteristics:

- temperature
- electrical conductivity
- turbidity
- dissolved oxygen
- pH
- salinity
- oxidation-reduction potential
- Total Dissolved solids

These measurements, as well as the time of sampling, are recorded onto the field datasheet. Generally, three measurements are taken for each water quality parameter, a few minutes apart, in order to calculate an average measurement.

## 6.3 Measuring chemical characteristics of water

Water samples are collected using a 500 mL plastic bottle containing no preservatives, which is supplied by a National Association of Testing Authorities (NATA) accredited contract laboratory. The bottle is filled by submerging it underwater in an area of current flow. The sample is then decanted into the following plastic bottles (also supplied by the contract laboratory):

- a 60 mL bottle containing trace amounts of nitric acid for measuring trace metals (e.g. lead, mercury, arsenic, etc.)
- a 125 mL bottle containing trace amounts of sulphuric acid for measuring nutrients (e.g. nitrates, phosphates, etc.)
- a 250 mL bottle containing trace amounts of sodium thiosulphate for measuring bacteria (e.g. *E. coli*, coliforms, etc.)

Decanting ensures that the preservatives in the bottles do not escape into waterways, and also prevents cross contamination of water samples. In order to minimise reactions with air which potentially alters the chemical contents of the sample, all bottles are completely filled leaving no headspace. Once the three bottles are filled, the 500 mL bottle is refilled from the stream using the same technique as before. This fourth sample (which contains no preservatives) is taken to measure a broad suite of water quality characteristics, including alkalinity, electrical conductivity, pH, turbidity, major cations and anions, suspended and dissolved solids. All sample bottles are then placed into a cooler/esky with ice / ice bricks present.

## 6.4 Macroinvertebrate sampling in riffle habitats

Macroinvertebrate sampling is conducted in suitable riffle habitats (if present) and edge habitats. AUSRIVAS guidelines are followed in identifying appropriate riffles (DEC 2004). A technique known as kick-sampling is used when sampling in riffles. This is performed by standing about knee deep in the riffle, facing downstream and holding an aquatic sampling net in front of both feet with the mouth of the net facing upstream (Environment Australia 2002, Chessman 2003, DEC 2004). With appropriate footwear (e.g. rubber boots, waders), the cobble and boulder substratum is disturbed by kicking and shuffling, allowing the water current to carry dislodged macroinvertebrates into the net where they are trapped (Environment Australia 2002, Chessman 2003, DEC 2004). Kick-sampling is repeated for a further 10 metres upstream, and may involve multiple riffles until 10 metres of riffle habitat have been sampled (Environment Australia 2002, Chessman 2003, DEC 2004). The net should be at least 60 cm long to prevent backwash, with a mesh size of 250 $\mu$m capable of trapping smaller species of macroinvertebrates (DEC 2004). After sufficient material is collected in the net (usually after 8-10 minutes), the sampled content is emptied into a bucket to await picking/sorting (Chessman 2003).

## 6.5 Macroinvertebrate sampling in edge habitats

In edge habitats, a technique known as sweep sampling is used. This generally consists of alternating back and forth between two successive sweeping motions: first by sweeping against various microhabitats to dislodge macroinvertebrates, then rapidly scooping upwards through the water column to trap macroinvertebrates in the net. The effectiveness of the first motion depends on how well the frame of the net scrapes material off microhabitat surfaces. The overall effectiveness is determined by how well the two types of sweeping motions are alternated and integrated in a continuous movement to maximise the number of macroinvertebrates caught. In practice, this may be more difficult after rainfall events when higher water levels, faster currents and increased amounts of suspended solids generate substantial water resistance on the net. Like riffle sampling, sweep sampling is conducted over 10 meters of suitable edge habitat for about 10 minutes or until sufficient material has been collected. The contents are then emptied into a bucket to await sorting/picking.

Ideally, the sampled content from riffles should be kept separate from sampled content from edge habitats, as the macroinvertebrate communities in the two habitat types can be quite distinct from one another and thus not directly comparable (Chessman 2003). However, faced with the changing hydrology and ecology of urban creeks described earlier, it may become necessary to combine riffle and edge habitat samples in the future (Chessman *et al*. 2007). Indeed, a recent study utilised this approach and homogenised macroinvertebrate samples from different habitat types

(Tippler *et al*. 2014). Presently, there are mixed views in the literature with some studies finding riffle habitats as having greater macroinvertebrate sensitivity to water quality impairment, while other studies have found the opposite (Chessman *et al*. 2007). Nonetheless, from a long-term monitoring perspective, there are inherent advantages to focus on sampling edge habitats, since they are almost always present in waterways across Sydney (Chessman *et al*. 2007). Council uses a combination of riffle and edge habitat sampling.

### 6.6 Data collection without sampling

In recognition of the potential impacts on local macroinvertebrate populations from sampling (especially if population is estimated to be small), certain macroinvertebrate species are not collected, but observations are recorded in the field datasheets instead. For example, *Cherax destructor* (common yabby) are not sampled but the number of individuals observed are recorded. Egg-carrying females of *Paratya australiensis* (freshwater shrimp) are another example of individuals that are not collected. Although fish and tadpoles are not invertebrates, observations and accidental sampling of individuals are also recorded before they are quickly released back into the stream. The presence of native fish may provide additional insight into water quality and ecosystem health (ANZECC/AMRCANZ 2000b). For similar reasons, significant native fauna like semi-aquatic reptiles and waterbirds are generally recorded if they are observed, and added to Council's fauna monitoring database.

### 6.7 Picking macroinvertebrates

The sampled contents are emptied from the bucket into white sorting trays. Water is added to keep the biota alive and assist visual identification of macroinvertebrates, which can be difficult to see depending on water quality. Using pipettes and forceps, live macroinvertebrates are picked from the sorting trays and placed into a container filled with 70% ethanol solution for preservation (Environment Australia 2002). The minimum picking time is 40 minutes. However, if new taxa are continuing to be found, continue picking up to 60 minutes (DEC 2004). Typically, a good sample size contains a minimum of 100 individuals and preferably 150-200 individuals (Chessman 2003). Care is taken to avoid bias towards macroinvertebrates that are easier to pick because of their size, colour or level of activity/movement speed. For families that are found to be highly abundant, efforts are made to limit the number of specimens to no more than 20 individuals. This is because more information on water quality can be known from family diversity rather than family abundance; hence there is little value in counting more than 20 individuals of the same families (this will be apparent from the calculation of the index that grades macroinvertebrates, see Chessman (2003)). When there is a sufficient sample collected (around 100 specimens), all unused biota are returned to the stream in order to minimise the ecological and population impacts of sampling.

### 6.8 Analysis of water and macroinvertebrate samples

The methodology described above is followed for each monitoring site. At the end of each day of sampling, the cooler containing the water samples and ice bricks is sent to the contract laboratory for physical, chemical and microbiological analyses. The current detection limits for key water quality parameters are summarised in Table 2 (for brevity not all parameters are shown, refer to Appendix B for the complete list). The macroinvertebrate samples are preserved in ethanol and do not require immediate analysis. At the end of the sampling period (i.e. end of spring or autumn) they are sent to an environmental consultancy for identification using a microscope and a range of Australian freshwater invertebrate taxonomic keys.

**Table 2.** Key water quality parameters and current detection limits

| Water Quality Parameter | Current Detection Limit | |
|---|---|---|
| pH | 0.01 | |
| Electrical Conductivity @ 25°C | 1 | μS/cm |
| Turbidity | 0.1 | NTU |
| Total Hardness as $CaCO_3$ | 1 | mg/L |
| Total Alkalinity as $CaCO_3$ | 1 | mg/L |
| Sulfate as SO4 - Turbimetric | 1 | mg/L |
| Chloride | 1 | mg/L |
| Fluoride | 0.1 | mg/L |
| Trace Metals | various | |
| Cations | various | |
| Anions | various | |
| Ammonia as N | 0.01 | mg/L |
| Nitrite as N | 0.01 | mg/L |
| Nitrate as N | 0.01 | mg/L |
| Total Nitrogen as N | 0.1 | mg/L |
| Total Phosphorus as P | 0.01 | mg/L |
| Reactive Phosphorus as P | 0.01 | mg/L |
| Faecal Coliforms | 1 | CFU/100mL |
| Escherichia coli | 1 | CFU/100mL |
| Coliforms | 1 | CFU/100mL |

## 7. Assessing Stream Health

### 7.1 Assessing water quality and aquatic ecosystem health

A water quality guideline is a numerical concentration limit or narrative statement recommended to support and maintain a designated water use (ANZECC/ARMCANZ 2000a). Guideline trigger values are derived to provide confidence that there will be no significant impact on environmental values as long as they are not exceeded (ANZECC/ARMCANZ 2000a). When trigger values are exceeded this could mean that an impact has already occurred or that there is potential for impact to occur; thus requiring appropriate management responses such as investigation, prevention and remediation (ANZECC/ARMCANZ 2000a). Given the tremendous diversity of aquatic habitats, trigger values are more informative when they are refined to account for regional, local and even site-specific environmental factors and variability (ANZECC/ARMCANZ 2000a). This is particularly relevant for Ku-ring-gai where highly localised environments have experienced environmental degradation, yet lack intact representative habitats for comparison (Findlay *et al*. 2005). To account for natural, localised environmental baselines and variability, Council has developed multiple sets of trigger values for physical, chemical and biological stressors (hereafter "water quality indicators") as a grading system (Table 3) that provides an indication for water quality and aquatic ecosystem health (Table 4).

**Table 3.** Regional Environmental Health Values (REHVs) and grades for key water quality indicators developed for Ku-ring-gai

| Physical/Chemical water quality indicators | Grade A | Grade B | Grade C | Grade D | Grade F |
|---|---|---|---|---|---|
| pH | 5.11 – 6.86 | 4.8 – 5.1, 6.87-7.4 | 4 – 4.79, 7.41 - 8 | | 0 - 3.99, 8.01 - 12 |
| Electrical Conductivity (µs/cm) | 156 - 350 | 144 – 155, 351 - 404 | 128 – 143, 405 - 457 | 112 – 127, 458 - 510 | 0 – 111, > 511 |
| Turbidity (NTU) | < 7.79 | 8.79 – 11.02 | 11.03 – 13.36 | 13.37 - 25 | > 25.01 |
| Dissolved Oxygen (%) | > 76 | 67 - 75 | 57 - 66 | 21 - 56 | < 20 |
| Ammonium Nitrogen ($NH_x$) (mg/L) | < 0.0200 | 0.0201 – 0.0370 | 0.0371 – 0.0385 | 0.0386 – 0.0400 | > 0.0401 |
| Oxidised Nitrogen ($NO_x$)(mg/L) | < 0.05 | 0.06 – 0.11 | 0.12 – 0.15 | 0.16 – 0.18 | > 0.19 |
| Total Nitrogen (mg/L) | < 0.40 | 0.41 – 0.50 | 0.51 – 0.60 | 0.61 – 0.70 | > 0.71 |
| Total Phosphorus (mg/L) | < 0.010 | 0.011 – 0.025 | 0.026 – 0.060 | 0.061 – 0.080 | > 0.081 |
| Faecal Coliforms (CFU/100ml) | < 150 | 151 - 600 | 601 - 1000 | 1001 - 4000 | > 4001 |
| SIGNAL 2 Score | > 5.44 | 4.68 – 5.43 | 4.17 – 4.67 | 3.16- 4.16 | < 3.15 |

These derived trigger values are known as Regional Environmental Health Values (REHVs). For each water quality indicator, the average value of the field measurements and/or the numerical value of the laboratory result[2] places it within a particular grading of A, B, C, D or F (Table 3). An indicator grade of A implies that the characteristics of water quality described by the indicator are equivalent to reference conditions, i.e. the highest water quality standards and/or ecological health. Moving lower from grades B through to F implies that water quality and/or aquatic ecosystem health is becoming increasingly impaired (Table 4).

These grades are used to provide an indication of the aquatic ecosystem health at monitoring sites, and by extension, the health of the waterways in each of Ku-ring-gai's major catchments. This summary is presented as an annual/seasonal water

[2] For laboratory measurements, if the result is a concentration so low that it is below the limit of detection using the appropriate method of testing (Table 2 and Appendix B), the measurement assumes a value that is exactly half the value of the limit of detection (e.g. if the limit of detection is 0.01 mg/L then the measurement is recorded as 0.005 mg/L).

quality report card which provides an overview of the health of Ku-ring-gai's aquatic ecosystems (see section 7.5).

**Table 4.** Water quality and aquatic ecosystem health as reflected by the associated indicator grade, adapted from Hornsby Shire Council (HSC 2012)

| Health grade | Ecological health description | Cleanliness of stream | Probable adverse impact on biota |
|---|---|---|---|
| A | Excellent | Clean | None |
| B | Good | Slightly degraded | Mild impairment |
| C | Fair | Moderately degraded | Moderate impairment |
| D | Poor | Seriously degraded | Serious impairment |
| F | Very Poor | Severely degraded | Severe impairment |

## 7.2 Deriving and refining Regional Environmental Health Values

ANZECC/ARMCANZ guidelines suggest using the 80$^{th}$ and 20$^{th}$ percentiles of reference site data distribution as an appropriate range for determining REHVs (ANZECC/ARMCANZ 2000a). This method requires multiple samples to be collected from each reference site over an extensive period of time, in order to derive reliable percentile values for each water quality indicator. However, due to limited resources Council has been unable to conduct sampling at all sites on a monthly basis, as recommended by the Guidelines (ANZECC/ARMCANZ 2000a). Instead, sampling is conducted twice a year (as described in section 5.1). The limitations of a biannual sampling frequency mean that the dataset is not large enough for a robust statistical grading system that is solely based on percentile values.

Following a literature review on similar water quality monitoring programs (Storey *et al*. 2007, Wright 2011, GRCCC 2015, Connolly *et al*. 2013, BMCC 2014), Council developed a grading system for each water quality indicator using a combination of data from Ku-ring-gai's reference and urban monitoring sites (1998-2013), ANZECC/ARMCANZ guidelines and trigger values from neighbouring Hornsby Shire Council (HSC 2012). For each water quality indicator, the values delineating the 95$^{th}$, 80$^{th}$, 20$^{th}$ and 5$^{th}$ percentiles from reference and urban site data are plotted onto a floating bar graph (similar to a box-and-whisker plot). Using professional judgement (Box 1), a range of values are determined to form the lower and upper limits of each indicator grade. This process may adopt values similar to those in the ANZECC/ARMCANZ guidelines and/or Hornsby Council's REHVs; however, modifications may be made depending on the ecological significance of the percentile values in a local and regional context, and the statistical distribution of data for Ku-ring-gai's reference and urban sites.

**Box 1.** Example of deriving REHVs for a water quality indicator: pH

From ANZECC/ARMCANZ guidelines:
"*professional judgement — may be used in cases where it will not be possible to obtain appropriate data for a reference ecosystem because insufficient study has been undertaken to provide an adequate data base. Such judgement should be supported by appropriate scientific information (e.g. information from 1992 ANZECC guidelines or other guideline documents, e.g. Hart 1974, Alabaster & Lloyd 1982, USEPA 1986, CCREM 1991), and the scientific literature.*"

The general process of applying professional judgement to derive REHVs involves two stages.

**Stage 1 – Plotting key percentiles of reference and urban site data**

Key percentiles from all reference site and urban site data (1998 - 2013) are plotted in a floating bar graph displaying:

- the 5th and 95th percentiles for reference sites (Reference Trigger Values);
- the 20th and 80th percentiles for reference sites (Reference Water Quality Guidelines);
- the 5th and 95th percentiles for urban sites (Urban Trigger Value); and
- the 20th and 80th percentiles for urban sites (Urban Water Quality Guideline).

**Stage 2 – Setting REHVs using key percentiles and other available scientific data**

Some of these percentile values may be used in defining the lower and upper limits of indicator grades; for the example of pH, the 5th and 95th percentile values were used to define the REHVs for the indicator grade of A. Other values from ANZECC/ARMCANZ guidelines and Hornsby Council have also been adopted, as documented in the table of REHVs (Appendix A).

It should also be noted that not all indicator grades are used for each parameter, e.g. for pH there are no REHVs associated with a D grade.

| Indictor grade | Lower limit of indicator grade | Explanatory notes | Upper limit of indicator grade | Explanatory notes |
|---|---|---|---|---|
| F | 0.00 | | 3.99 | |
| C | 4.00 | Lowest recording at a reference site for Ku-ring-gai | 4.79 | |
| B | 4.80 | Lowest trigger value for pH used by Hornsby Council | 5.10 | |
| A | 5.11 | 5th percentile trigger value for reference sites for Ku-ring-gai | 6.86 | 95th percentile trigger value for reference sites for Ku-ring-gai |
| B | 6.87 | | 7.40 | 80th percentile value for urban sites in Ku-ring-gai; as suggested by ANZECC/ARMCANZ guidelines |
| C | 7.41 | | 8.00 | ANZECC/ARMCANZ guideline upper limit for pH for upland rivers in South-eastern Australia |
| F | 8.01 | | 12.00 | |

For example, an examination of pH across Ku-ring-gai suggests that water is naturally slightly acidic (90% of reference site data has a pH between 5.11 and 6.68, Box 1). The overall phenomenon of naturally dilute, acidic, and poorly buffered water at all reference sites was previously noted in Wright *et al*. (2007) to be consistent with other similar studies, such as Walsh (2006). In contrast, urban streams tend to be buffered and/or have medium to high alkalinity (Wright *et al*. 2007). In the case of Ku-ring-gai, the 5$^{th}$ and 95$^{th}$ percentile values for reference site data were adopted to be the lower and upper limits of the indicator grade of A, after consideration of percentile values for urban sites, as well as trigger values used by Hornsby and those recommended by ANZECC/ARMCANZ guidelines. More details of the derivation of REHVs for pH are shown in Box 1, and the derivation of all of Ku-ring-gai's REHVs are summarised in Appendix A.

For chemical compounds and heavy metals which are, above specific concentrations, directly toxic to organic life, ANZECC/ARMCANZ guidelines and trigger values have been adopted. Due to the lack of industrial land use, directly toxic substances are typically absent in waterways in the LGA, or in very low concentrations below that of ANZECC/ARMCANZ trigger values. Nonetheless, the laboratory results are continually monitored to safeguard public and environmental health. It should also be noted that not all indicator grades are used for each parameter, such as pH not having any indicator values for a D grade. This is generally due to insufficient information to be able to delineate grade values.

As the amount of data increases, a better representation of the ecological conditions of Ku-ring-gai's waterways is expected to emerge. To ensure that the accuracy of the grading system is enhanced over time, REHVs are to be reviewed every 5 years and adjusted as necessary.

### 7.3 Assessing ecosystem health with a biological water quality indicator

After obtaining the macroinvertebrate identification results from the consultants, Council analyses macroinvertebrate communities for each monitoring site using a scoring system known as SIGNAL 2 (Stream Invertebrate Grade Number Average Level). A SIGNAL 2 score can provide some indication towards the type(s) of pollution and other physical and chemical influences that are affecting macroinvertebrate communities (Chessman 2003).

SIGNAL 2 allocates a grade number between 1 and 10 to every taxonomic family of macroinvertebrates, depending on their sensitivity to and tolerance of pollution (Chessman 2003). Sensitive families receive a higher grade number (10 being the highest) compared to tolerant families, which are allocated a lower grade number (Chessman 2003). A weight factor/multiplier is then applied to the family's grade number, based on how many individuals from that family were sampled. Essentially, this produces a weighted grade that accounts for the observed abundance of each species (by using family as a proxy for species).

The overall SIGNAL 2 score for each site is derived by dividing the sum of all weighted grades by the sum of all weight multipliers (Chessman, Williams and Besley 2007). The numerical value of this score is then assessed against the SIGNAL 2 REHVs developed by Council (Table 3) to determine the overall SIGNAL 2 grade for the site. As with physical and chemical water quality indicators, the ecological health condition reflected by the final SIGNAL 2 grade for a site is shown in Table 4. For a step-by-step outline of SIGNAL 2 grade calculation, refer to Chessman (2003).

### 7.4 Determining overall site grade

For each monitoring site, the determination of a site grade takes into account:

- the physical and chemical characteristics of water samples,
- the laboratory results of microbes present in water samples (using faecal coliforms as a proxy), and
- the calculated SIGNAL 2 score (based on macroinvertebrates present and their abundance).

These three aspects of water quality and aquatic ecosystem health are addressed by the same 10 water quality indicators outlined in Table 3:

i. pH
ii. electrical conductivity
iii. turbidity
iv. dissolved oxygen
v. ammonium nitrogen
vi. oxidised nitrogen
vii. total nitrogen
viii. total phosphorous
ix. faecal coliforms
x. SIGNAL 2

Each of the 10 water quality indicator grades is assigned an indicator score of 9, 7, 5, 3 or 1 for grades of A, B, C, D or F respectively. This produces 10 scores that are averaged to produce a single score (i.e. the average indicator score) for the monitoring site. Based on the numerical value of this average indicator score, an overall site grade is assigned to the monitoring site. This scoring and grading system largely follows the methodology adopted by Hornsby Shire Council, which is summarised in Figure 3 below. Refer to Box 2 for a worked example.

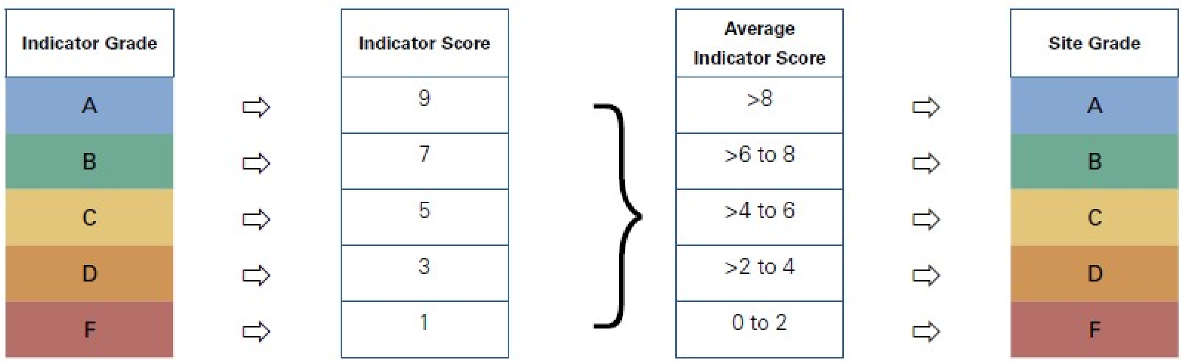


**Figure 3.** Excerpt from Hornsby Shire Council's *Water Quality Companion Technical Report* illustrating the conversion of 10 indicator grades into 10 indicator scores, averaging 10 scores to produce an average indicator score, and the conversion of the average indicator score into an overall site grade.

**Box 2.** Determining the overall site grade for a monitoring site at an example creek

Suppose for this example creek, the field averages and laboratory measurements for the 10 water quality indicators are as follows:

| Example Creek | Electrical Conductivity (µS/cm) | Turbidity (NTU) | Dissolved Oxygen (% saturation) | pH | Ammonium Nitrogen ($NH_x$) (mg/L) | Oxidised Nitrogen ($NO_x$) \(mg/L) | Total Nitrogen (mg/L) | Total Phosphorous (mg/L) | Faecal Coliforms (CFU/100mL) | SIGNAL 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Result | 271 | 1.6 | 65.63 | 6.98 | 0.04 | 0.89 | 1.30 | 0.11 | 470 | 3.78 |

Using the REHVs (Table 3), an indicator grade can be determined for each of the 10 water quality indicators:

| Example Creek | Electrical Conductivity (µS/cm) | Turbidity (NTU) | Dissolved Oxygen (% saturation) | pH | Ammonium Nitrogen ($NH_x$) (mg/L) | Oxidised Nitrogen ($NO_x$) \(mg/L) | Total Nitrogen (mg/L) | Total Phosphorous (mg/L) | Faecal Coliforms (CFU/100mL) | SIGNAL 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Indicator Grade | A | A | C | B | D | F | F | F | B | C |

The indicator grades are then converted into indicator scores, with a grade of A assigned a score 9, B assigned as 7, C as 5, D as 3, and F as 1:

| Example Creek | Electrical Conductivity (µS/cm) | Turbidity (NTU) | Dissolved Oxygen (% saturation) | pH | Ammonium Nitrogen ($NH_x$) (mg/L) | Oxidised Nitrogen ($NO_x$) \(mg/L) | Total Nitrogen (mg/L) | Total Phosphorous (mg/L) | Faecal Coliforms (CFU/100mL) | SIGNAL 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Indicator Score | 9 | 9 | 5 | 7 | 3 | 1 | 1 | 1 | 7 | 5 |

Now that there are 10 indicator scores, the arithmetic mean is taken to give an average indicator score, which in this example is 4.8:

i.e. $(9 + 9 + 5 + 7 + 3 + 1 + 1 + 1 + 7 + 5) \div 10 = 4.8$

Finally, following the method shown in Figure 3, the overall site grade is derived. Because 4.8 is greater than 4 but less than 6, this corresponds to a site grade of C. The above worked example actually represents the Spring 2015 stream health for Lovers Jump Creek. The results suggest that there are elevated levels of nitrogen and phosphorous-based compounds, which may be due to urban runoff, or potentially from other sources. If, for example, this appears to be a trend that continues over multiple, consecutive sampling seasons, investigation and management actions may be warranted.

## 7.5 Water quality report card

The water quality report card is an annual/seasonal summary of the water quality and ecosystem health of monitoring sites, and can be taken as a representative picture of the overall stream health of waterways and catchments in Ku-ring-gai. An example is shown in Figure 4 below.

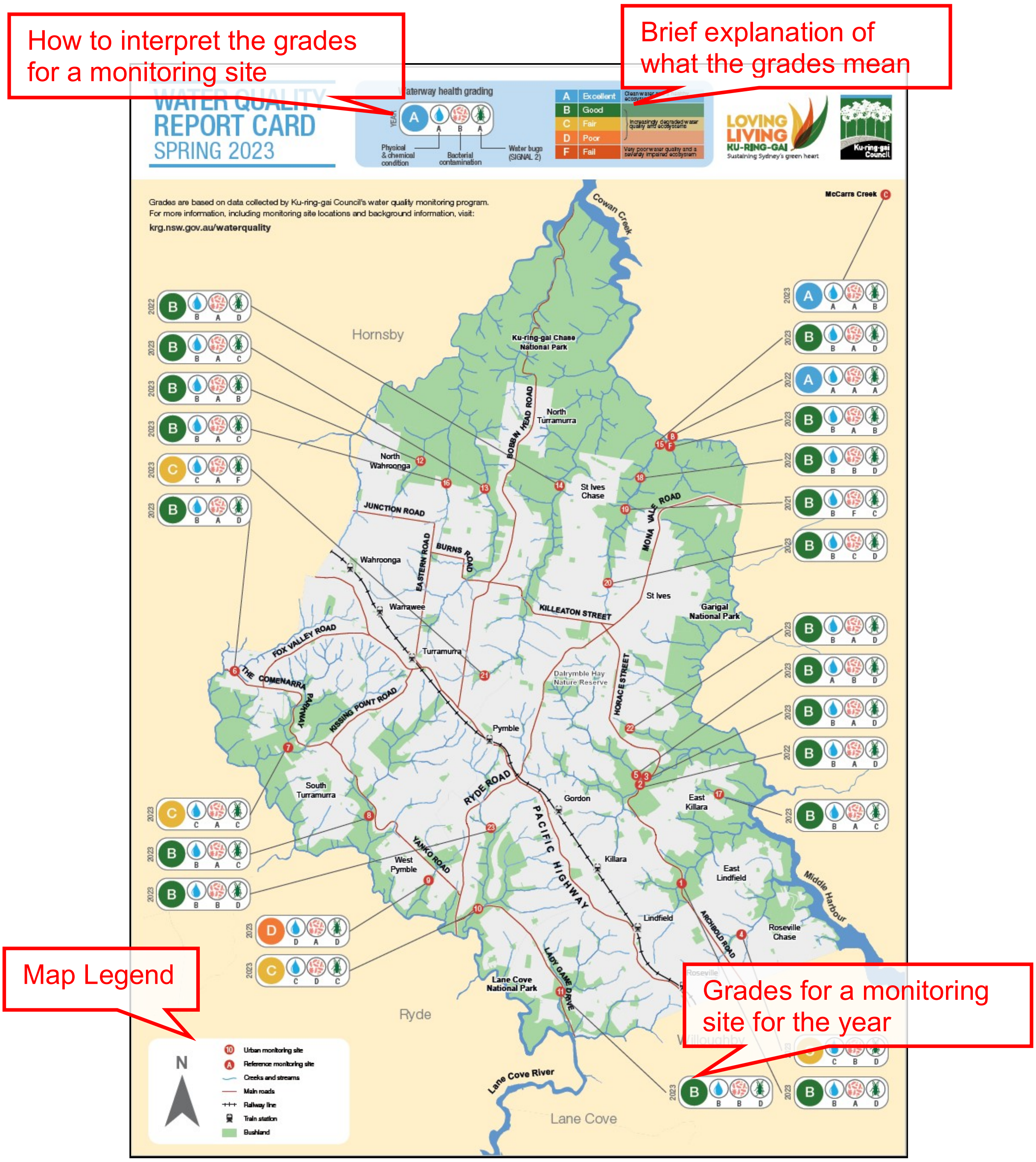


**Figure 4.** Water quality report card for the Spring 2023 sampling season, with explanations.

Each monitoring site is shown on the map, and has four grades associated with it, which are (from left to right):

- the overall site grade
- a grade for physical and chemical qualities
- a grade for faecal coliforms (microbiological water quality)
- a SIGNAL 2 grade (macroinvertebrate health)

The latter three grades correspond to the same three aspects of water/ecosystem health described in section 7.4.

It should be noted that the grade for physical and chemical qualities comprises electrical conductivity, turbidity, dissolved oxygen, pH, NHx, NOx, total nitrogen, and total phosphorous. These eight water quality indicators are scored according to their grades, averaged to produce an average score, which is then converted into a single grade for physical and chemical qualities. This is the same process used derive the overall site grade, which was outlined in Box 2.

Since not all of the monitoring sites are sampled every sampling season, some of the grades will be from previous years even if they are the most recent grades available. Because of this, the year in which monitoring was last undertaken is shown on the left of the overall site grade.

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## Appendix A. Regional Environmental Health Values for Ku-ring-gai.

| pH | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| F | 0 | 3.99 |
| C | 4.00 | 4.79 |
| B | 4.8 (Hornsby Trigger) | 5.10 |
| A | 5.11 | 6.86 (95th percentile – Reference sites) |
| B | 6.87 | 7.40 (80th percentile – Urban sites) |
| C | 7.41 | 8.00 (ANZECC) |
| F | 8.01 | 12.00 |

| Electrical Conductivity (µs/cm) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| F | 0 | 111 |
| D | 112 | 127 |
| C | 128 | 143 |
| B | 144 (95th percentile – Reference sites) | 155 |
| A | 156 (20th percentile – Reference sites) | 350 (ANZECC) |
| B | 351 | 404 |
| C | 405 | 457 |
| D | 458 | 510 |
| F | 511 | 1000 |

| Turbidity (NTU) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 7.79 (80th percentile – Reference sites) |
| B | 8.79 | 11.02 (95th percentile – Reference sites) |
| C | 11.03 | 13.36 (20th percentile – Urban sites) |
| D | 13.37 | 25 (ANZECC) |
| F | 25.01 | 100 |

| Dissolved Oxygen (% saturation) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 76 (80th percentile – Reference sites) | 150 |
| B | 67 (Median – Urban sites) | 75 |
| C | 57 (95th percentile – Reference sites) | 66 |
| D | 21 (20th percentile – Urban sites) | 56 |
| F | 0 | 20 |

| $NH_x$ (mg/L) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 0.02 (Median – Reference sites) |
| B | 0.0201 | 0.037 (95th percentile – Reference sites) |
| C | 0.0371 | 0.0385 |
| D | 0.03886 | 0.04 (Median – Urban sites) |
| F | 0.0401 | 5 |

| $NO_x$ (mg/L) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 0.05 (Hornsby trigger) |
| B | 0.051 | 0.104 (95th percentile – Reference sites) |
| C | 0.105 | 0.1745 |
| D | 0.1755 | 0.245 (Median – Urban sites) |
| F | 0.246 | 5 |

| Total Nitrogen (mg/L) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 0.4 (95th percentile – Reference sites) |
| B | 0.41 | 0.5 (ANZECC) |
| C | 0.51 | 0.6 |
| D | 0.61 | 0.7 (Median – Urban sites) |
| F | 0.71 | 5 |

| Total Phosphorous (mg/L) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 0.01 (Hornsby trigger) |
| B | 0.011 | 0.025 (ANZECC) |
| C | 0.026 | 0.06 (Median – Reference sites) |
| D | 0.061 | 0.08 (Median – Urban sites) |
| F | 0.081 | 5 |

| Faecal Coliforms (cfu/100mL) | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 0 | 150 (ANZECC primary contact - Median) |
| B | 151 | 600 (Primary contact - Maximum) |
| C | 601 | 1,000 (Secondary contact - Median) |
| D | 1,001 | 4,000 (Secondary contact - Maximum) |
| F | 4,001 | 20,000 |

| SIGNAL 2 | Lower limit of indicator grade | Upper limit of indicator grade |
|---|---|---|
| A | 5.44 (Median – Reference sites) | 10 |
| B | 4.68 | 5.43 |
| C | 3.92 | 4.67 |
| D | 3.16 | 3.91 |
| F | 0 | 3.15 (20th percentile – Urban sites) |

## Appendix B. Testing methods and detection limits for water quality parameters (up-to-date as of Jan 2024)

| Water Quality Parameter | Detection Limit | | Testing Method Reference |
|---|---|---|---|
| pH | 0.01 | | APHA 4500 $H^+$ - B |
| Sodium Adsorption Ratio | 0.01 | mg/kg | APHA 3120B Ca, Mg, Na |
| Electrical Conductivity @ 25°C | 1 | µS/cm | APHA 2510 B |
| Total Dissolved Solids | 1 | mg/L | In-house by contract laboratory (E.C. multiplied by 0.65) |
| Suspended Solids | 5 | mg/L | APHA 2540 D |
| Turbidity | 0.1 | NTU | APHA 2130 B |
| Total Hardness as $CaCO_3$ | 1 | mg/L | APHA 2340 B |
| Hydroxide Alkalinity as $CaCO_3$ | 1 | mg/L | APHA 2320 B |
| Carbonate Alkalinity as $CaCO_3$ | 1 | mg/L | APHA 2320 B |
| Bicarbonate Alkalinity as $CaCO_3$ | 1 | mg/L | APHA 2320 B |
| Total Alkalinity as $CaCO_3$ | 1 | mg/L | APHA 2320 B |
| Sulfate as SO4 - Turbimetric | 1 | mg/L | APHA 4500 $SO_4$-E |
| Chloride | 1 | mg/L | APHA 4500-$Cl^-$ -G |
| Dissolved Calcium | 1 | mg/L | ICP/MS/CV/FIMS |
| Dissolved Magnesium | 1 | mg/L | ICP/MS/CV/FIMS |
| Dissolved Sodium | 1 | mg/L | ICP/MS/CV/FIMS |
| Dissolved Potassium | 1 | mg/L | ICP/MS/CV/FIMS |
| Total Aluminium | 0.01 | mg/L | ICP/MS/CV/FIMS |
| Total Arsenic | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Boron | 0.05 | mg/L | ICP/MS/CV/FIMS |
| Total Barium | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Beryllium | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Cadmium | 0.0001 | mg/L | ICP/MS/CV/FIMS |
| Total Cobalt | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Chromium | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Copper | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Iron | 0.05 | mg/L | ICP/MS/CV/FIMS |
| Total Manganese | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Nickel | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Lead | 0.001 | mg/L | ICP/MS/CV/FIMS |
| Total Selenium | 0.01 | mg/L | ICP/MS/CV/FIMS |
| Total Vanadium | 0.01 | mg/L | ICP/MS/CV/FIMS |
| Total Zinc | 0.005 | mg/L | ICP/MS/CV/FIMS |
| Total Mercury | 0.0001 | mg/L | ICP/MS/CV/FIMS |
| Fluoride | 0.1 | mg/L | APHA 4500-$F^-$C |
| Ammonia as N | 0.01 | mg/L | APHA 4500 $NH_3^-$ - G |
| Nitrite as N | 0.01 | mg/L | APHA 4500 $NO_2^-$ - I |
| Nitrate as N | 0.01 | mg/L | APHA VCl3 reduction 4500 $NO_3^-$ + $NO_2^-$B |
| Nitrite + Nitrate as N | 0.01 | mg/L | APHA VCl3 reduction 4500 $NO_3^-$ + $NO_2^-$B |
| Total Kjeldahl Nitrogen as N | 0.1 | mg/L | APHA 4500 $N_{org}$ – D + APHA 4500 $NH_3^-$G |
| Total Nitrogen as N | 0.1 | mg/L | APHA 4500 $N_{org}$/$NO_3$ |
| Total Phosphorus as P | 0.01 | mg/L | APHA 4500 P - F |
| Reactive Phosphorus as P | 0.01 | mg/L | APHA 4500 P - F |
| Total Anions | 0.01 | meq/L | In-house by contract laboratory |
| Total Cations | 0.01 | meq/L | APHA 3120B or 3125B |
| Faecal Coliforms | 1 | CFU/100mL | AS 4276.7-2007 |
| Escherichia coli | 1 | CFU/100mL | AS 4276.7-2007 |
| Coliforms | 1 | CFU/100mL | AS 4276.5-2007 |

# Appendix C. List of monitoring sites for Ku-ring-gai

| Site ID | Creek Name | Code | Historical Location Description |
|---|---|---|---|
| **Reference monitoring sites** | | | |
| **A** | Deep Creek | **DC** | Left bank tributary, Garigal National Park (not in use since 2007) |
| **B** | Cowan Creek / Keirans Creek | **CO** | Left bank tributary, Ku-ring-gai Wildflower Garden |
| **C** | McCarrs Creek | **MC** | At McCarrs Creek Road Bridge, Ku-ring-gai Chase National Park |
| **D** | Little Cattai Creek | **LCC** | At Paulls Road, South Maroota (Not in use since 2003) |
| **E** | Salvation Creek | **SC** | West Head Road, Ku-ring-gai Chase National Park (Not in use since 2007) |
| **F** | Tree Fern Gully Creek | **TF** | In Ku-ring-gai Wildflower Garden, St Ives |
| **Urban monitoring sites** | | | |
| **1** | Gordon Creek | **GO** | At Eastern Arterial Road |
| **2** | Rocky Creek Upper | **RU** | 100 m upstream of High Ridge Creek junction |
| **3** | Rocky Creek | **RO** | 100 m downstream of High Ridge Creek junction |
| **4** | Moores Creek | **MO** | Off Carlyle Road |
| **5** | High Ridge Creek | **HR** | |
| **6** | Coups Creek (Upper) | **CP** | 100 m downstream of Comenarra Parkway |
| **7** | Fox Valley Creek | **FV** | 100 m upstream of Lane Cove River |
| **8** | Avondale Creek | **AV** | At Comenarra Parkway |
| **9** | Quarry Creek | **QU** | 100 m downstream of Yanko Road |
| **10** | Blackbutt Creek | **BB** | Downstream of Lady Game Drive |
| **11** | Little Blue Gum Creek | **LBG** | At Lady Game Drive |
| **12** | Fraser Brook | **FR** | Off Barton Cresent |
| **13** | Lovers Jump Creek | **LJ** | Off Clissold Road |
| **14** | (South) Branch of Cowan Creek | **BC** | Off Timbarra Road |
| **15** | Ku-ring-gai Creek (Lower/downstream) | **KU-L** | At Ku-ring-gai Wildflower Garden |
| **16** | Caley Brook | **CA** | |
| **17** | Southern Creek | **SO** | Old She-Oak Reserve, East Killara |
| **18** | Ku-ring-gai Creek (Above Falls) | **KU-AF** | |
| **19** | Ku-ring-gai Creek (Warrimoo Track) | **KU-WAR** | Also referred to as Ku-ring-gai Creek (Mid) |
| **20** | Ku-ring-gai Creek (Upper/upstream) | **KU-U** | |
| **21** | Bannockburn Park | **BAN** | |
| **22** | Barra-Brui Creek | **BBR** | |
| **23** | Blackbutt-Minamurra | **MIN** | |