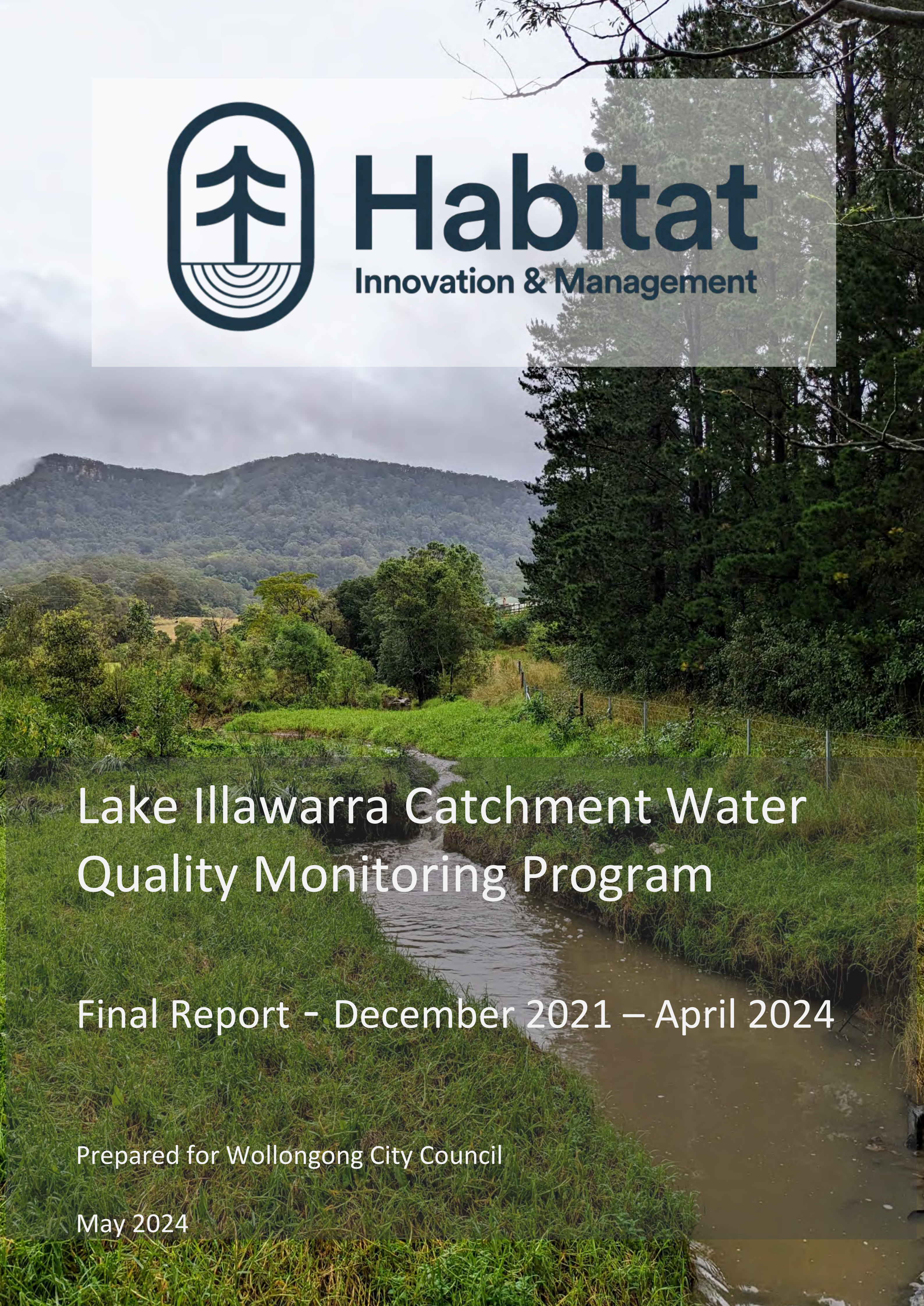

Habitat Innovation & Management

Lake Illawarra Catchment Water Quality Monitoring Program

Final Report - December 2021 – April 2024

Prepared for Wollongong City Council

May 2024

Document Tracking

Project	Lake Illawarra Catchment Water Quality Monitoring. Final Report December 2021 – April 2024	
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Table of Contents

Figures

Tables

Executive Summary

As part of Wollongong and Shellharbour City Council's water quality monitoring program, Habitat Innovation and Mangment were engaged to assess waterways throughout the Lake Illawarra catchment. A summary of the findings from waterway monitoring conducted from December 2021 to April 2024 from 21 sites are presented in this report.

Surveys were conducted to measure water quality at 21 sites over 14 dry weathering sampling events and 11 wet weather monitoring events. Water quality samples were collected from all 21 sites, which included measuring *in-situ* physicochemical water quality parameters of dissolved oxygen, turbidity, electrical conductivity, pH, and water temperature. Surface water grab samples were collected for analysis of total suspended solids, ammonia - nitrogen, nitrates-nitrites, total nitrogen, total phosphorus, phosphate (PO_4^{-3}), chlorophyll-*a*, and *Enterococci* (CFU/100 mL). Data was compared between wet and dry weather monitoring events, and against the ANZECC (2000) guidelines for Aquatic Ecosystems (Lowland River in south-eastern Australia).

Water quality in the streams and rivers of the Lake Illawarra catchment ranged from 'good' to 'fair', with most sites experiencing 'fair' water quality. The relatively healthy scores experienced by waterways within the Lake Illawarra catchment are influenced by naturally vegetated areas present at the headwaters of streams that flow into Lake Illawarra. Moving downstream, land use becomes more intense, shifting from bushland, to farmland to the urban environment. This shift in land use corresponds to a reduction in water quality.

Comparison of median water quality results from the Lake Illawarra catchment waterway sites with the appropriate ANZECC (2000) guidelines shows that all sites were non-compliant with at least one water quality guideline throughout the monitoring period (Table 4 - Table 9). Throughout the December 2021 to April 2024 monitoring period, waterways with catchments dominated by urbanisation or industrial land use were typically found to have elevated electrical conductivity and depleted dissolved oxygen. The majority of sites were within the ANZECC (2000) guideline values for pH, with the exclusion of M5 (maximum of 8.24 pH units during dry weather monitoring). Median electrical conductivity was compliant with the ANZECC (2000) guideline at one site (F1) during dry weather monitoring and five sites (DA1, F1, R3, SCC5, and SCC6) of the 21 sites during wet weather monitoring, however, high electrical conductivity results are linked with saline water in this catchment as the estuary is brackish. Median dissolved oxygen was compliant with the ANZECC (2000) guideline at only three of the 21 sites (F1, M5, and SCC6) during dry and wet weather monitoring. Median turbidity was compliant with the ANZECC (2000) guidelines at all sites on all occasions (during both wet and dry weather monitoring).

Increased levels of nutrients above the ANZECC (2000) water quality guidelines were recorded at the majority of sites. Total nitrogen did comply with the ANZECC (2000) guidelines at only three sites during dry weather

monitoring (DA1, F1, and R3). During wet weather monitoring, median total nitrogen was compliant with the ANZECC (2000) guideline at only one site, F1. Ammonia concentrations were compliant with the ANZECC (2000) guidelines at five sites during dry weather monitoring. The compliant sites were D1, D2, F1, M5, and R3. During wet weather monitoring, median ammonia levels were compliant with the ANZECC (2000) guideline at three sites (DA1, F1, and R3). Concentrations of nitrate and nitrite as N (NOx) were compliant with the ANZECC (2000) guidelines at five sites during dry weather monitoring (BD1, D1, D2, H1, and SCC1). During wet weather monitoring, median NOx concentrations were non-compliant at all sites.

Median total phosphorus concentrations were compliant with the ANZECC (2000) guidelines at six sites (DA1, F1, M5, R3, SCC5, and SCC6) throughout dry weather monitoring events. During wet weather monitoring, median total phosphorus levels were compliant with the ANZECC (2000) guideline at two out of 21 sites (F1 and M5). Median phosphate concentrations did not comply with the ANZECC (2000) guidelines at two sites during dry weather monitoring (SCC2 and MIN1). During wet weather monitoring, median phosphate was non-compliant with the ANZECC (2000) guideline at eight out of 21 sites, including at B1, BD1, H1, MIN1, SCC1, SCC2, SCC3, and SCC5.

Seventeen sites recorded *Enterococci* that exceeded the ANZECC (2000) primary contact guideline of 35 CFU/100 mL during dry weather monitoring and one site (M5) was above the primary guideline during wet weather monitoring. Three sites recorded *Enterococci* that exceeded the ANZECC (2000) secondary contact guideline of 230 CFU/100 mL during dry weather monitoring and 20 sites (excluding M5) were above the secondary guideline during wet weather monitoring. Mean chlorophyll-*a* levels did not comply with the ANZECC (2000) guidelines for all 21 sites across both dry and wet weather monitoring events. No ANZECC (2000) guidelines are currently available for total suspended solids (TSS) and temperature.

Overall, these findings highlight that whilst urban areas reflect a significant contribution of contaminants to the sites in the lower region of the Lake Illawarra catchment, sites in the upper reaches of the catchment that experience rural land use are also sources of degraded water quality. Across all sites within the Lake Illawarra catchment, sites in the lower catchment area had consistently higher electrical conductivity (which is expected due to estuarine conditions), nutrient concentrations (including ammonia, NOx, total nitrogen, and total phosphorus), total suspended solids, turbidity, chlorophyll-a, and *Enterococci*. These sites are in predominantly urban, peri-urban, and industrial areas of the catchment. During wet weather, there was an increase in nutrients (particularly NOx), total suspended solids, and *Enterococci* in lower catchment sites. This reflects nutrients and biological contaminants being washed downstream into the Lake Illawarra system following rainfall. Conversely, pH and NOx were higher in sites located in the upper reaches of the catchment, which have higher vegetation cover in the catchment but also includes rural land use.

During dry weather monitoring, the catchments with the highest median values that reflect a significant contribution to the Lake Illawarra catchment for each assessed parameter were Reid Creek for pH and turbidity, whereas electrical conductivity, ammonia, NOx, and *Enterococci* were highest for the Macquarie

Rivulet catchment, and Estuarine sites had the lowest dissolved oxygen and the highest total nitrogen, total phosphorus, chlorophyll-*a*, and total suspended solids. Phosphate was low across all sites during dry weather monitoring. During wet weather monitoring, Mullet Creek had the highest median pH, whereas median turbidity, ammonia, NOx, total nitrogen, and *Enterococci* were highest at Reid Creek sites. Estuarine sites had the lowest dissolved oxygen and the highest electrical conductivity, total phosphorus, phosphate, and total suspended solids. Total nitrogen and chlorophyll-*a* were both elevated at sites within the Reid Creek and Estuarine catchments.

Contaminants which alter water quality typically enter waterways via directly connected impervious surfaces collected and discharged from stormwater systems. Stormwater is a major source of pollutants. Many materials are washed from urban and industrial land uses into waterways through traditional concrete stormwater infrastructures, which are designed with a single focus of "efficient drainage" with no consideration of replicating the stream function that would occur in natural waterways. Surrounding urban and industrial land uses, plus reduced buffering capacity through removal of riparian vegetation, are typically associated with degraded water quality and aquatic ecosystems. The impacts of rural and agricultural land use can also impact water quality, for example contributing to elevated nutrient levels, increased erosion due to stock access, and increasing the presence of faecal coliforms in waterways.

For waterways in the Lake Illawarra catchment, there are multiple impacts owing to intensified human uses of the landscape surrounding waterways. Mechanisms for impacts on the ecological condition of waterways likely include a combination of altered flow and degraded water quality, and this may have impacts for the biotic community. Altered flow conditions are also a typical symptom of the urban stream syndrome and known to severely degrade aquatic ecosystems.

Introduction

Habitat Innovation and Mangement was commissioned by Wollongong City Council to undertake monitoring across waterways in the Lake Illawarra catchment. This program seeks to provide Wollongong City and Shellharbour City Councils with baseline water quality monitoring data for a number of environmentally and aesthetically important urban and rural creeks within the Lake Illawarra catchment to assist in current and future environmental management and development decisions.

Central to the monitoring program is the assessment of water quality to provide a detailed snapshot of the condition of the waterways within the Lake Illawarra catchment. Monitoring undertaken from December 2021 to April 2024 was conducted using a scientifically robust approach for the assessment of urban waterways.

Monitoring results have been compared between wet and dry weather monitoring events and with the ANZECC (2000) guidelines for Aquatic Ecosystems (Lowland River in south-eastern Australia). Results and recommendations from this assessment provide a platform for the ongoing sustainable management of waterways within the Lake Illawarra catchment.

Study Area

Wollongong Local Government Area (LGA) is located on the southern fringe of the Sydney metropolitan area, 80 km from Sydney's CBD. In 2021, the population of Wollongong was 220,659 residents, with a forecast increase to 252,514 residents by 2032 (Wollongong City Council, 2022). In 2021, the population of Shellharbour was 74,622 residents, with a forecast increase to 102,950 residents by 2041 (Shellharbour City Council, 2022).

Surveys were conducted at 21 sites across 14 waterways within the catchment of Lake Illawarra across the Wollongong and Shellharbour LGA (Table 1; Figure 1). Sample sites were representative of waterways surrounded by major land uses which include urban, new urban release and agricultural/forested, and likely to influence ecological condition which occur in the Lake Illawarra catchment.

Table 1: Lake Illawarra catchment aquatic ecosystem monitoring sites, site code, land use and GPS coordinates.

Sample Site	Site Code	Section	Land Use	Latitude	Longitude
Brooks Creek	B1	Lower	Urban	34˚29’47”S	150˚48’36”E
Budjong Creek	BD1	Lower	Urban	34˚28’45”S	150˚51’17”E
City Park	SCC1	Lake	Urban	34˚33’51”S	150˚49’59”E
Dapto Creek	DA1	Middle	Agriculture/Forested	34˚30’37”S	150˚44’30”E
Duck Creek	D1	Lower	Agriculture/Forested	34˚31’42”S	150˚47’37”E
Duck Creek	D2	Middle	Agriculture/Forested	34˚31’36”S	150˚46’35”E
Forrest Creek	F1	Upper	Agriculture/Forested	34˚27’59”S	150˚49’58”E
Hooka Creek	H1	Lower	Urban	34˚28’58”S	150˚50’20”E
Horsley Creek	SCC3	Upper	Urban	34˚33’52”S	150˚48’13”E
Horsley Creek	SCC4	Entrance	Urban	34˚33’47”S	150˚48’32”E
Macquarie Rivulet	SCC5	Upper	Agriculture/Forested	34˚34’37”S	150˚43’34”E
Macquarie Rivulet	SCC6	Lower	Urban	34˚34’05”S	150˚45’49”E
Minnegang Creek	MIN1	Lower	Urban	34˚29’21”S	150˚52’26”E
Mullet Creek	M1	Lower	New Urban Release	34˚28’44”S	150˚48’35”E
Mullet Creek	M2	Lower	New Urban Release	34˚30’04”S	150˚47’06”E
Mullet Creek	M5	Upper	Agriculture/Forested	34˚30’44”S	150˚43’57”E
Oakey Creek	SCC2	Lower	Urban	34˚33’29”S	150˚49’30”E
Reid Creek	RE1	Lower	Agriculture	34˚28’46”S	150˚47’46”E
Robins Creek	R3	Upper	New Urban Release	34˚28’44”S	150˚48’35”E
Robins Creek	R1	Lower	New Urban Release	34˚29’35”S	150˚45’15”E
Robins Creek	R2	Middle	New Urban Release	34˚29’04”S	150˚46’04”E

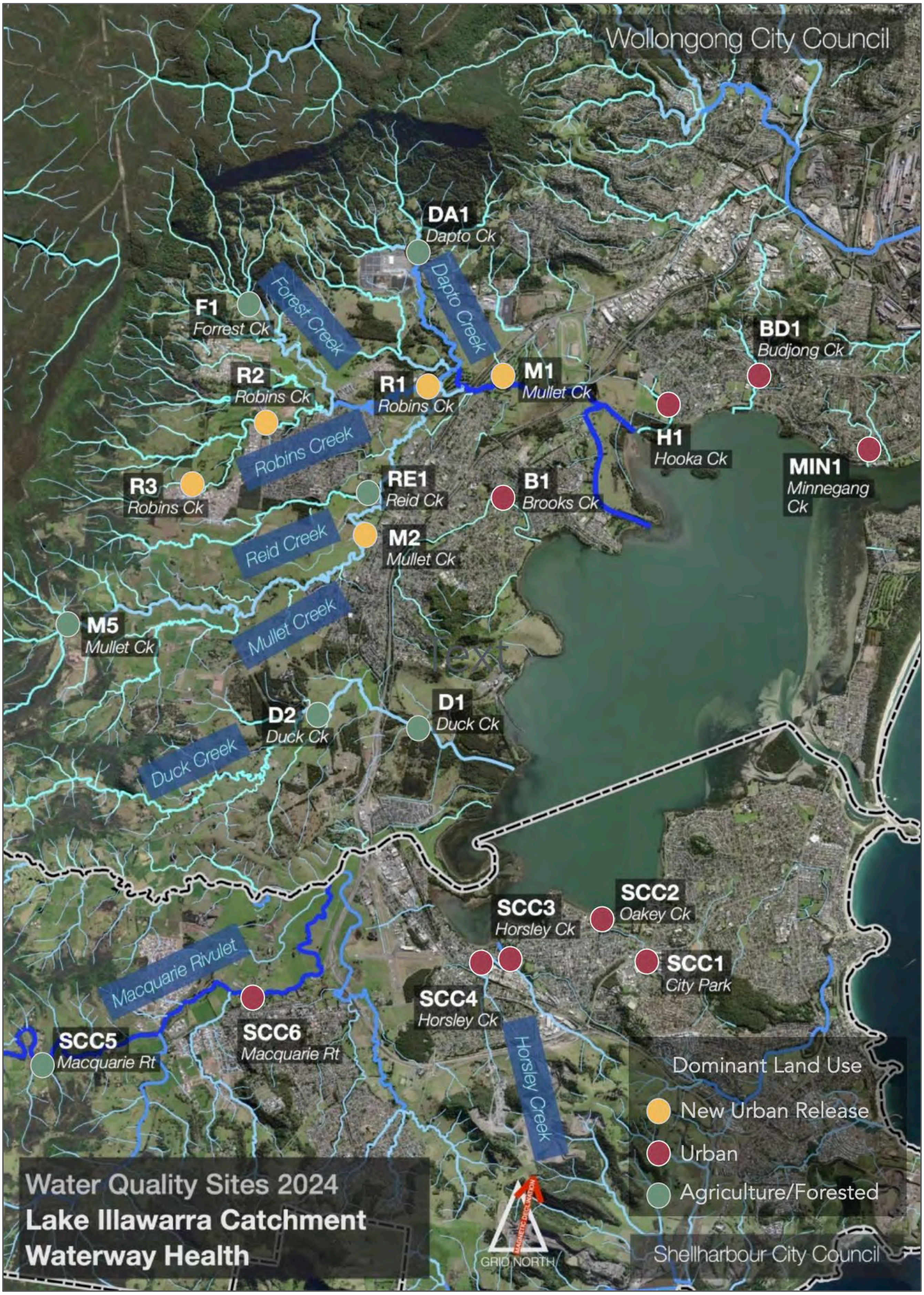

Figure 1: Location of water quality monitoring sites and dominant land use.

Methods

Rainfall

Data from the Bureau of Meteorology (Bellambi AWS Meteorological Station) was used to quantify the rainfall during the 2021-2023 sampling events. Rainfall data has been collected at this station since 1997 (BOM, 2024). Rainfall for the 2023-2024 period was derived from Wollongong City Council for monitoring at Cleveland Rd and Wongawilli MHL stations.

Water quality parameters

Nitrogen

Nitrogen is one of the two major nutrients necessary for primary productivity, the other being phosphorus. However, excessive quantities of these nutrients in waterways can result in an event known as eutrophication and can cause excessive plant growth. When the nutrient supply declines, due to uptake by plants or being washed downstream, dieback of aquatic plants occurs. As the dead organic material decomposes, dissolved oxygen is consumed, and the environment can become anoxic which can result in events such as fish dieback, for example observed by Day *et al.,* (2014).

Inorganic N may exist in the free-state as a gaseous N_2, or as nitrate NO_3^-, nitrite NO_2^- or soluble ammonia NH_3. Organic N, found in proteins, is continually recycled by plants and animals. Concentrations of ammonia, NOx and TN are significant indicators of aquatic ecosystem health (ANZECC, 2000).

Ammonia

Elevated levels of ammonia-nitrogen (NH_3-N) in water can indicate poor water quality (ANZECC, 2000). NH_3 is a metabolic waste product and at high concentrations is toxic to most aquatic life, including fish. NH_3 toxicity to aquatic life increases as pH and temperature increases (ANZECC, 2000). Plants are more tolerant of NH_3 than animals, and invertebrates are more tolerant than fish (ANZECC, 2000). High NH_3 concentrations adversely affect structural development, hatching, and growth rates of fish (Yuen and Chew, 2010).

Most of the NH_3 produced in Australia is used in fertilisers as ammonium sulfate, nitrate, and urea. It is also used in the production of ice and in refrigerating plants, and in household cleaning products. Since NH_3 is a decomposition product from urea and protein, it is found in domestic wastewater; sewage treatment plants (STPs) can be expected to discharge substantial NH_3 loads in their effluents (Monda *et al.,* 1995). Sites downstream of STPs that discharge to waterways can be expected to have elevated NH_3 concentrations (Monda *et al.,* 1995).

NH_3 is monitored here as "ammonia as N (NH_3 –N)" and is a measure of the soluble form of total ammonia. As described in ANZECC (2000), the toxicity of NH_3 is primarily attributed to the un-ionised NH_3 form. The un-ionised NH_3 can penetrate the epithelial membranes of aquatic organisms more readily than ammonium.

This effect is exaggerated where stream pH is elevated which favours the presence of the more toxic NH_3 rather than ammonium (ANZECC, 2000).

Oxides of Nitrogen

The occurrence of high levels of nitrates and nitrites (NO_x-N) is an indicator of various sources of water contamination, including from fertiliser, wastewater, stormwater runoff, leaking septic tanks, manure from livestock, animal wastes and discharges from car exhausts (ANZECC, 2000). As described in ANZECC (2000), organic nitrogen undergoes bacterial degradation and denitrification via NH_3, nitrite, and nitrate, ultimately to elemental nitrogen, as N_2. In oxygen-limited systems, these reactions can stop at NH_3.

As per other nutrients, NO_x can stimulate the growth of phytoplankton, which provides food for higher organisms (invertebrates and fish). However, excess phytoplankton growth can lead to eutrophic conditions, obvious algal overgrowth and oxygen depletion (ANZECC, 2000).

Total Nitrogen

Total Nitrogen (TN) concentration is the sum of NH_3, organic and reduced nitrogen, nitrate and nitrate concentrations. It is regarded by ANZECC (2000) as a key stressor of water-based ecosystems, able to fuel excessive growth of aquatic plants.

Total Phosphorus

Phosphorus (P) is a key element necessary for growth of all plants and animals. Phosphates can exist in multiple forms. All forms of P may exist in solution, as particles, loose fragments or in the bodies of aquatic organisms. As with other nutrients, phosphorus inputs can be derived from natural phenomena and from human activities; with wastewater discharges and diffuse runoff in urban areas normally expected to contribute the largest amounts (ANZECC, 2000).

Phosphates stimulate the growth of plankton and aquatic plants, which provide food for fish. This may cause an increase in the fish population and improve the overall water quality. However, under excess P concentrations, algae and aquatic plants could grow excessively and choke waterways. As with other nutrient inputs promoting excess algal growth, this can lead to eutrophic conditions, algal overgrowth, and oxygen depletion (ANZECC, 2000).

Total phosphorus (TP) is a combination of the readily available and the particle-bound fractions of phosphorus. The latter fraction of P becomes available only under reducing (anoxic) conditions, often in the bottom of poorly mixed lakes. TP is a critical indicator of water quality because P is often the limiting nutrient for cyanobacterial growth (ANZECC, 2000).

Many cyanobacteria can fix atmospheric N_2 through heterocysts, and therefore, N does not limit their growth. On the other hand, P is often the limiting factor for most cyanobacteria. High concentration P inputs are therefore the major concern in pre-disposing waterways to algal blooms. As discussed by the ANZECC

(2000) guidelines, it is not just the concentration of one nutrient that determines algal growth or plant growth, but the sum of the key nutrients (i.e., N and P), together with other factors such as strong sunlight, warm temperatures, stagnant conditions and stable water column conditions.

Many Australian studies have shown that the balance between the nutrients (e.g., the N: P ratio) can influence the composition and abundance of the algal community (Cullen *et al.,* 1993). As described earlier, the ratio of available nutrients is an important determinant of which algal species would flourish during a bloom; with N:P ratios of below ~16:1 presenting favourable conditions for nitrogen-fixing cyanobacteria, such as *Anabaena* and *Cylindrospermopsis* (ANZECC, 2000).

Temperature

Temperature was monitored *in-situ*. Guideline ranges for temperature are highly specific for any given study area, whilst temperature is seasonally dependent and varies through each day, and so no generic guideline is provided in ANZECC (2000) or applied to the temperature data here. As can be expected, temperature variation is primarily seasonally affected, and no substantial water quality effects are expected to result from natural seasonal variation.

pH

pH was monitored *in-situ*. Most of the effects of pH extremes are recorded for water with low pH values, effectively where pH of less than 6.5 pH units is recorded. However, pH is elevated in urban streams of Sydney (Reid and Tippler, 2019). Within ANZECC (2000), the potential implications of waters with elevated pH (i.e., over 8.00 pH units) are not described, but it is noted that almost all water quality guidelines around the world recommend that pH should be maintained in the range 6.50 to 9.00 pH units to protect freshwater aquatic organisms.

Electrical Conductivity

Electrical conductivity (EC) was monitored *in-situ*. EC is a measure of the types of salts (inorganic ions) in the water, including the anions chlorides (Cl^-), sulfates (SO_4^{2-}), carbonates (CO_3^-), phosphates (PO_4^{3-}), and nitrates (NO_3^-), and the cations sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+).

Concentrations of individual ions contributing to these measures can vary in their composition. Measures of salinity and EC broadly indicate whether the chemical nature of aquatic ecosystems has been altered, providing a warning of the potential loss of native biota (ANZECC, 2000).

Dissolved Oxygen

Dissolved oxygen (DO) was monitored *in-situ*. The concentration of DO in water is highly dependent on temperature, salinity, biological activity (microbial, primary production) and the rate of transfer from the atmosphere, which has a much higher concentration of oxygen than water. Under natural conditions, DO levels change, sometimes considerably, during a daily cycle (diurnal change) as aquatic plants release oxygen into water whilst photosynthesising, which occurs through the day but not at night.

Low DO concentration has an adverse effect on many aquatic organisms, including fish, invertebrates, and aerobic microorganisms, which depend upon oxygen dissolved in the water for efficient functioning. Lack of DO creates reducing conditions in sediments, which can release previously sediment-bound nutrients and toxicants to the water column (ANZECC, 2000).

There is currently a lack of consensus as to the effect of high DO concentrations on fish and other organisms, and there is uncertainty about the maximum concentration threshold (NIWA, 2013). Of greatest concern for water quality is the significant decrease in DO that can occur when organic matter is added. The depletion of DO depends on the load of biodegradable organic material, microbial activity, and any re-aeration mechanisms operating (ANZECC, 2000)

Total Suspended Solids

Total suspended solids (TSS) consist of an inorganic fraction (such as silts and clays) and an organic fraction (algae, zooplankton, bacteria and detritus) carried within the water column. The inorganic fraction is usually considerably higher than the organic fraction. TSS reduces light penetration, reducing algal photosynthesis, thereby potentially controlling phytoplankton growth. Suspended solids can also clog fish gills, either killing them or reducing their growth rate (ANZECC, 2000).

When TSS settles out and drops to the bottom, this causes the water to clear, but as the silt or sediment is deposited it may change the nature of the bottom of the water body. The silt may smother bottom-dwelling organisms, cover breeding areas, and smother eggs. Indirectly, suspended solids also affect other parameters, such as temperature and DO. Siltation, or sediment deposition, eventually may fill waterway banks and convert them into wetlands. A positive effect of the presence of suspended solids in water is that toxic chemicals, such as pesticides and metals, tend to be adsorbed or complexed by them, which makes such toxicants less bioavailable (ANZECC, 2000).

Turbidity

Turbidity was monitored *in-situ*. Turbidity is a measure of how light is scattered by suspended particulate material in the water. Increased turbidity can reduce the light climate and change an ecosystem significantly. Measures of turbidity are often reflective of the extent of catchment and riverbank erosion, and how much the light regime is being affected (ANZECC, 2000).

Chlorophyll-*a*

Chlorophyll-*a* is the primary green photosynthetic pigment, which captures sunlight, and is found in all plants, including phytoplanktonic algae. Chlorophyll-*a* levels in water are a proven indicator of the condition of a waterway (ANZECC, 2000).

Nutrients alone cannot indicate whether a waterbody has a nuisance plant problem, whereas increased chlorophyll-*a* in the water indicates that plants, algae, or cyanobacteria are growing, and that appropriate management action should be taken to identify species. Chlorophyll-*a* can be used as a non-specific indicator of the trophic status (level of pollution) of a waterbody (ANZECC, 2000). Low chlorophyll-*a* concentrations are often associated with less impacted waterways with good quality water, with high levels characteristic of water that has been nutrient-enriched, where algal productivity is high (eutrophic). Chlorophyll-*a* concentrations often reflect the integrated effect of many of the water quality factors that may be altered in water bodies by human activities (ANZECC, 2000).

Enterococci

Enterococci are a subgroup of faecal streptococci and include four streptococci species. *Enterococci*, in contrast to faecal coliforms, survive for longer periods in seawater and are thus good indicators of the presence of aged faecal contamination (Ahmed, 2008).

Water quality monitoring

Physicochemical water quality parameters were measured in-situ at all sites using a calibrated TPS WP-82Y meter with a YSI dissolved oxygen probe for dissolved oxygen (%), TPS WP-88 turbidity meter with a TPS turbidity sensor for turbidity (NTU) and a TPS WP-81 conductivity, pH and temperature meter with TPS conductivity and temperature probe and a TPS submersible k407 pH sensor for conductivity (µS/cm), pH (pH units) and temperature (˚C). In addition, surface water grab samples were taken at each site for analysis of total suspended solids (TSS; dried at 104˚C), total nitrogen (TN), ammonia (NH_3), nitrate and nitrite as N (NOx), total phosphorus (TP), chlorophyll-*a*, and *Enterococci* (CFU/100 mL). Grab samples were collected in decontaminated, acid preserved sample containers. After collection, samples were stored in a chilled esky and delivered to a commercial laboratory for analysis (ALS Smithfield, NSW). All grab samples were analysed using standard methods (APHA, 1998) by a National Associations of Testing Authorities (NATA) accredited laboratory.

Microbial Source Tracking (MST) Analysis using Bacteroides

Faecal contamination is commonly used as an indicator to determine the condition and safety of waterways. Frequently used indicators of faecal contamination often include *Enterococci* and *Esherichia coli* (E.coli), however, these may not necessarily give an indication of the source of the contamination (ALS, 2023). An in-depth analysis of Bacteroidales, which are an order of bacteria that consists of the genera Bacteroides and Prevotella, using molecular markers can be used to assist to differentiate between sources of faecal contamination, including whether it is derived from human or animal sources (Bernhard and Field, 2000; Reischer *et al.*, 2006; Stapleton *et al*., 2009). This information is useful to better understand the potential sources of contamination that may be occurring within a catchment and waterway, and the risks that this may pose to waterways users.

Bacteroides were assessed during two monitoring events during the 2022-2023 period. Water samples were collected in sterile plastic jars and analysed by a NATA accredited laboratory using recognised methods to identify the potential source of faecal contamination. Water samples were analysed using polymerase chain reaction (PCR) to identify rDNA and 16S rRNA genetic markers of bacteroides in the water (Bernhard and

Field, 2000; Reischer *et al.*, 2006; Stapleton *et al*., 2009). The genetic sequence of key groups of molecular markers were identified compared to known DNA sequences, amplified, and quantified as the number of copies for each molecular marker per millilitre (therefore does not represent a direct count of bacteroides present). This included for human bacteroides, which can reflect evidence of human faecal contamination such as sewage leaks and stormwater, ruminant bacteroides (which are herbivorous mammals with more than one stomach such as cows and sheep), and animal bacteroides (all other animals excluding ruminants), which show evidence of faecal contamination of water sources by animals.

Statistical analysis

Water quality data was analysed using the software package R version 4.3.2 (R Core Team, 2021). Data for the 2021-2024 monitoring period was assessed using boxplots to demonstrate the distribution of the data. The lower and upper limit of the central box is indicative of the lower 25% percentile and upper 75% percentile of the data, with the median shown by the central line across the box. The whiskers extending out from the box indicate the minimum and maximum values recorded, with outliers shown by dots. Water quality data, including the median for each catchment, was also compared with the ANZECC (2000) guidelines for Aquatic Ecosystems (Lowland River in south-eastern Australia).

Calculation of waterway health grades

Waterway health grades have become a popular and effective tool to communicate technical scientific information in a format easily understood by a diverse audience. Calculation of waterway health grades for waterways in the Lake Illawarra catchment are based on the method applied by the South East Queensland Healthy Waterways Program (EHMP, 2008). In summary, this process involves the comparison of water quality data collected from waterways to the region-specific guideline and ‘worst-case scenario’ for each parameter or metric. This comparison enables the calculation of standardised scores for all parameters and metrics, which are then averaged (where replicate surveys/samples were taken) to provide an overall standardised score for each monitoring site.

The water quality parameters used include pH, electrical conductivity, dissolved oxygen, turbidity, ammonia as N, nitrate and nitrate (NOx), total nitrogen, total phosphorus, phosphate, chlorophyll-*a*, and *Enterococci*. Standardised scores represent the degree by which the ecological condition at a site differs from that at reference sites. Waterway health grades are determined based on the corresponding standardised score for each monitoring site and reflect ecosystem condition of the waterway at the time of sampling (Table 2).

Formulation of guidelines and worst-case scenario values

To formulate region specific guidelines for waterways in the Lake Illawarra catchment, the rationale set out in Chapter 3 ‘Aquatic Ecosystems’ of the ANZECC guidelines (ANZECC, 2000) was applied. The appropriate guideline values were sourced from the ANZECC guidelines for south-east waterways (ANZECC, 2000) and from the NSW Water Quality and River Flow Objectives (2006). These guidelines were adopted, as no locally derived reference water quality data was available. The worst-case scenario values represent the most degraded conditions for waterways. The worst-case scenario for indicators were calculated from all data collected across all monitoring sites across the Lake Illawarra catchment, using the 90th percentile (e.g. for nutrients) or 10th percentile (e.g. for dissolved oxygen). River Health sites where the values of most variables are like worst-case scenario values are graded F, reflecting severe degradation. Due to the differing nature, separate guideline values and worst-case scenario values are calculated for both the lowland river catchment and the estuarine environments within the Lake Illawarra catchment.

Table 2: Waterway health grades corresponding to standardised score ranges, ecosystem condition and a brief description of the relationship with parameters used as indicators.

Standardised score	Grade	Ecosystem condition	Description
0.95	A+	Excellent Equals reference conditions	Most indicators equivalent to reference conditions and comply with regional guidelines.
0.90	A	Good Mild departure from reference conditions	Most indicators equivalent to reference conditions and comply with regional guidelines, with minor impacts or evidence of disturbance.
	A-		
0.85	B+		
	B	Fair Moderately impacted sites	Numerous indicators outside regional guideline limits and show signs of departure from reference conditions.
0.75			
0.70	B-		
0.65	C+		
0.60	C		
0.55	C-		

0.50	D+	Poor Severely impacted sites	Most indicators non-compliant with regional guidelines and show significant departure from reference conditions.
0.45	D		
0.40	D-		
0.35	E+		
0.30	E		
0.25	E-		
0.20	F+		

Results

Rainfall

From December 2021 to April 2024, water quality monitoring was undertaken on 25 occasions, with 14 dry weather and 11 wet weather monitoring events (determined in consultation with Council staff). Weather conditions at the time of sampling for each monitoring event are outlined in Table 3. The highest rainfall was recorded prior to sampling in July 2022, with a total of 409 mm of rainfall in the seven days prior to wet weather monitoring occurring.

Table 3: Sum of rainfall (mm) seven days prior to each sampling event in 2021-2024 from Bellambi AWS Meteorological Station (BOM, 2024), Cleveland St and Wongawilli MHL stations. – indicates that data was not available from this station for the identified period.

Sample Round	Rainfall (mm)		
Dry Weather Monitoring	Bellambi AWS	Cleveland St	Wongawilli
08/12/2021	9.6	-	-
31/01/2022	1.6	-	-
18/02/2022	57.6	-	-
27/04/2022	28.8	-	-
27/06/2022	5.4	-	-
29/08/2022	13.8	-	-
19/12/2022	10.0	-	-
16/02/2023	128.0	-	-
13/04/2023	4.2	-	-
01/06/2023	0.0	0.0	0.0
23/08/2023	23.2	5.0	6.0
27/10/2023	0.6	2.5	5.0
14/12/2023	3.2	7.0	5.0
02/02/2024	5.8	1.5	4.0
Wet Weather Monitoring			
08/02/2022	67.4	-	-
21/02/2022	60.2	-	-
12/05/2022	64.8	-	-
07/07/2022	409.0	-	-
25/10/2022	34.2	-	-
23/01/2023	39.0	-	-

29/06/2023	4.8	4.5	7.0
15/08/2023	32.0	27.5	24.5
06/11/2023	183.2	69.0	61.0
29/11/2023	57.8	86.0	62.5
08/04/2024	231.6	252.5	261.5
Bacteroides Monitoring			
13/04/2023	4.2	-	-
15/08/2023	32.0	27.5	24.5

Water quality monitoring

Water quality in the streams and rivers of the Lake Illawarra catchment ranged from ‘good’ to ‘fair’, with most sites (total of 18) experiencing ‘fair’ water quality (Figure 2). The relatively healthy scores experienced by waterways within the Lake Illawarra catchment are influenced by naturally vegetated areas present at the headwaters of streams that flow into Lake Illawarra. Moving downstream, land use becomes more intense, shifting from bushland, to farmland, to the urban environment.

The downstream transition to more intense land use cooresponds to a reduction in water quality. This deteriation of water quality is most evident for Mullet Creek and Macquarie Rivulet. The uppermost site (SCC5) on Macquarie Rivulet recorded the highest water quality grade of all of the sampling sites, with a grade of B+ (good water quality), and this was consistent downstream at SCC6. However, at the southern end of Lake Illawarra, sites SCC4, SCC3, SCC2 and SCC1 recorded slightly lower scores of C, C+, C-, and C+, which are considered to reflect fair water quality. Mullet Creek sites also show higher scores in the upper to middle catchment sites, ranging from B at M5, B+ at F1, and B- at DA1, to a reduced score of C- at M2 in the lower catchment. However, M1 received a score of B-. The lowest water quality grade was C- (fair water quality), and this was observed at four sites (BD1, M2, MIN1, and SCC2), all of which were in the lower catchment sections. Grades for the other Estuarine sites ranged from C to C+. Overall, water quality grades showed a slight decline in grade for the overall 2021-2024 period compared to the previous monitoring period (2022-2023), with decline in grade at 11 sites (including B1, D1, M1, M2, DA1, R1, SCC4, SCC3, SCC2, SCC1, and H1), an increase in grade at one site (BD1), and nine sites maintained the same grade score (D2, F1, M5, MIN1, R2, RE1, R3, SCC5, and SCC6). However, due to the small sample size (this is only the third round of grade assessments for the monitoring sites) and as this grade is based only on the assessment of surface water quality (which can be dependent on environmental conditions), these results should be interpreted with caution.

Physiochemical water quality parameters were sampled at each monitoring site on 14 occasions during dry weather (December 2021, January 2022, February 2022, April 2022, June 2022, August 2022, December 2022, February 2023, April 2023, June 2023, August 2023, October 2023, December 2023, and February 2024) and on 11 occasions during wet weather events (on two occasions in February 2022, May 2022, July 2022, October 2022, January 2023, June 2023, August 2023, on two occasions in November 2023, and April 2024). Median data per site was compared to the ANZECC (2000) Lowland River Guidelines and ANZECC (2000)

Primary and Secondary Contact Guidelines, and between wet and dry weather monitoring for each waterway.

Comparison of median water quality results from the Lake Illawarra catchment sites with the appropriate ANZECC (2000) guidelines shows all sites were non-compliant with at least one water quality guideline throughout the monitoring period (Table 4 -Table 9). There was also variation between wet and dry weather monitoring events, and catchments.

Median pH was non-compliant with the ANZECC (2000) guideline at one out of 21 sites, M5 (8.24 pH units) during dry weather monitoring (Table 4). All sites were within the guideline values for pH during wet weather monitoring (Table 7).

Median electrical conductivity was compliant with the ANZECC (2000) guideline at one of the 21 sites (Table 4). The compliant site was F1 (257.14 µS/cm). During wet weather monitoring, median electrical conductivity was compliant with the ANZECC (2000) guideline at five of the 21 sites, DA1 (276.00 µS/cm), F1 (241.00 µS/cm), R3 (289.00 µS/cm), SCC5 (158.40 µS/cm), and SCC6 (201.10 µS/cm; Table 7). Electrical conductivity exceeded the detection limit of equipment used on 55 occasions, and this is due to the influence of saline water at sites across the Lake Illawarra catchment as the estuary is brackish.

Median dissolved oxygen was non-compliant with the ANZECC (2000) guideline at 18 of the 21 sites (Table 4). The compliant sites were F1 (98.45%), M5 (97.50%), and SCC6 (95.05%). During wet weather monitoring, median dissolved oxygen was also compliant with the ANZECC (2000) guideline at three of the 21 sites, including F1 (89.05%), M5 (93.05 %), and SCC6 (95.40%) (Table 7). However, overall dissolved oxygen was markedly below the ANZECC (2000) guidelines across the majority of sites during both dry and wet weather monitoring. This indicates the potential eutrophication of waterways due to high nutrient availability.

Median turbidity was compliant with the ANZECC (2000) guidelines at all 21 sites for both the dry weather and wet weather monitoring events. The ANZECC (2000) guidelines reflect a wide range of turbidity values (6-50 NTU), and during the monitoring period all sites did experience events where turbidity was elevated, however, the median values did not exceed the guidelines.

Total nitrogen did comply with the ANZECC (2000) guidelines at only three sites during dry weather monitoring (Table 5). This included DA1 (0.20 mg/L), F1 (0.20 mg/L), and R3 (0.20 mg/L). During wet weather monitoring, median total nitrogen was compliant with the ANZECC (2000) guideline at only one of the 21 sites, F1 (0.40 mg/L) (Table 8). This suggests that waterways across this catchment pose a significant source of nitrogen to Lake Illawarra.

Ammonia concentrations were compliant with the ANZECC (2000) guidelines at only five sites during dry weather monitoring (Table 5). The compliant sites were D1 (0.01 mg/L), D2 (0.01 mg/L), F1 (0.01 mg/L), M5 (0.01 mg/L), and R3 (0.01 mg/L). During wet weather monitoring, median ammonia levels were compliant with the ANZECC (2000) guideline at three sites, F1 (0.01 mg/L), M5 (0.01 mg/L), and R3 (0.01 mg/L) (Table 8). Elevated ammonia across waterways within the Lake Illawarra catchment indicates a high level of bioavailable nitrogen to this system.

Concentrations of nitrate and nitrite as N (NOx) were compliant with the ANZECC (2000) guidelines at five sites during dry weather monitoring (Table 5). This included BD1 (0.03 mg/L), D1 (0.01 mg/L), D2 (0.01 mg/L), H1 (0.01 mg/L), and SCC1 (0.01 mg/L). During wet weather monitoring, median NOx concentrations did not comply with the ANZECC (2000) guideline at all 21 sites (Table 8). Similar to ammonia, high concentrations of NOx across waterways within the Lake Illawarra catchment indicates a high level of bioavailable nitrogen to this system.

Median total phosphorus concentrations were compliant with the ANZECC (2000) guidelines at only six sites during dry weather monitoring (Table 5). This included DA1 (0.02 mg/L), F1 (0.01 mg/L), M5 (0.01 mg/L), R3 (0.03 mg/L), SCC5 (0.04 mg/L), and SCC6 (0.03 mg/L). During wet weather monitoring, median total phosphorus levels were compliant with the ANZECC (2000) guideline at two out of 21 sites, including at F1 (0.02 mg/L), and M5 (0.03 mg/L) (Table 8). This highlights that during wet weather waterways within the Lake Illawarra catchment are a notable source of nutrients to this system.

Median phosphate concentrations did not comply with the ANZECC (2000) guidelines at two sites during dry weather monitoring (Table 5). This included MIN1 (0.07 mg/L) and SCC2 (0.03 mg/L). During wet weather monitoring, median phosphate was non-compliant with the ANZECC (2000) guideline at eight out of 21 sites, including at B1 (0.03 mg/L), BD1 (0.04 mg/L), H1, (0.04 mg/L), MIN1 (0.12 mg/L), SCC1 (0.02 mg/L), SCC2 (0.02 mg/L), SCC3 (0.02 mg/L), and SCC5 (0.03 mg/L) (Table 8).

Mean chlorophyll-*a* levels did not comply with the ANZECC (2000) guidelines for all 21 sites across both dry and wet weather monitoring events (Table 6; Table 9). High levels of chlorophyll-*a* in the water indicates that plants, algae, or cyanobacteria are highly abundant (ANZECC, 2000), and this is closely linked with available nutrients, which were also high across sites, and environmental conditions including low rainfall (to minimise flushing of the system), warmer temperature and light availability to promote photosynthesis.

ANZECC (2000) identifies primary and secondary contact guidelines for *Enterococci* of 35 CFU/100 mL and 230 CFU/100 mL respectively. During dry weather monitoring, one site (RE1) was compliant with the guidelines, 17 sites recorded Enterococci that exceeded the ANZECC (2000) primary contact guideline, and three sites exceeded the secondary contact guideline (Table 6). During wet weather monitoring, one site recorded *Enterococci* that exceeded the ANZECC (2000) primary contact guideline (M5), and the remaining 20 sites exceeded the secondary contact guideline (Table 9).

No ANZECC (2000) guidelines are currently available for total suspended solids (TSS) and temperature. However, TSS values were high at a number of sites across the Lake Illawarra catchment, which indicates an increased risk of siltation of waterways, and may contribute to biological impacts such as contributing to reduced light penetration and algal photosynthesis, and implications for aquatic species such as fish.

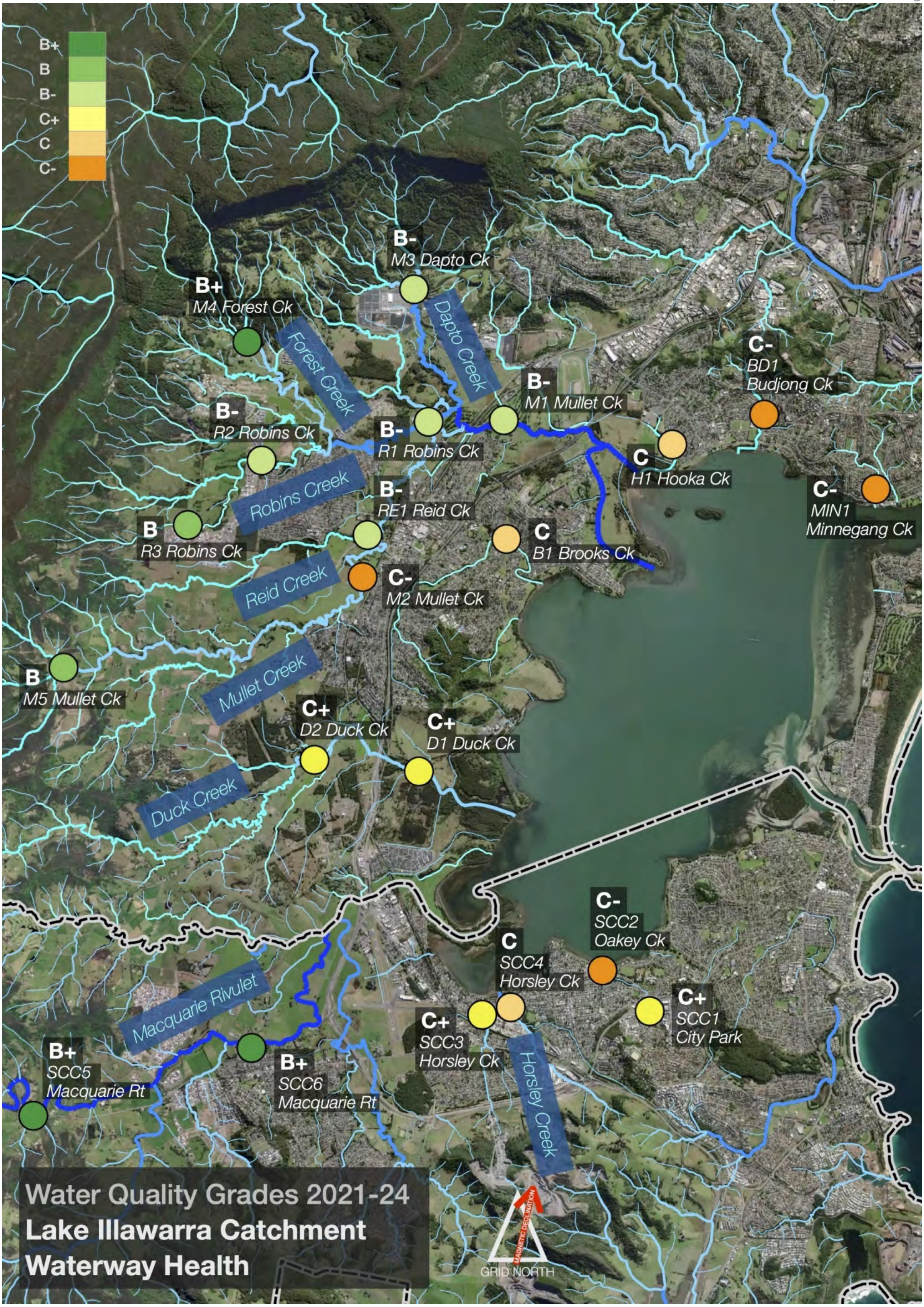

Figure 2: Waterway grades for sampling sites in the Lake Illawarra catchment for the 2021-2024 monitoring period.

Table 4: Mean in-situ physical water quality parameters at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during dry weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

Site	pH units				Electrical Conductivity (µS/cm)				Temperature (°C)				Dissolved Oxygen (%)				Turbidity (NTU)			
	Mean (±SE)	Median	Min	Max	Mean (±SE)	Median	Min	Max	Mean (±SE)	Median	Min	Max	Mean (±SE)	Median	Min	Max	Mean (±SE)	Median	Min	Max
ANZECC Guideline	6.5-8.0				200-300				-				85-110				6-50			
B1	7.48 (±0.13)	7.44	6.87	8.15	1153.58 (±137.21)	1127.50	104.1	1993	19.58 (±1.48)	19.05	11.70	29.10	50.64 (±5.26)	58.25	10.10	71.00	6.88 (±2.52)	2.66	0.57	34.50
BD1	7.51 (±0.09)	7.52	6.88	8.64	3103.34 (±1569.29)	835.50	7.81	30000.00	19.78 (±1.25)	20.60	11.80	26.30	59.48 (±7.83)	51.30	21.60	145.00	5.68 (±1.28)	2.90	0.46	19.96
D1	7.59 (±0.10)	7.54	6.93	8.64	4248.08 (±2381.41)	781.00	430	30000	20.07 (±1.68)	21.40	11.80	26.30	74.68 (±9.65)	60.40	28.70	145.00	6.27 (±1.87)	2.65	0.46	19.96
D2	7.59 (±0.11)	7.56	7.06	8.60	25854.00 (±57.00)	600.00	359.00	1128.00	19.32 (±1.55)	18.65	11.00	27.00	49.59 (±4.06)	51.90	25.00	79.10	5.61 (±1.09)	4.05	1.13	13.40
H1	7.53 (±0.08)	7.54	6.83	8.18	25719.93 (±26396.41)	30000.00	1896	30000	21.68 (±1.47)	21.45	13.90	29.20	66.39 (±6.92)	63.40	24.70	119.20	8.36 (±1.24)	6.93	1.86	15.60
M1	7.46 (±0.10)	7.45	6.67	8.33	15504.57 (±3529.70)	8025.00	523.00	30000.00	24.49 (±2.66)	24.25	13.20	50.00	71.73 (±6.01)	73.60	18.90	109.40	8.84 (±2.08)	6.01	1.21	24.00
M2	7.66 (±0.09)	7.56	7.03	8.21	1645.07 (±1001.46)	667.50	391.00	14660.00	20.01 (±1.52)	19.40	11.70	30.20	43.01 (±5.67)	43.40	12.10	83.90	6.71 (±1.07)	5.56	1.33	13.85
DA1	7.61 (±0.08)	7.60	6.91	8.01	504.71 (±16.50)	495.50	361.00	598.00	18.23 (±1.39)	17.65	10.30	26.00	70.75 (±5.52)	68.30	36.80	102.60	4.14 (±0.77)	2.94	1.50	11.00
F1	7.80 (±0.10)	7.76	7.03	8.35	310.06 (±49.47)	257.15	170.00	924.00	18.53 (±1.44)	17.50	10.60	25.20	95.36 (±2.71)	98.45	70.80	107.00	3.03 (±0.90)	1.70	0.68	12.10
M5	8.13 (±0.13)	8.24	7.36	8.80	553.56 (±46.00)	584.00	196.00	861.00	18.50 (±1.37)	18.10	10.90	26.70	99.74 (±5.09)	97.50	66.20	142.40	2.71 (±0.75)	1.30	0.40	8.34
MIN1	7.32 (±0.13)	7.30	6.54	8.25	798.64 (±65.29)	753.50	526.00	1270.00	18.29 (±1.10)	18.80	12.30	23.00	36.42 (±5.86)	33.30	11.30	77.10	6.94 (±1.63)	4.62	1.35	20.80
R1	7.55 (±0.10)	7.66	6.97	8.08	487.07 (±78.29)	402.00	239	1420	19.51 (±1.51)	18.35	11.30	27.40	64.10 (±3.90)	66.90	31.70	90.20	6.65 (±1.15)	4.78	2.17	15.90
R2	7.52 (±0.08)	7.57	6.81	7.94	726.57 (±57.81)	693.00	413.00	1100.00	19.05 (±1.44)	18.70	10.70	25.40	61.62 (±4.18)	61.10	35.10	90.70	5.23 (±0.95)	3.95	1.97	14.60
RE1	7.53 (±0.10)	7.48	6.62	8.13	899.50 (±80.15)	791.00	632.00	1645.00	18.20 (±1.42)	18.55	10.10	24.00	48.26 (±7.63)	43.50	9.50	110.00	7.44 (±1.10)	6.22	1.59	17.80
R3	7.67 (±0.12)	7.80	6.97	8.34	359.29 (±19.57)	396.50	189.00	432.00	18.31 (±1.40)	18.25	10.40	24.20	68.86 (±5.12)	69.65	31.70	100.60	3.78 (±0.90)	2.63	0.30	12.50
SCC1	7.73 (±0.18)	7.64	6.57	9.14	873.29 (±318.32)	434.00	281.00	4860.00	20.84 (±1.40)	21.05	12.40	28.10	52.05 (±8.20)	43.20	12.20	106.00	5.27 (±1.24)	2.83	1.20	15.61
SCC2	7.52 (±0.06)	7.60	7.06	7.84	28112.14 (±1285.12)	30000.00	16010.00	30000.00	21.50 (±1.32)	21.80	14.50	28.90	54.21 (±6.49)	54.90	18.40	100.10	16.18 (±8.05)	6.30	1.34	118.00
SCC3	7.59 (±0.08)	7.56	7.09	8.00	14548.50 (±2926.70)	11145.00	2047.00	30000.00	20.47 (±1.55)	20.85	13.00	28.60	51.39 (±3.86)	48.60	28.70	73.40	9.64 (±4.01)	5.95	1.48	59.90

SCC4	7.59 (±0.07)	7.59	7.10	8.03	23186.43 (±2516.08)	30000.00	3980.00	30000.00	21.21 (±1.60)	21.25	13.40	31.70	50.68 (±6.20)	56.00	9.60	86.40	9.72 (±3.01)	4.45	1.38	43.30
SCC5	7.73 (±0.12)	7.65	6.67	8.58	151.43 (±6.02)	150.90	107.70	190.50	18.91 (±1.33)	19.30	11.80	25.20	84.98 (±5.49)	81.35	56.30	126.00	4.30 (±1.46)	1.78	0.80	17.59
SCC6	7.52 (±0.14)	7.54	6.77	8.35	213.54 (±12.90)	206.25	143.00	331.00	18.70 (±1.36)	18.65	11.50	25.20	94.02 (±4.21)	95.05	70.50	114.90	4.18 (±1.21)	2.09	1.01	17.40

Table 5: Mean water quality nutrient parameters at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during dry weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

	Ammonia as N (mg/L)				Nitrite + Nitrate as N (mg/L)				Total Nitrogen as N (mg/L)				Total Phosphorus as P (mg/L)				Reactive Phosphorus as P (mg/L)			
Site	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum
ANZECC Guideline	0.02				0.04				0.50				0.05				0.02			
B1	0.05 (±0.01)	0.04	0.005	0.18	0.30 (±0.10)	0.11	0.005	1.16	0.94 (±0.14)	0.75	0.30	1.90	0.09 (±0.01)	0.07	0.02	0.22	0.02 (±0.01)	0.01	0.005	0.11
BD1	0.05 (±0.01)	0.03	0.005	0.22	0.21 (±0.06)	0.03	0.005	0.84	0.98 (±0.16)	0.70	0.30	2.80	0.11 (±0.02)	0.06	0.02	0.40	0.02 (±0.00)	0.01	0.005	0.05
D1	0.03 (±0.01)	0.01	0.005	0.16	0.02 (±0.00)	0.01	0.005	0.04	0.58 (±0.08)	0.50	0.30	1.20	0.06 (±0.01)	0.05	0.02	0.17	0.01 (±0.00)	0.01	0.005	0.01
D2	0.02 (±0.00)	0.01	0.005	0.05	0.02 (±0.01)	0.01	0.005	0.09	0.72 (±0.10)	0.60	0.30	1.70	0.09 (±0.01)	0.07	0.03	0.22	0.01 (±0.00)	0.01	0.005	0.01
H1	0.10 (±0.03)	0.07	0.02	0.46	0.04 (±0.02)	0.01	0.005	0.25	0.94 (±0.09)	0.95	0.40	1.40	0.19 (±0.04)	0.15	0.07	0.60	0.01 (±0.00)	0.01	0.005	0.05
M1	0.05 (±0.01)	0.04	0.005	0.16	0.15 (±0.07)	0.03	0.005	0.82	0.68 (±0.10)	0.55	0.30	1.40	0.08 (±0.02)	0.06	0.02	0.26	0.01 (±0.00)	0.01	0.005	0.02
M2	0.09 (±0.06)	0.04	0.005	0.80	0.84 (±0.37)	0.13	0.005	3.63	1.55 (±0.46)	0.65	0.40	5.30	0.10 (±0.02)	0.08	0.04	0.29	0.01 (±0.00)	0.01	0.005	0.02
DA1	0.04 (±0.02)	0.02	0.005	0.24	0.04 (±0.01)	0.03	0.005	0.08	1.60 (±1.32)	0.20	0.05	18.80	0.17 (±0.15)	0.02	0.01	2.12	0.01 (±0.00)	0.01	0.005	0.04
F1	0.01 (±0.00)	0.01	0.005	0.02	0.06 (±0.01)	0.04	0.005	0.18	0.19 (±0.03)	0.20	0.05	0.40	0.01 (±0.00)	0.01	0.01	0.04	0.01 (±0.00)	0.01	0.005	0.01
M5	0.53 (±0.49)	0.01	0.005	6.89	0.33 (±0.11)	0.17	0.04	1.52	1.11 (±0.74)	0.30	0.10	10.60	0.02 (±0.01)	0.01	0.01	0.08	0.01 (±0.00)	0.01	0.005	0.01
MIN1	0.04 (±0.01)	0.03	0.02	0.09	0.42 (±0.11)	0.27	0.02	1.34	1.14 (±0.16)	1.05	0.50	2.40	0.31 (±0.06)	0.24	0.07	0.86	0.06 (±0.01)	0.07	0.005	0.13
R1	0.03 (±0.01)	0.02	0.005	0.09	0.05 (±0.01)	0.04	0.005	0.10	0.48 (±0.05)	0.45	0.20	0.80	0.06 (±0.01)	0.04	0.03	0.16	0.01 (±0.00)	0.01	0.005	0.05
R2	0.03 (±0.00)	0.03	0.005	0.05	0.03 (±0.01)	0.02	0.005	0.14	0.46 (±0.05)	0.45	0.20	0.90	0.06 (±0.01)	0.05	0.03	0.14	0.01 (±0.00)	0.01	0.005	0.01
RE1	0.03 (±0.01)	0.02	0.005	0.09	0.04 (±0.01)	0.03	0.005	0.14	0.91 (±0.13)	0.75	0.50	2.40	0.13 (±0.03)	0.10	0.04	0.47	0.01 (±0.00)	0.01	0.005	0.01
R3	0.01 (±0.00)	0.01	0.005	0.02	0.02 (±0.01)	0.02	0.005	0.08	0.27 (±0.04)	0.20	0.10	0.60	0.03 (±0.00)	0.03	0.01	0.04	0.01 (±0.00)	0.01	0.005	0.01

SCC1	0.05 (±0.01)	0.03	0.005	0.13	0.09 (±0.04)	0.01	0.005	0.38	0.72 (±0.09)	0.60	0.30	1.50	0.07 (±0.01)	0.08	0.03	0.11	0.01 (±0.00)	0.01	0.005	0.06
SCC2	0.10 (±0.02)	0.09	0.04	0.24	0.12 (±0.04)	0.05	0.005	0.48	0.84 (±0.08)	0.80	0.40	1.30	0.20 (±0.05)	0.14	0.07	0.78	0.05 (±0.02)	0.03	0.005	0.28
SCC3	0.05 (±0.01)	0.05	0.01	0.13	0.25 (±0.07)	0.14	0.005	0.70	0.77 (±0.09)	0.70	0.25	1.40	0.11 (±0.02)	0.08	0.04	0.26	0.01 (±0.00)	0.01	0.005	0.03
SCC4	0.12 (±0.02)	0.11	0.05	0.34	0.12 (±0.04)	0.05	0.005	0.57	0.84 (±0.10)	0.85	0.25	1.40	0.20 (±0.06)	0.13	0.06	0.98	0.01 (±0.00)	0.01	0.005	0.03
SCC5	0.04 (±0.01)	0.02	0.005	0.11	0.15 (±0.03)	0.17	0.005	0.28	0.39 (±0.03)	0.40	0.20	0.60	0.03 (±0.00)	0.04	0.01	0.06	0.01 (±0.00)	0.01	0.005	0.01
SCC6	0.02 (±0.01)	0.02	0.005	0.06	0.10 (±0.02)	0.10	0.005	0.21	0.31 (±0.03)	0.30	0.10	0.50	0.03 (±0.00)	0.03	0.01	0.05	0.01 (±0.00)	0.01	0.005	0.02

Table 6: Mean total suspended solids, chlorophyll-*a*, and *Enterococci* at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during dry weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. For *Enterococci*, exceedance of the ANZECC (2000) primary (orange) and secondary (red) guideline is also shown. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

	Total Suspended Solids (mg/L)				Chlorophyll *a* (mg/L)				*Enterococci* (CFU/100 mL)			
Site	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum
ANZECC Guideline	-				0.005				Primary - 35 Secondary - 230			
B1	14.50 (±7.22)	2.50	2.50	103.00	8.43 (±3.14)	5.00	0.50	44.00	1450.79 (±695.64)	215.00	20.00	7500.00
BD1	18.43 (±6.64)	15.00	2.50	101.00	7.40 (±1.50)	5.00	1.00	24.00	1362.80 (±593.12)	73.00	2.00	7600.00
D1	6.77 (±1.12)	6.00	2.50	14.00	7.08 (±1.77)	4.00	2.00	22.00	94.31 (±45.05)	35.00	2.00	600.00
D2	11.50 (±2.92)	6.00	2.50	34.00	12.79 (±3.10)	8.00	2.00	36.00	104.29 (±34.75)	72.00	1.00	490.00
H1	24.50 (±4.73)	20.50	9.00	80.00	16.50 (±3.20)	12.50	2.00	46.00	245.89 (±113.11)	97.00	2.50	1500.00
M1	13.46 (±3.32)	10.50	2.50	48.00	4.86 (±1.01)	4.00	0.50	11.00	837.54 (±570.27)	45.00	4.50	7800.00
M2	85.64 (±66.57)	9.50	2.50	942.00	4.39 (±1.32)	2.00	0.50	19.00	76.86 (±21.55)	37.50	5.00	240.00
DA1	76.00 (±49.74)	5.50	2.50	694.00	55.57 (±53.28)	0.50	0.50	748.00	274.14 (±69.65)	220.00	3.00	980.00
F1	3.64 (±0.82)	2.50	2.50	13.00	4.25 (±3.07)	0.75	0.50	44.00	197.21 (±36.13)	175.00	35.00	560.00
M5	5.57 (±2.34)	2.50	2.50	34.00	4.32 (±2.53)	0.75	0.50	34.00	182.57 (±42.86)	150.00	10.00	500.00
MIN1	44.18 (±21.84)	7.00	2.50	234.00	4.18 (±1.53)	1.00	0.50	20.00	954.79 (±429.75)	425.00	47.00	6000.00
R1	13.00 (±2.89)	8.50	2.50	34.00	95.39 (±74.89)	1.25	0.50	1050.00	99.00 (±31.12)	36.00	1.00	360.00
R2	18.18 (±8.47)	6.50	2.50	119.00	9.96 (±3.98)	3.00	0.50	57.00	361.11 (±203.10)	80.50	4.50	2900.00
RE1	115.07 (±70.34)	17.00	2.50	1010.00	18.21 (±7.97)	5.00	1.00	89.00	70.89 (±31.60)	31.50	1.00	420.00
R3	5.25 (±1.20)	2.50	2.50	15.00	3.21 (±1.50)	0.50	0.50	20.00	71.36 (±19.73)	43.50	10.00	300.00

SCC1	4.93 (±1.33)	2.50	2.50	20.00	17.21 (±7.47)	6.00	1.00	105.00	194.14 (±52.05)	95.00	5.00	500.00
SCC2	57.57 (±29.46)	24.50	2.50	429.00	7.93 (±1.91)	7.50	0.50	29.00	1141.71 (±489.46)	750.00	24.00	7200.00
SCC3	23.00 (±13.99)	6.00	2.50	198.00	5.57 (±1.09)	5.00	0.50	14.00	1330.46 (±725.57)	140.00	4.50	7900.00
SCC4	36.61 (±14.51)	14.00	2.50	205.00	7.14 (±1.49)	5.00	1.00	18.00	1347.64 (±730.06)	260.00	2.00	9700.00
SCC5	8.11 (±3.46)	2.50	2.50	48.00	3.32 (±1.71)	0.50	0.50	24.00	130.79 (±15.71)	145.00	30.00	220.00
SCC6	4.14 (±0.88)	2.50	2.50	14.00	1.39 (±0.41)	0.50	0.50	5.00	194.71 (±56.93)	120.00	15.00	700.00

Table 7: Mean in-situ physical water quality parameters at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during wet weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

	pH units				Electrical Conductivity (µS/cm)				Temperature (°C)				Dissolved Oxygen (%)				Turbidity (NTU)			
Site	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum
ANZECC Guideline	6.5-8.0				200-300				-				85-110				6-50			
B1	7.32 (±0.08)	7.34	6.84	7.74	579.64 (±113.42)	497.00	123.00	1423.00	18.19 (±1.45)	19.90	8.50	23.50	64.67 (±8.42)	64.80	28.70	103.90	8.79 (±1.64)	7.41	1.77	16.79
BD1	7.46 (±0.10)	7.51	6.87	7.98	674.09 (±146.59)	503.00	222.00	1725.00	18.35 (±1.09)	19.20	12.60	23.70	54.43 (±7.00)	53.25	18.08	90.00	14.74 (±3.04)	15.80	2.53	33.40
D1	7.33 (±0.10)	7.34	6.85	7.87	3312.42 (±2673.71)	678.00	118.00	30000.00	18.43 (±1.52)	19.00	8.70	25.80	67.45 (±7.24)	65.20	25.90	103.80	20.47 (±7.83)	13.48	1.49	92.00
D2	7.42 (±0.09)	7.40	6.82	7.94	552.76 (±114.96)	491.00	119.00	1264.00	18.84 (±1.42)	20.00	11.10	25.90	68.90 (±7.71)	67.20	44.00	117.30	22.25 (±7.69)	12.30	1.62	71.90
H1	7.42 (±0.11)	7.44	6.82	8.15	12674.45 (±4378.16)	3350.00	433.00	38400.00	18.91 (±1.45)	19.80	11.70	26.30	63.78 (±4.28)	57.20	51.60	93.70	13.06 (±2.98)	7.94	3.17	30.80
M1	7.39 (±0.08)	7.42	6.75	7.77	3660.18 (±1273.02)	746.00	152.00	12164.00	19.94 (±1.62)	19.80	11.80	26.40	70.24 (±1.71)	68.20	64.10	81.50	33.14 (±12.57)	16.88	2.54	143.00
M2	7.70 (±0.08)	7.71	7.13	8.02	401.06 (±50.28)	382.00	139.00	648.00	18.62 (±1.41)	18.70	11.70	26.30	64.17 (±7.13)	62.35	30.89	95.90	38.40 (±26.41)	9.70	2.12	300.00
DA1	7.46 (±0.08)	7.52	7.02	7.79	344.66 (±54.31)	276.00	8.24	622.00	17.45 (±1.13)	18.30	10.90	23.00	78.05 (±4.86)	77.79	56.30	100.60	21.71 (±6.08)	17.85	5.30	74.40
F1	7.62 (±0.07)	7.59	7.22	8.00	239.69 (±26.42)	241.00	142.30	394.00	16.97 (±1.08)	18.10	10.60	23.60	91.53 (±5.13)	89.05	71.60	112.00	14.87 (±3.46)	13.34	1.67	41.80
M5	7.90 (±0.13)	7.91	7.19	8.59	471.27 (±74.63)	530.00	121.00	872.00	17.77 (±1.34)	18.90	10.60	24.20	91.72 (±5.16)	93.05	66.00	114.10	10.12 (±2.70)	7.40	1.52	28.80
MIN1	7.38 (±0.11)	7.42	6.70	8.06	494.45 (±67.82)	495.00	176.00	1037.00	17.87 (±1.32)	18.70	10.20	23.60	64.47 (±8.06)	62.85	19.87	102.30	9.29 (±1.70)	6.97	1.59	20.10
R1	7.50 (±0.07)	7.56	7.01	7.86	440.09 (±91.21)	354.00	239.00	1264.00	18.53 (±1.30)	18.70	11.20	25.10	68.96 (±4.24)	69.20	49.40	96.10	25.51 (±6.68)	16.30	3.74	81.30
R2	7.52 (±0.08)	7.41	7.23	7.98	472.64 (±65.99)	457.00	252.00	831.00	18.07 (±1.21)	18.70	11.10	24.30	74.24 (±5.74)	75.95	45.57	104.80	19.24 (±4.55)	12.77	3.95	43.70
RE1	7.54 (±0.09)	7.58	6.91	8.01	593.64 (±99.61)	535.00	187.00	1136.00	18.34 (±1.19)	20.30	11.00	23.20	71.87 (±4.01)	72.80	49.20	96.40	27.85 (±8.02)	17.46	2.41	84.10
R3	7.62 (±0.10)	7.67	6.95	8.13	287.38 (±38.84)	289.00	7.78	527.00	17.78 (±1.08)	18.70	11.40	22.40	74.42 (±4.64)	76.15	43.80	90.90	12.05 (±2.22)	13.50	1.07	23.00
SCC1	7.76 (±0.10)	7.68	7.31	8.41	1609.05 (±765.43)	753.00	99.50	8460.00	18.75 (±1.27)	18.90	11.70	24.00	60.41 (±7.78)	61.05	25.40	104.40	12.95 (±4.20)	6.45	1.25	44.90
SCC2	7.40 (±0.10)	7.51	6.82	7.86	18063.15 (±4246.21)	30000.00	6.67	30000.00	19.54 (±1.49)	19.80	11.60	25.70	62.52 (±5.04)	68.05	32.90	81.70	22.22 (±13.42)	8.23	1.31	154.00
SCC3	7.51 (±0.12)	7.58	6.92	7.96	7183.97 (±2986.75)	2509.00	207.70	30000.00	19.00(±1.26)	19.80	12.20	24.10	66.78 (±3.33)	62.75	54.70	86.40	15.12 (±3.63)	11.60	1.84	38.40

SCC4	7.46 (±0.14)	7.55	6.69	8.09	10831.73 (±3542.85)	5820.00	236.00	30000.00	19.05 (±1.46)	19.40	9.90	25.50	71.02 (±2.73)	68.90	59.40	82.80	27.87 (±11.05)	13.24	2.64	131.00
SCC5	7.49 (±0.12)	7.54	6.86	8.08	183.56 (±16.44)	158.40	143.10	311.00	17.63 (±1.23)	19.00	10.40	24.00	84.40 (±3.54)	81.45	66.00	106.00	11.96 (±3.91)	5.16	1.17	42.30
SCC6	7.50 (±0.11)	7.56	6.69	8.04	271.21 (±95.36)	201.10	96.50	1213.00	17.76 (±1.21)	17.50	10.60	25.20	93.63 (±3.87)	95.40	75.50	117.60	19.10 (±9.57)	7.51	1.30	112.00

Table 8: Mean water quality nutrient parameters at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during wet weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

	Ammonia as N (mg/L)				Nitrite + Nitrate as N (mg/L)				Total Nitrogen as N (mg/L)				Total Phosphorus as P (mg/L)				Reactive Phosphorus as P (mg/L)			
Site	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum
ANZECC Guideline	0.02				0.04				0.5				0.05				0.02			
B1	0.03 (±0.01)	0.03	0.01	0.06	1.33 (±0.36)	1.14	0.01	3.54	2.13 (±0.45)	2.10	0.50	5.20	0.11 (±0.02)	0.09	0.02	0.21	0.04 (±0.01)	0.03	0.01	0.11
BD1	0.06 (±0.01)	0.05	0.03	0.09	0.83 (±0.17)	0.63	0.08	1.71	1.72 (±0.23)	1.60	0.70	3.00	0.14 (±0.01)	0.12	0.08	0.22	0.05 (±0.01)	0.04	0.03	0.10
D1	0.06 (±0.02)	0.05	0.01	0.22	0.29 (±0.12)	0.09	0.01	1.11	1.35 (±0.36)	0.90	0.30	4.50	0.16 (±0.04)	0.11	0.03	0.43	0.03 (±0.01)	0.01	0.01	0.09
D2	0.05 (±0.01)	0.05	0.01	0.12	0.24 (±0.09)	0.19	0.01	0.87	1.15 (±0.20)	0.90	0.40	2.60	0.12 (±0.03)	0.10	0.03	0.31	0.02 (±0.00)	0.01	0.01	0.04
H1	0.14 (±0.03)	0.12	0.05	0.34	0.69 (±0.21)	0.64	0.01	1.93	1.77 (±0.36)	1.60	0.20	4.40	0.18 (±0.03)	0.17	0.05	0.36	0.07 (±0.02)	0.04	0.02	0.23
M1	0.14 (±0.06)	0.09	0.01	0.69	0.33 (±0.10)	0.24	0.01	0.87	1.47 (±0.33)	1.40	0.30	3.90	0.17 (±0.04)	0.13	0.03	0.50	0.02 (±0.00)	0.01	0.01	0.05
M2	0.42 (±0.34)	0.06	0.03	3.77	0.58 (±0.13)	0.40	0.07	1.45	2.55 (±0.50)	2.40	0.50	5.40	0.28 (±0.09)	0.24	0.02	1.01	0.02 (±0.00)	0.01	0.01	0.04
DA1	0.02 (±0.00)	0.02	0.01	0.05	0.28 (±0.07)	0.25	0.01	0.80	0.71 (±0.15)	0.60	0.20	1.90	0.06 (±0.01)	0.06	0.01	0.13	0.01 (±0.00)	0.01	0.01	0.01
F1	0.02 (±0.01)	0.01	0.01	0.05	0.19 (±0.03)	0.19	0.05	0.39	0.48 (±0.09)	0.40	0.10	1.10	0.04 (±0.01)	0.02	0.01	0.15	0.01 (±0.00)	0.01	0.01	0.03
M5	0.01 (±0.00)	0.01	0.01	0.03	0.41 (±0.05)	0.38	0.16	0.67	0.69 (±0.10)	0.60	0.20	1.30	0.03 (±0.01)	0.03	0.01	0.10	0.01 (±0.00)	0.01	0.01	0.02
MIN1	0.05 (±0.01)	0.04	0.03	0.09	1.23 (±0.28)	1.06	0.07	2.94	2.16 (±0.41)	1.90	0.50	4.60	0.23 (±0.04)	0.20	0.08	0.54	0.12 (±0.02)	0.12	0.03	0.20
R1	0.03 (±0.01)	0.02	0.01	0.06	0.27 (±0.08)	0.24	0.01	0.80	1.15 (±0.22)	1.00	0.30	2.70	0.21 (±0.08)	0.14	0.03	0.86	0.01 (±0.01)	0.01	0.01	0.06
R2	0.04 (±0.01)	0.04	0.01	0.09	0.40 (±0.13)	0.38	0.01	1.50	1.06 (±0.22)	0.80	0.40	2.80	0.10 (±0.02)	0.06	0.04	0.21	0.02 (±0.01)	0.01	0.01	0.10
RE1	0.04 (±0.02)	0.04	0.01	0.20	0.28 (±0.09)	0.11	0.01	0.76	1.14 (±0.16)	1.20	0.40	1.80	0.12 (±0.03)	0.08	0.02	0.41	0.02 (±0.01)	0.01	0.01	0.09
R3	0.02 (±0.01)	0.01	0.01	0.07	0.36 (±0.09)	0.50	0.01	0.78	0.85 (±0.19)	0.90	0.20	2.10	0.06 (±0.01)	0.06	0.01	0.15	0.01 (±0.00)	0.01	0.01	0.03

SCC1	0.11 (±0.05)	0.05	0.01	0.56	0.39 (±0.17)	0.16	0.01	1.99	1.19 (±0.26)	0.90	0.40	3.00	0.13 (±0.05)	0.07	0.04	0.62	0.02 (±0.01)	0.02	0.01	0.06
SCC2	0.12 (±0.03)	0.08	0.03	0.38	0.56 (±0.17)	0.54	0.01	1.93	1.20 (±0.24)	1.10	0.25	3.30	0.09 (±0.02)	0.06	0.00	0.23	0.03 (±0.00)	0.02	0.01	0.06
SCC3	0.04 (±0.01)	0.04	0.01	0.06	0.54 (±0.09	0.43	0.14	1.18	1.27 (±0.13)	1.30	0.60	1.90	0.12 (±0.02)	0.11	0.03	0.23	0.02 (±0.00)	0.02	0.01	0.06
SCC4	0.16 (±0.07)	0.09	0.01	0.84	0.59 (±0.18)	0.41	0.01	2.06	1.59 (±0.33)	1.50	0.50	4.50	0.24 (±0.06)	0.17	0.05	0.68	0.04 (±0.02)	0.03	0.01	0.20
SCC5	0.06 (±0.02)	0.02	0.01	0.24	0.46 (±0.12)	0.40	0.01	1.32	1.20 (±0.45)	0.80	0.30	5.60	0.16 (±0.08)	0.06	0.02	0.90	0.03 (±0.01)	0.01	0.01	0.09
SCC6	0.04 (±0.01)	0.02	0.01	0.13	0.45 (±0.15)	0.22	0.06	1.68	1.02 (±0.27)	0.80	0.30	3.30	0.10 (±0.04)	0.05	0.02	0.40	0.02 (±0.01)	0.01	0.01	0.05

Table 9: Mean total suspended solids, chlorophyll-*a*, and *Enterococci* at Lake Illawarra catchment waterway monitoring sites for 2021-2024 during wet weather monitoring. Red font indicates non-compliance with the ANZECC guideline values. For *Enterococci*, exceedance of the ANZECC (2000) primary (orange) and secondary (red) guideline is also shown. SE refers to standard error, min to minimum values, and max is maximum recorded value. – indicates that there is currently no ANZECC (2000) guideline for this parameter.

	Total Suspended Solids (mg/L)				Chlorophyll a (mg/L)				*Enterococci* (CFU/100 mL)			
Site	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum	Mean (±SE)	Median	Minimum	Maximum
ANZECC Guideline	-				0.005				Primary - 35 Secondary - 230			
B1	5.64 (±1.12)	2.50	2.50	11.00	1.00 (±0.20)	0.50	0.50	2.00	8530.91 (±6979.00)	620.00	130.00	78000.00
BD1	13.73 (±3.04)	12.00	2.50	33.00	1.50 (±0.34)	1.00	0.50	3.00	3460.55 (±1565.63)	1600.00	56.00	18000.00
D1	41.09 (±17.90)	10.00	2.50	194.00	4.55 (±0.88)	5.00	0.50	10.00	3701.82 (±2686.06)	500.00	2.00	30000.00
D2	28.05 (±9.94)	12.00	2.50	109.00	4.05 (±0.88)	4.00	0.50	11.00	1623.18 (±879.28)	310.00	5.00	8900.00
H1	24.64 (±5.18)	21.00	8.00	64.00	3.59 (±1.10)	2.00	0.50	12.00	9283.64 (±4501.36)	4000.00	20.00	50000.00
M1	37.64 (±13.56)	20.00	2.50	132.00	2.77 (±0.77)	2.00	0.50	9.00	4253.73 (±2718.48)	630.00	1.00	30000.00
M2	270.68 (±100.38)	52.00	2.50	972.00	5.18 (±2.12)	2.00	0.50	21.00	1909.64 (±703.02)	470.00	20.00	6100.00
DA1	59.82 (±29.04)	25.00	2.50	330.00	1.59 (±0.60)	0.50	0.50	7.00	453.82 (±117.17)	360.00	24.00	1400.00
F1	14.50 (±4.38)	10.00	2.50	42.00	0.73 (±0.14)	0.50	0.50	2.00	751.82 (±467.30)	250.00	40.00	5400.00
M5	5.86 (±1.82)	2.50	2.50	22.00	0.77 (±0.23)	0.50	0.50	3.00	159.00 (±52.83)	81.00	11.00	520.00
MIN1	24.86 (±12.74)	6.00	2.50	122.00	5.23 (±1.81)	2.00	0.50	16.00	7228.18 (±3403.28)	620.00	200.00	30000.00
R1	93.32 (±54.15)	20.00	2.50	622.00	7.09 (±5.24)	1.00	0.50	59.00	3022.36 (±1490.78)	690.00	36.00	16000.00
R2	13.05 (±3.99)	7.00	2.50	47.00	2.36 (±0.87)	1.00	0.50	8.00	1588.64 (±639.53)	510.00	35.00	6400.00
RE1	29.82 (±15.25)	17.00	2.50	179.00	2.32 (±0.65)	2.00	0.50	7.00	1391.18 (±627.20)	590.00	14.00	5500.00
R3	8.23 (±2.76)	5.00	2.50	33.00	1.14 (±0.31)	0.50	0.50	3.00	694.09 (±325.89)	450.00	4.00	3800.00
SCC1	16.77 (±13.13)	2.50	2.50	148.00	2.82 (±1.11)	0.50	0.50	12.00	1158.18 (±465.99)	490.00	40.00	5000.00

SCC2	44.41 (±29.98)	12.00	2.50	306.00	2.55 (±0.64)	2.00	0.50	6.00	2080.91 (±883.54)	890.00	70.00	9700.00
SCC3	20.41 (±4.34)	16.00	2.50	53.00	2.23 (±0.72)	1.00	0.50	7.00	2874.55 (±916.51)	1500.00	100.00	8800.00
SCC4	33.59 (±10.24)	27.00	2.50	124.00	4.73 (±1.82)	2.00	0.50	17.00	5475.91 (±2714.44)	2100.00	45.00	31000.00
SCC5	14.32 (±4.85)	6.00	2.50	47.00	1.32 (±0.27)	1.00	0.50	3.00	3305.00 (±2399.62)	370.00	15.00	27000.00
SCC6	32.91 (±16.54)	10.00	2.50	180.00	1.32 (±0.25)	1.00	0.50	3.00	1051.18 (±474.83)	300.00	35.00	5300.00

Bacteroides

The collection of water samples for bacteroides analysis occurred on two occasions, in April and August 2023. During the April sampling event, conditions were mild with 2.4 mm of rain falling in the 24 hours prior to sampling and 26.2 mm of rain occurring on the day of sampling (BOM, 2024). Conditions during the August monitoring event were cool to mild with 32.0 mm of rain falling in the seven days prior to sampling (BOM, 2024).

Bacteroides were detected in water from all ten sites across Lake Illawarra catchment, including from both human and animal sources. A summary of results is outlined in Table 10.

Findings show that human bacteroides were generally low across the ten sites sampled, typically being <0.4 copies/mL at seven sites in April 2023 (M1, M2, F1, R1, R2, R3, and SCC6) and five sites in August 2023 (M1, M2, F1, M5, and R1). The highest level of human bacteroides was detected at RE1 in August 2023, with 29 copies/mL. Low levels of human bacteroides were also detected at SCC5 (1.2 copies/mL) and RE1 (<4 copies/mL) in April 2023, and at R2 (4.3 copies/mL), R3 (<4 copies/mL), SCC5 (10.0 copies/mL), and SCC6 (5.0 copies/mL) in August 2023. Sources of human bacteroides include potential sewage leaks and stormwater runoff into waterways.

Conversely, all sites had higher levels of animal bacteroides (all animals excluding ruminants) compared to human derived sources for both sampling events. The highest detected animal bacteroides levels occurred at SCC5 (37,000 copies/mL) in August 2023, whereas the highest concentration in April 2023 was at M5 (2,300 copies/mL).

This is in line with expectations as agricultural land use and livestock, including cows, are found in the Macquarie Rivulet and Mullet Creek catchments. This is also reflected in the high ruminant (such as cows and deer) bacteroides value (25,000 copies/mL and 16,000 copies/mL) at these two sites respectively.

Animal bacteroides were also detected across the urban catchments at lower levels which can be attributed to animals such as dogs, horses, wallabies and kangaroos.

The occurrence of ruminant bacteroides across all sites highlights the presence of cattle and feral deer within the Lake Illawarra catchment and that faecal contamination has the potential to be transported downstream to urban areas, with levels ranging from 4.8 copies/mL at R3 to 560 copies/mL at R1 in April 2023, and 35 copies/mL at R3 to 25,000 copies/mL at R1 in August 2023.

Table 10: Mean bacteroides, including human, animal, and ruminant bacteroides, in water quality samples from ten Lake Illawarra catchment monitoring sites for two sampling events in April and August 2023.

	Date	Human Bacteroides (copies/mL)	Animal Bacteroides (copies/mL)	Ruminant Bacteroides (copies/mL)
M1	April 2023	<0.4	19	39
	August 2023	<0.4	87	62
M2	April 2023	<0.4	12	9.3
	August 2023	<0.4	1400	1400
F1	April 2023	<0.4	12	37
	August 2023	<0.4	230	190
M5	April 2023	2.3	2300	16000
	August 2023	<0.4	470	410
R1	April 2023	<0.4	19	560
	August 2023	<0.4	25000	12000
R2	April 2023	<0.4	48	470
	August 2023	4.3	8300	8300
RE1	April 2023	<4	16	<4
	August 2023	29	160	140
R3	April 2023	<0.4	11	4.8
	August 2023	<4	35	33
SCC5	April 2023	1.2	670	1800
	August 2023	10.0	37000	25000
SCC6	April 2023	<0.4	490	2200
	August 2023	5.0	1300	930

Catchment summaries

This section provides an overview of conditions at each site within each catchment, based on interpretation of water quality results. It is intended that the information provided for each site and catchment assists Council in their assessment of waterway health.

Mullet Creek

Five sites (M1, M2, DA1, F1 and M5) were sampled within the Mullet Creek catchment on 25 occasions between December 2021 and April 2024, with 14 dry weather monitoring events and 11 wet weather monitoring events. A summary of findings for each water quality parameter is outlined below.

pH

Overall, pH remained similar across all Mullet Creek sites during dry weather monitoring for the 2021-24 period (Figure 3). Whilst there was some variability in median pH at all sites, recorded values within the upper and lower quartiles of data largely overlapped between sites and were highest at M5. Outlier values were observed at M1 and DA1.

During wet weather monitoring, there was more variability in pH at Mullet Creek sites, however, ranges still largely overlapped and M5 maintained the highest pH values recorded (Figure 4).

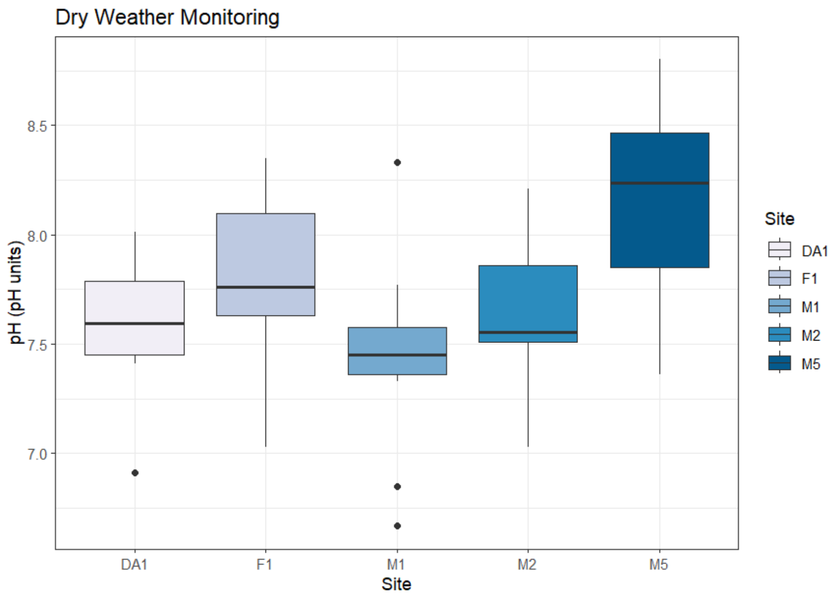

Figure 3: Summary of pH (pH units) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

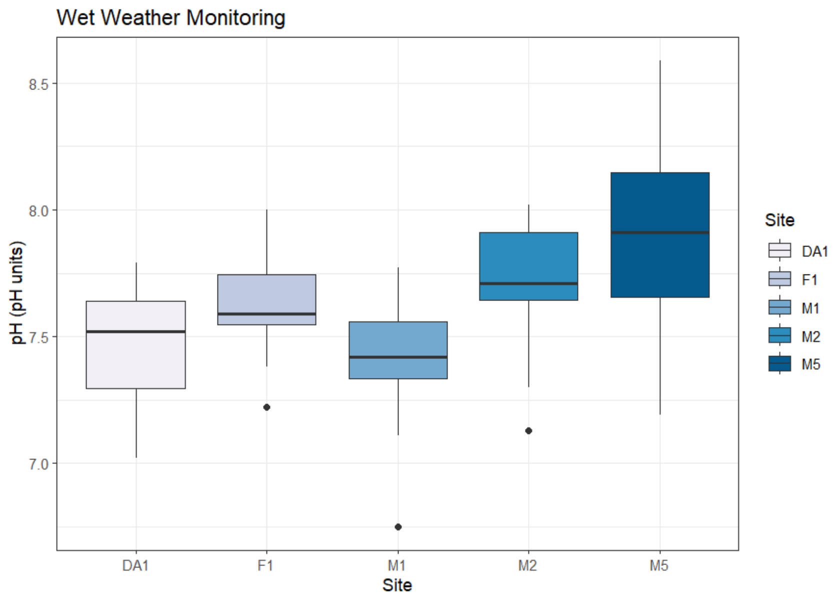

Figure 4: Summary of pH (pH units) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, pH at Mullet Creek sites was predominantly within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units (Figure 5). However, the upper guideline limit was exceeded on 19 occasions. This included at M1 in February 2024, on three occasions at M2 (in February, June and August 2023), on two occasions (February and June 2023) at DA1, on three occasions at F1 (in February, June and August 2023), and on nine occasions at M5 (in December 2021, 2022, and 2023, January 2022, February 2022 and 2023, August 2022 and 2023, and October 2023). The highest pH was recorded at M5 in August 2023, at 8.80 pH units. The median pH for Mullet Creek sites (7.70 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

During wet weather monitoring, pH at Mullet Creek sites was predominantly within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units (Figure 6). The upper guideline limit was exceeded on seven occasions, at M2 in May 2022, F1 in January 2023, and at M5 on four occasions (in January, June, August, and November 2023). The median pH for Mullet Creek sites (7.60 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

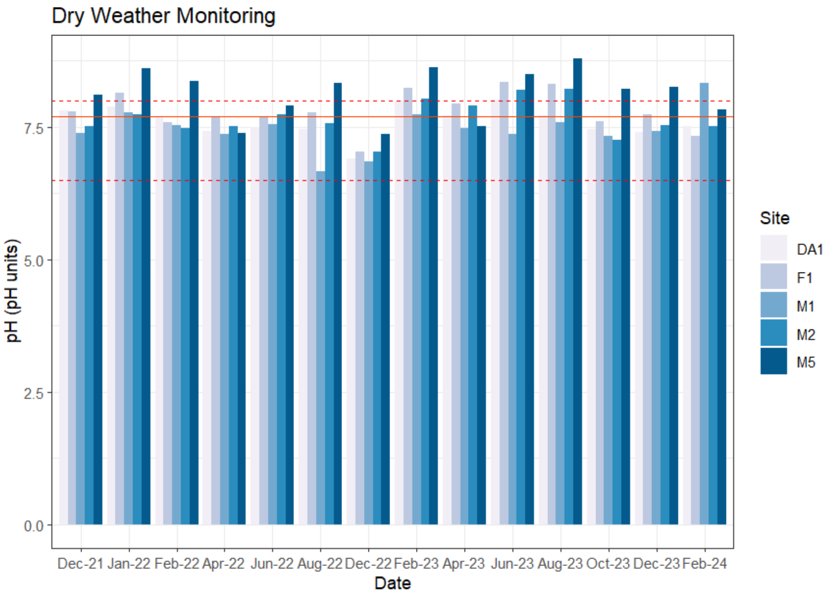

Figure 5: pH (pH units) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

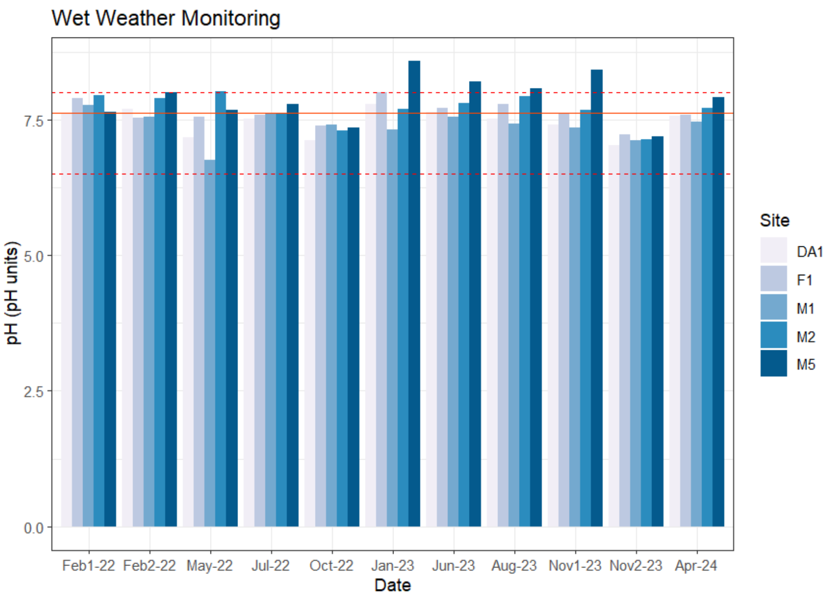

Figure 6: pH (pH units) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Electrical conductivity

Electrical conductivity experienced a wide range at M1 compared to the other Mullet Creek sites during dry weather monitoring for the 2021-24 period (Figure 7). All other sites had a narrow range of observed values that largely overlapped, and outlier values were observed at M2.

During wet weather monitoring, this trend was maintained, with a wide range of variability in electrical conductivity at M1, however, maximum values were lower compared to dry weather monitoring. Ranges still largely overlapped for the other four sites (Figure 8).

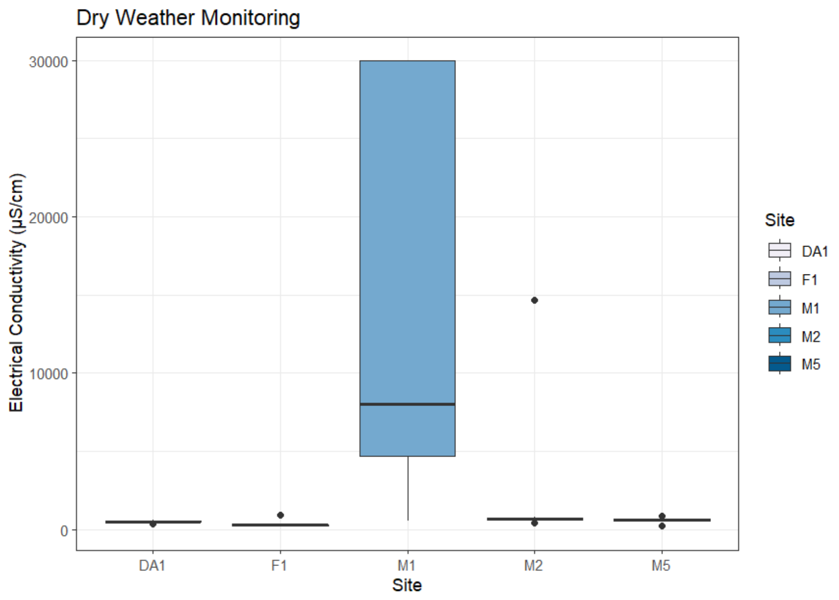

Figure 7: Summary of electrical conductivity (µS/cm) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

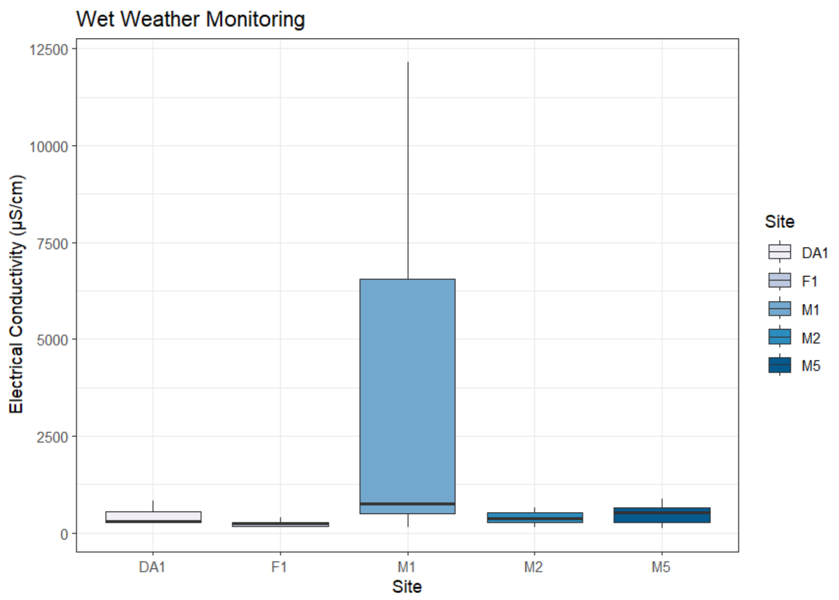

Figure 8: Summary of electrical conductivity (µS/cm) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, electrical conductivity at Mullet Creek sites frequently exceeded the upper ANZECC (2000) guideline of 300 µS/cm at all sites (Figure 9). Compliance was only observed on 12 occasions. M1 had consistently high electrical conductivity relative to other Mullet Creek sites and was non-compliant on all 14 occasions, with a maximum that was over the detection threshold of equipment used (30,000 µS/cm) in December 2022, April, June, August, October, and December 2023. M2 and DA1 also exceeded the upper guideline on all 14 occasions during the 2021-2024 monitoring period. Electrical conductivity at F1 exceeded 300 µS/cm on four occasions across the monitoring period, in June, August, October 2023, and February 2024. M5 was compliant on two occasions, in April 2023 and February 2024. The median electrical conductivity for Mullet Creek sites (577.0 µS/cm) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, electrical conductivity at Mullet Creek was overall lower compared to dry weather monitoring. However, the upper ANZECC (2000) guideline was still exceeded at all sites on 32 occasions (Figure 10). In line with dry weather monitoring, M1 had consistently high electrical conductivity relative to other Mullet Creek sites, with a maximum of 12,164 µS/cm in June 2023. All sites were compliant with the ANZECC (2000) guidelines on at least one occasion during wet weather monitoring, including at M1 in October 2022 (152.0 µS/cm), M2 in May 2022 (264.0 µS/cm) and October 2022 (139.0 µS/cm), DA1 on six occasions (in May, July, and October 2022, January and November 2023, and April 2024). F1 was non-compliant on only two occasions, in February 2022 and June 2023, whereas M5 was compliant on four occasions (in July and October 2022, November 2023, and April 2024). The median electrical conductivity for Mullet Creek sites (491.0 µS/cm) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

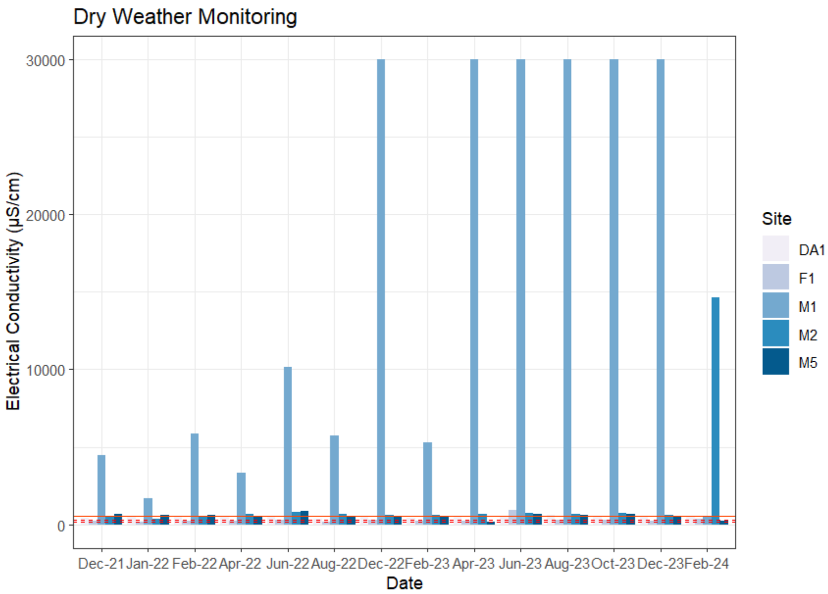

Figure 9: Electrical conductivity (µS/cm) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

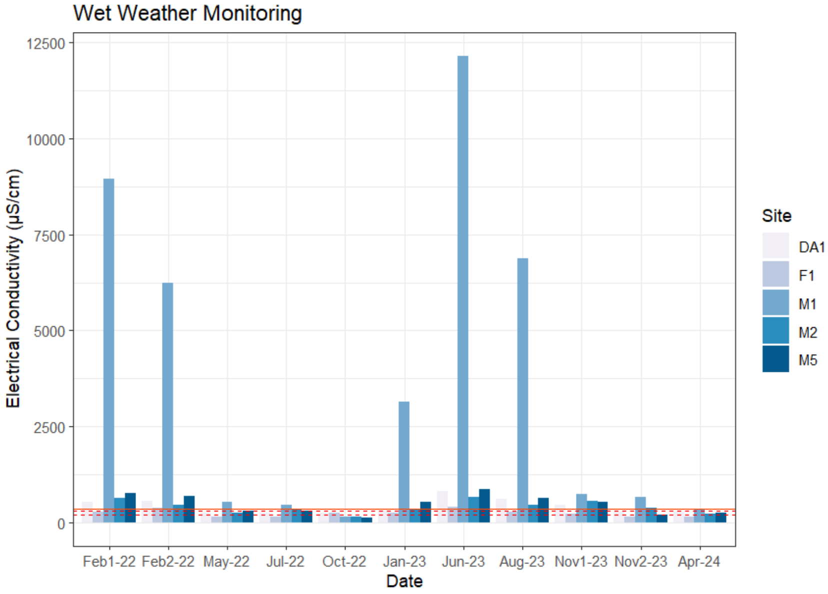

Figure 10: Electrical conductivity (µS/cm) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Temperature

Temperature remained consistent between the Mullet Creek sites throughout the 2021-2024 dry weather monitoring period (Figure 11), with the range of all sites overlapping.

During wet weather monitoring, temperature at all sites remained consistent, however, there was a wider range at M1 (Figure 12).

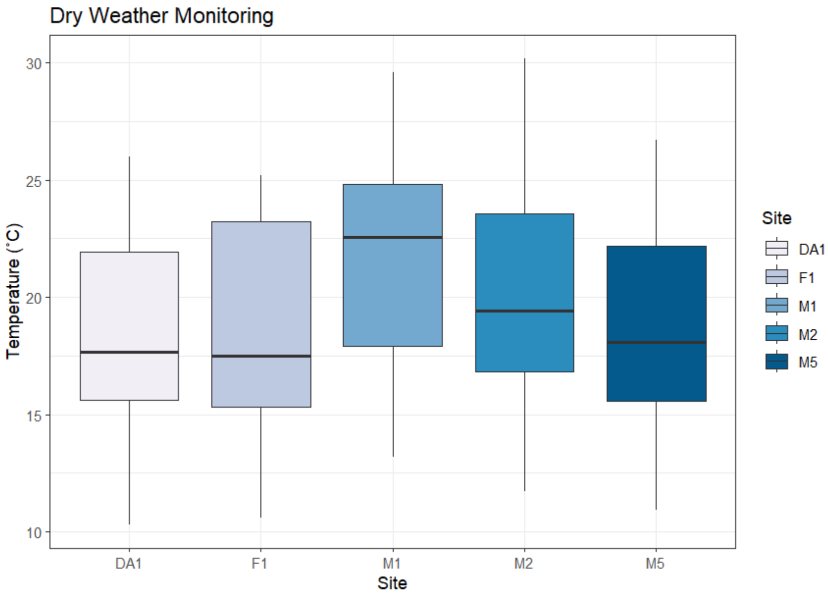

Figure 11: Summary of temperature (˚C) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

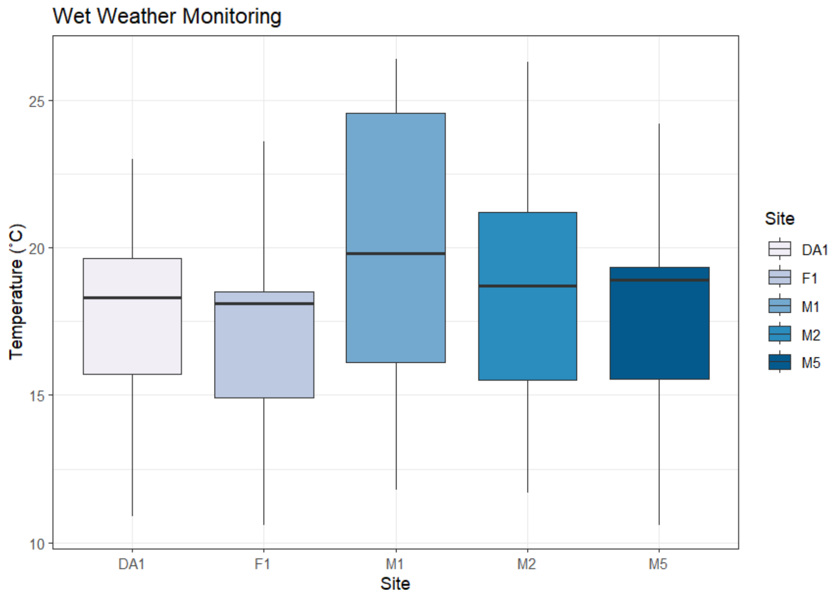

Figure 12: Summary of temperature (˚C) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, temperature ranged from a maximum of 30.2˚C at M2 in February 2024 and a minimum of 10.3˚C at DA1 in June 2022 (Figure 13). Mullet Creek sites all showed similar temperature trends. Temperature was not recorded during April and June 2023 monitoring due to equipment error. The median temperature for Mullet Creek sites was 19.6˚C during dry weather monitoring.

During wet weather monitoring, temperature ranged from a maximum of 26.4˚C at M1 in February 2022 and a minimum of 10.6˚C in June 2023 at F1 and August 2023 at M5 (Figure 14). Mullet Creek sites all showed similar temperature trends. There are currently no ANZECC (2000) guidelines for temperature for lowland rivers and temperature can also experience temporal and diurnal changes at sites. The median temperature for Mullet Creek sites was 18.9˚C during wet weather monitoring.

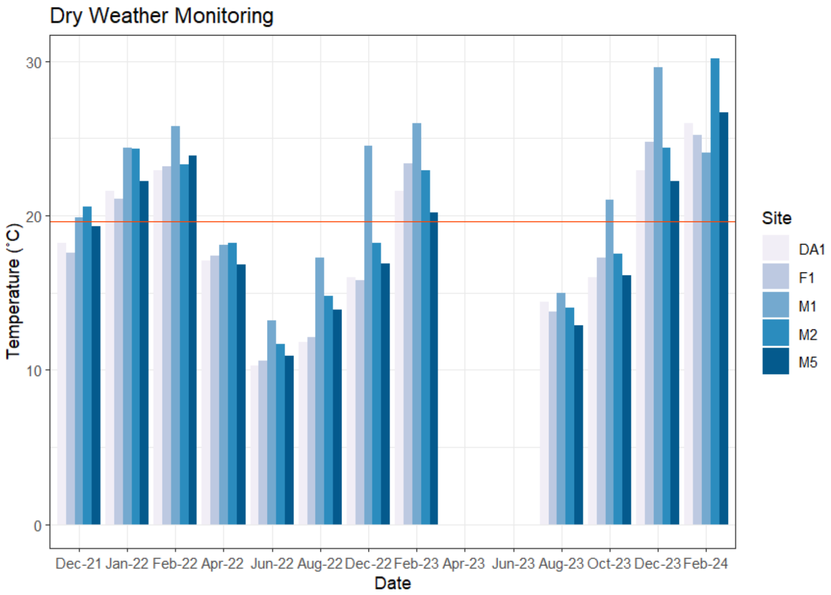

Figure 13: Temperature (˚C) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment. Temperature was not recorded in April 2023 and June 2023 due to equipment error.

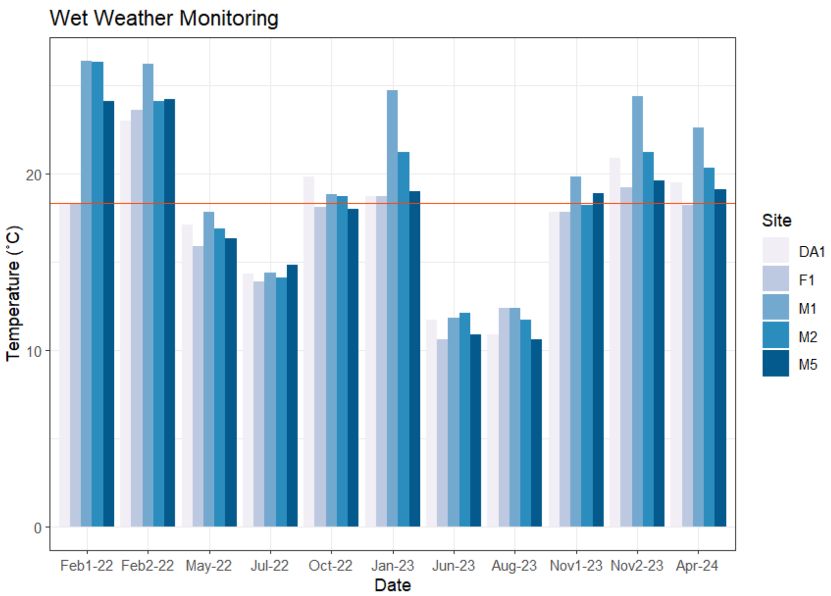

Figure 14: Temperature (˚C) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Dissolved oxygen

Dissolved oxygen was variable between Mullet Creek sites during dry weather monitoring for the 2021-24 period (Figure 15). Whilst there was some overlap between the ranges of each site, M2 had the lowest recorded values and M5 had the highest dissolved oxygen.

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped, with more variation at M2 and M5 maintained the highest dissolved oxygen values recorded (Figure 16).

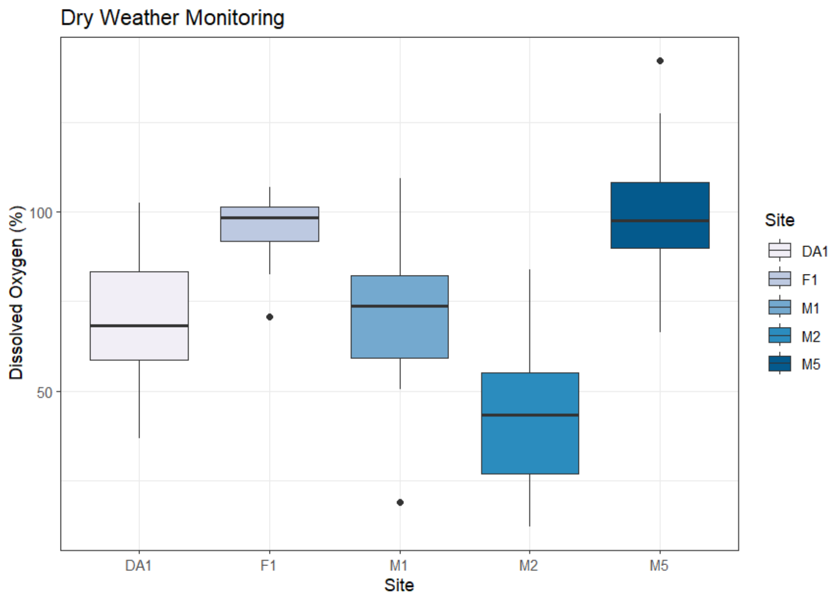

Figure 15: Summary of dissolved oxygen (%) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

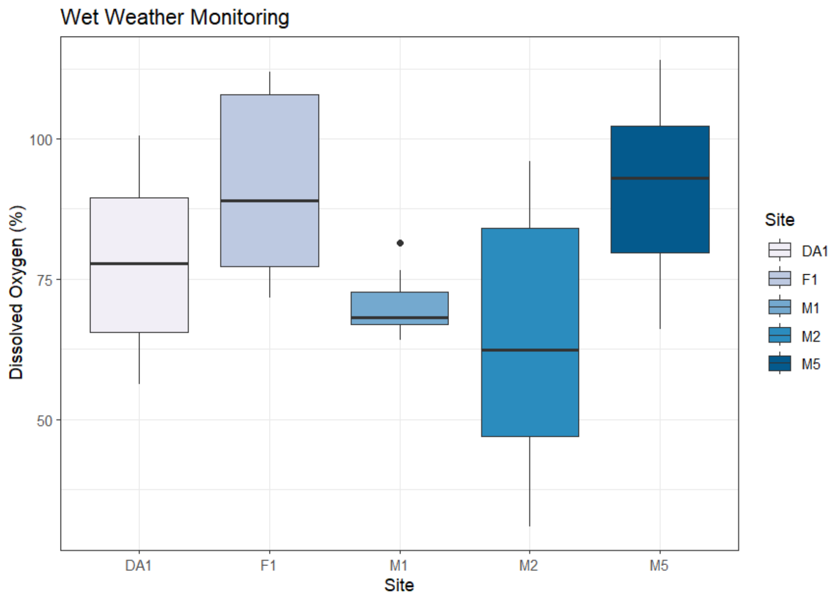

Figure 16: Summary of dissolved oxygen (%) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, dissolved oxygen levels at Mullet Creek sites were compliant with the ANZECC (2000) guidelines of 85-110% on 31 occasions (Figure 17). This included at M1 in February 2023 and 2024 and April 2023, however, M2 did not comply with the guidelines during the 2021-2024 monitoring period. DA1 was compliant on three occasions (in April and August 2022, and February 2023). At F1 dissolved oxygen was non-compliant in October 2023 and February 2024, and at M5 non-compliance occurred in June 2022. The highest dissolved oxygen was recorded at M5 in August 2023 (142.4%) and the lowest was at M2 in February 2022 (12.1%). The median dissolved oxygen for Mullet Creek sites (81.20%) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, dissolved oxygen levels at Mullet Creek sites had lower compliance compared to dry weather monitoring (Figure 18). Dissolved oxygen was compliant with the ANZECC (2000) guidelines on 19 occasions. This included at M2 in May and October 2022, and August 2023, and DA1 in May and October 2022, and January 2023. M1 was not compliant with the guidelines during the 2021-2024 monitoring period, and there was non-compliance at F1 in February 2022, July 2022, January 2023, and August 2023, and at M5 in February 2022, July 2022, and June 2023. The median dissolved oxygen for Mullet Creek sites (71.35%) during wet weather monitoring was below the ANZECC (2000) guidelines.

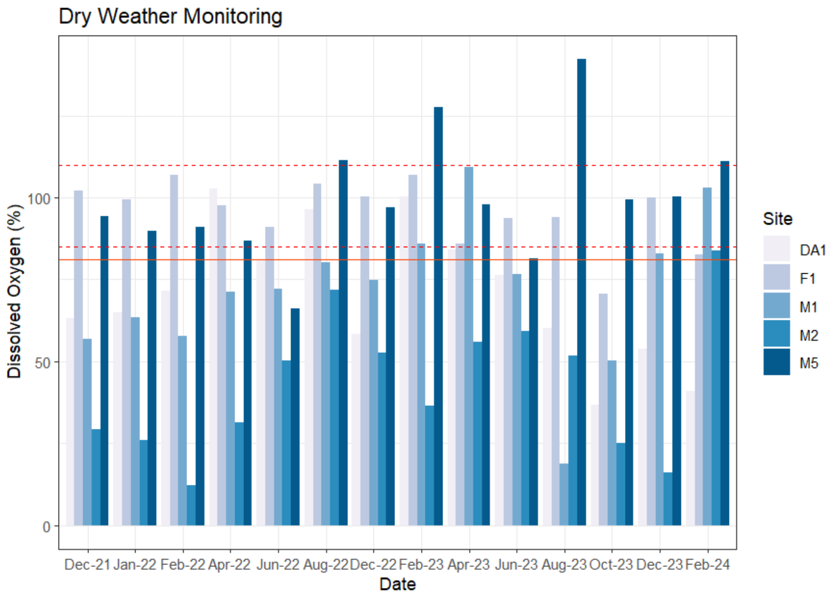

Figure 17: Dissolved oxygen (%) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

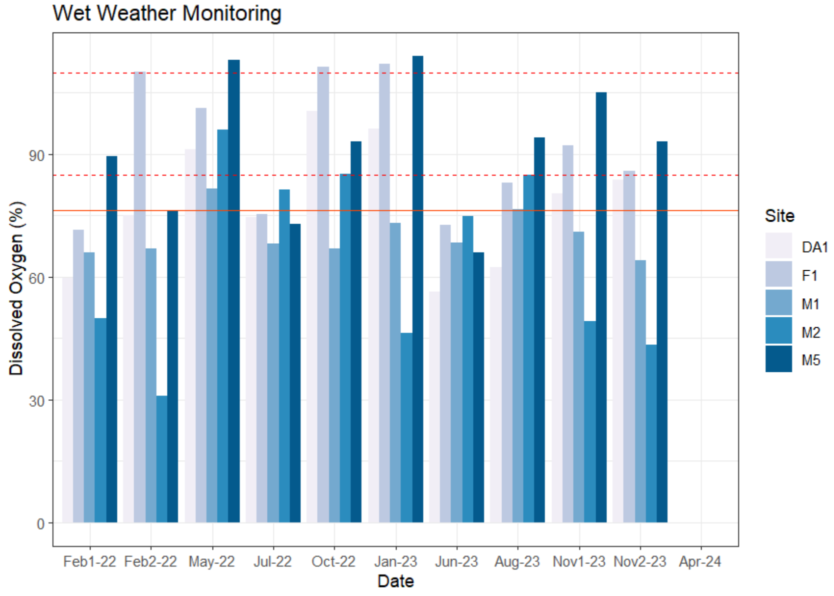

Figure 18: Dissolved oxygen (%) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Turbidity

Turbidity was variable between Mullet Creek sites during dry weather monitoring for the 2021-24 period (Figure 19). Whilst there was some overlap between the ranges of each site and the medians were similar, M1 had the widest range of turbidity values recorded and M5 had the lowest range but outliers were present.

During wet weather monitoring, there was less variability within each site. However, ranges still largely overlapped, and outliers occurred at all sites (excluding M5), and this was most notable at M2 (Figure 20).

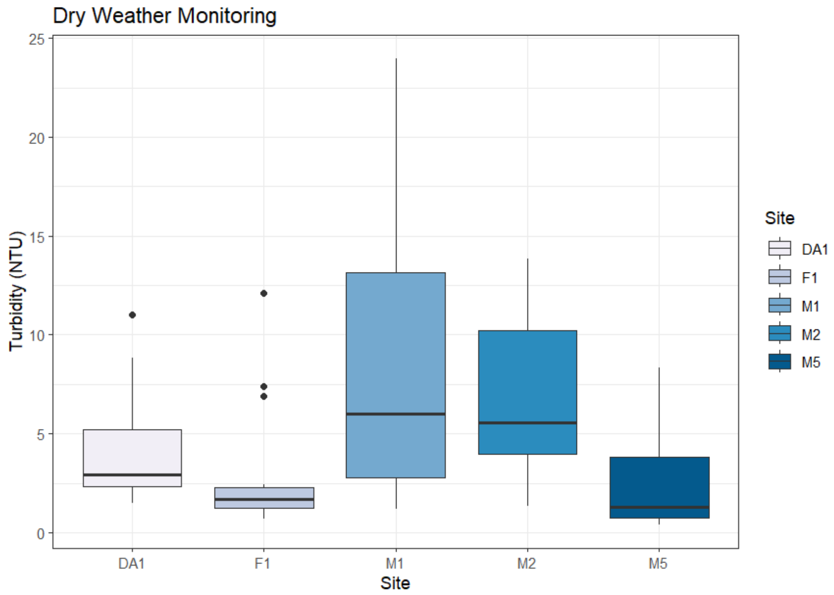

Figure 19: Summary of turbidity (NTU) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

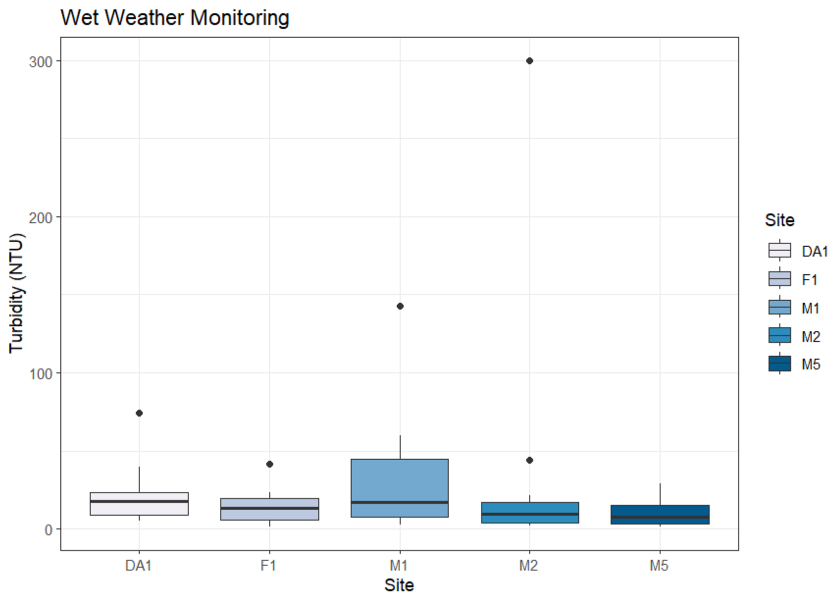

Figure 20: Summary of turbidity (NTU) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, turbidity at Mullet Creek sites remained within or below the ANZECC guideline range of 6 – 50 NTU at all sites. Maximum turbidity was recorded at M1 (24.0 NTU) in August 2022 (Figure 21). The median turbidity for Mullet Creek sites (2.94 NTU) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, turbidity at Mullet Creek sites largely remained within the ANZECC guideline range of 6 – 50 NTU. However, turbidity levels were slightly higher compared to dry weather monitoring and exceeded the ANZECC guidelines on five occasions (Figure 22). This included at M1 in May 2022, November 2023, and April 2024, at M2 in November 2023, and at DA1 in May 2022. The highest turbidity was recorded as M2 (300.0 NTU) in November 2023. The median turbidity for Mullet Creek sites (11.6 NTU) during wet weather monitoring was below the ANZECC (2000) guidelines. Results below 6 NTU should not be considered as non-compliant, instead is representative of very low suspended sediments, which is a positive result.

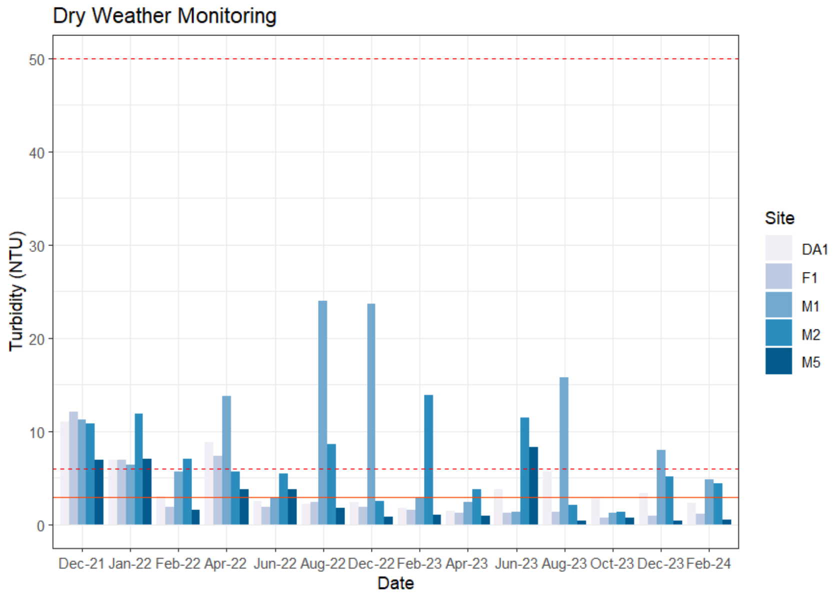

Figure 21: Turbidity (NTU) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

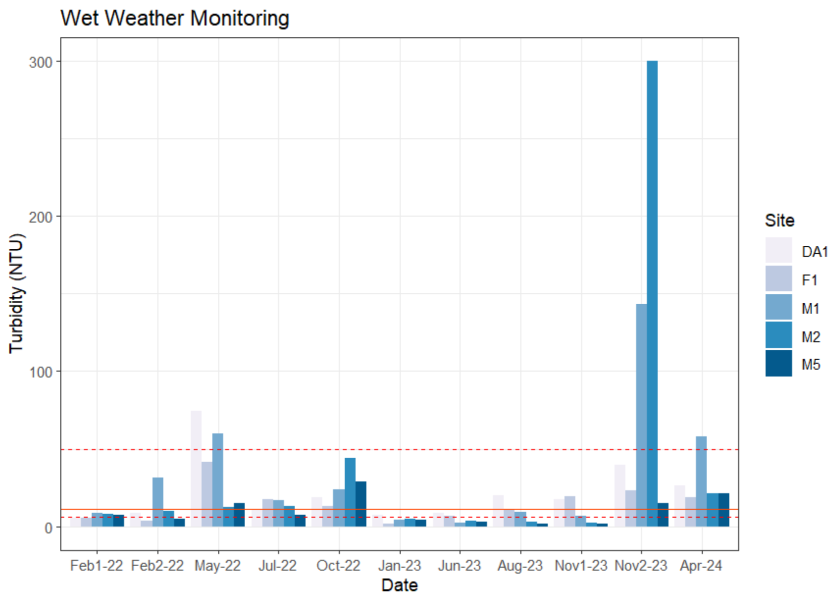

Figure 22: Turbidity (NTU) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Total Nitrogen

Total nitrogen remained consistent between Mullet Creek sites during dry weather monitoring for the 2021-24 period, and the range of all sites predominantly overlapped. However, each site experienced events where total nitrogen was elevated, as shown by the outliers present (Figure 23).

During wet weather monitoring, there was more variability within each site, and this was most evident at M1 and M2. However, ranges still largely overlapped for DA1, F1 and M5 (Figure 24).

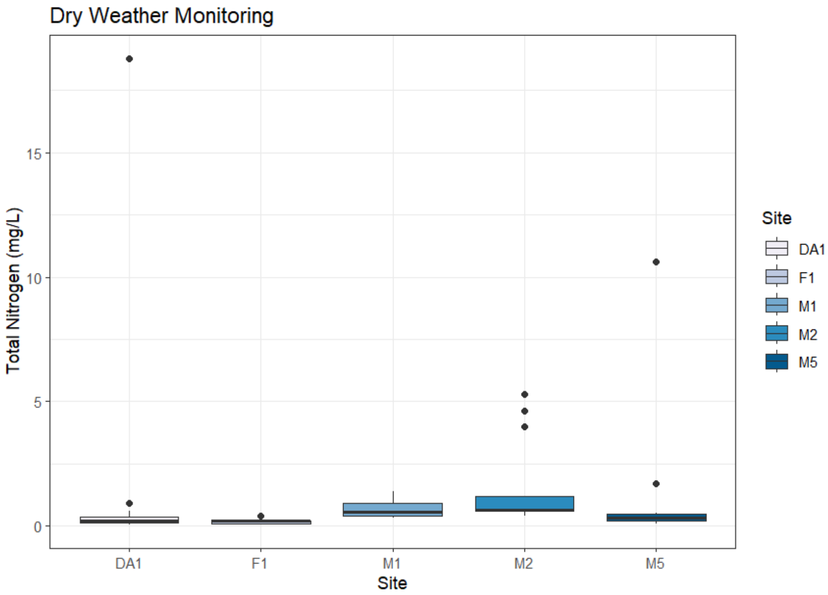

Figure 23: Summary of total nitrogen (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

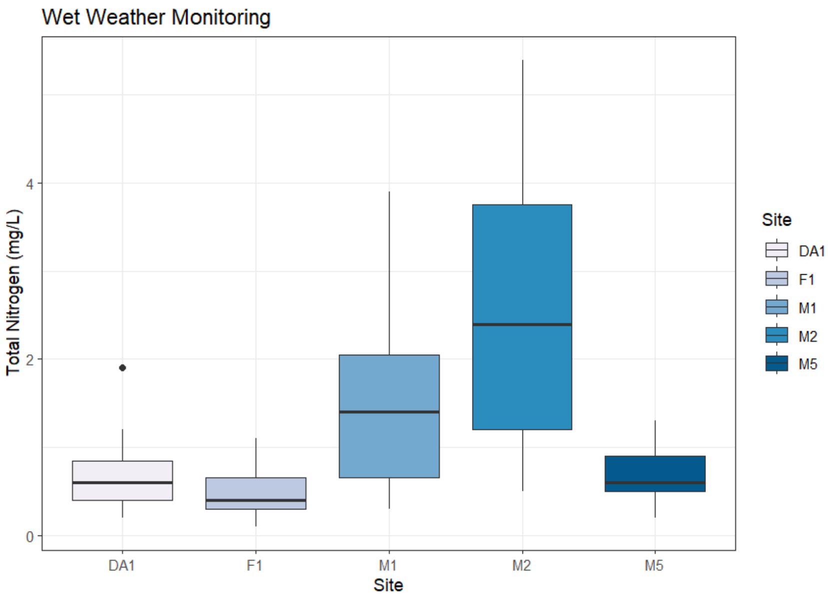

Figure 24: Summary of total nitrogen (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total nitrogen concentrations at Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.5 mg/L on 28 occasions (Figure 25). This included on nine occasions at M1 (in December 2021, 2022, and 2023, April 2022 and 2023, June 2022, August 2022, February 2023 and 2024), on 12 occasions at M2 (excluding in February 2022 and August 2023), on three occasions at DA1 (in June, August, and October 2023), and on four occasions at M5 (in December 2021, June 2022 and 2023, and February 2023). Total nitrogen at F1 was compliant with the ANZECC guideline for all sampling events. The median total nitrogen for Mullet Creek sites (0.4 mg/L) during wet weather monitoring was just below the ANZECC (2000) guidelines.

During wet weather monitoring, non-compliance with the ANZECC (2000) guideline for total nitrogen increased slightly at Mullet Creek sites. Total nitrogen concentrations exceeded the ANZECC (2000) guideline on 39 occasions (Figure 26). This included on nine occasions at M1 (excluding in June and August 2023), on all occasions at M2, on eight occasions at DA1 (excluding during both February 2022 events and in June 2023), on four occasions at F1 (in May 2022, October 2022 and both November 2023 sampling events), and on seven occasions at M5 (in May 2022, October 2022, January 2023, August 2023, November 2023 (both sampling events), and April 2024). The median total nitrogen for Mullet Creek sites (1.0 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

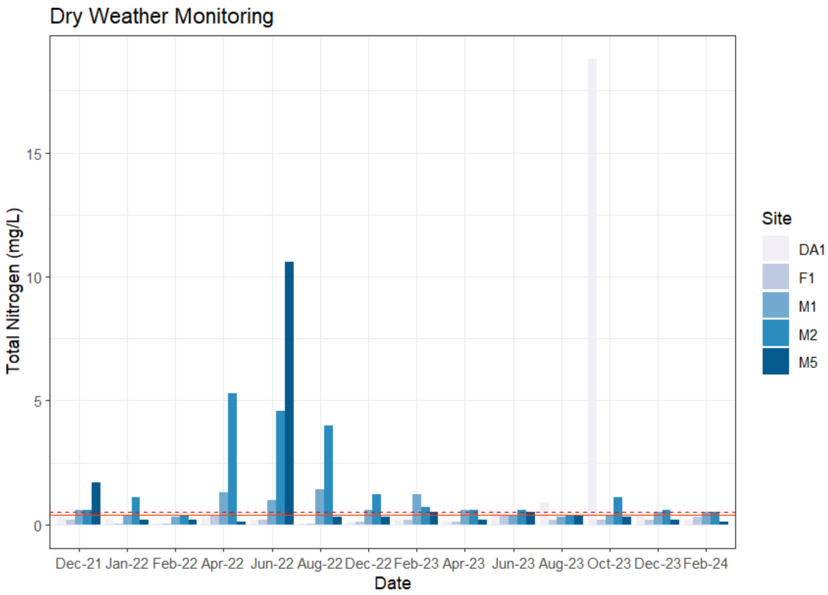

Figure 25: Total nitrogen (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

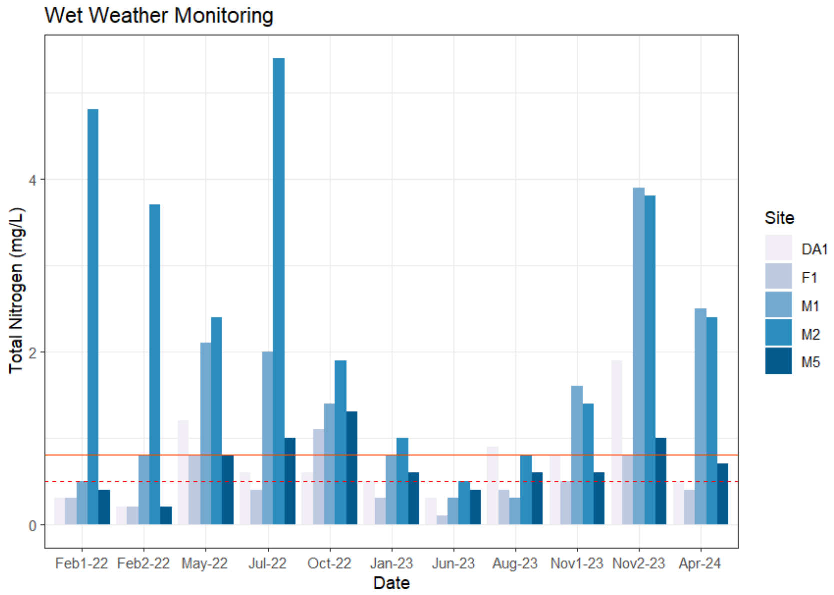

Figure 26: Total nitrogen (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Ammonia

Ammonia was within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. However, each site experienced events where ammonia was elevated (particularly at M5), as shown by the outliers present (Figure 27).

During wet weather monitoring, there was slightly more variability within each site. However, ranges still largely overlapped for all sites, and the highest value was recorded at M2 (Figure 24).

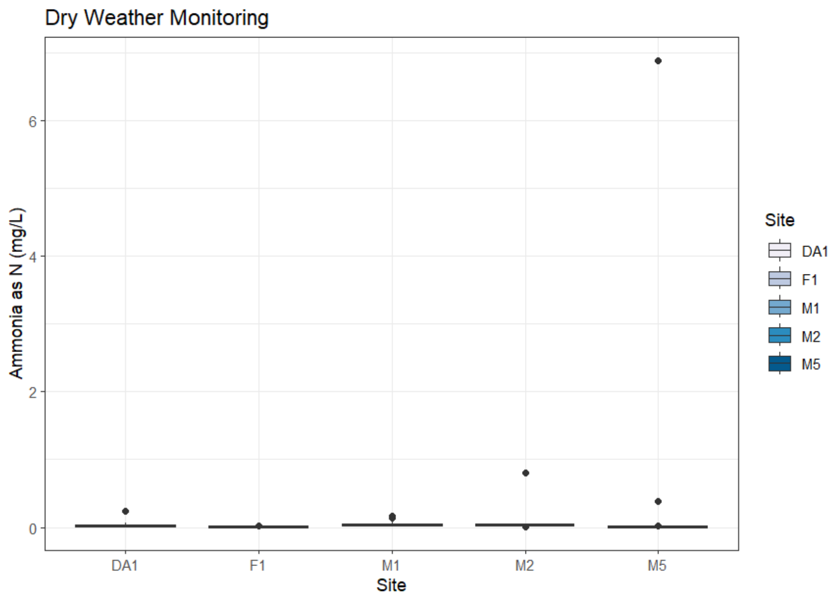

Figure 27: Summary of ammonia (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

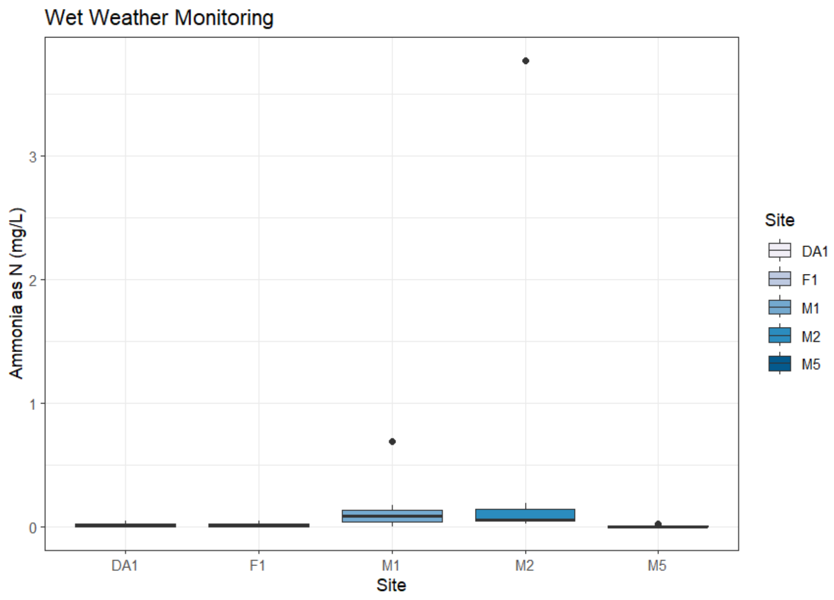

Figure 28: Summary of ammonia (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, ammonia concentrations at Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.02 mg/L on 39 occasions (Figure 29). This included on 11 occasions at M1 (excluding in April 2022, December 2022, and February 2023), on 11 occasions at M2 (excluding in August and December 2023), on ten occasions at DA1 (excluding in April 2022 and 2023, and December 2022 and 2023), on three occasions at F1 (in June 2022, October 2023, and February 2024), and on three occasions at M5 (in December 2021, and June 2022 and 2023). The highest ammonia value of 6.89 mg/L was recorded at M5 in June 2022. The median total nitrogen for Mullet Creek sites (0.02 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

During wet weather monitoring, ammonia concentrations at Mullet Creek sites also did not comply with the ANZECC (2000) guideline of 0.02 mg/L on 35 occasions (Figure 30). This included on ten occasions at M1 (excluding in the second February 2022 event), on all occasions at M2, on seven occasions at DA1 (excluding in May, July, October 2022, and April 2024), on five occasions at F1 (in May 2022, October 2022, January 2023, November 2023, and April 2024), and on two occasions at M5 (in January 2023 and November 2023). The maximum recorded ammonia value for wet weather monitoring was 3.77 mg/L at M2 in July 2022. The median total nitrogen for Mullet Creek sites (0.04 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

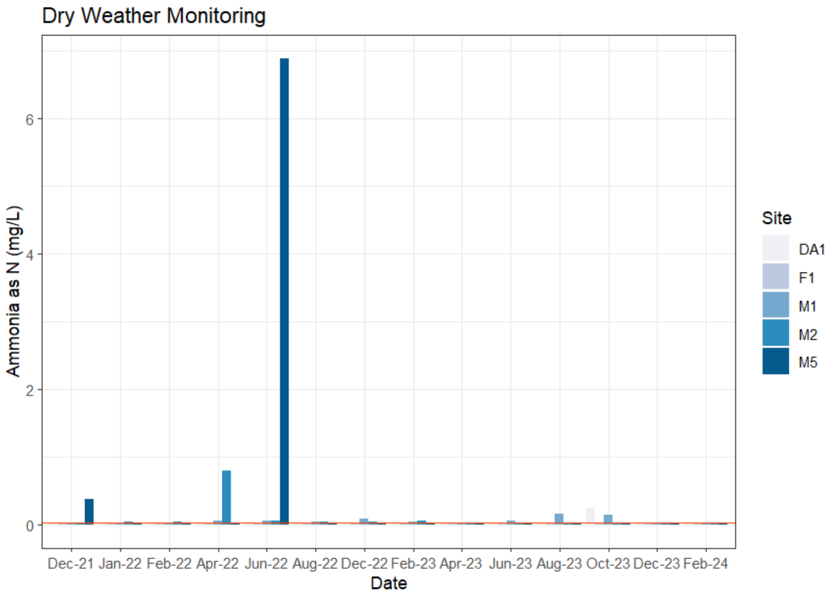

Figure 29: Ammonia (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

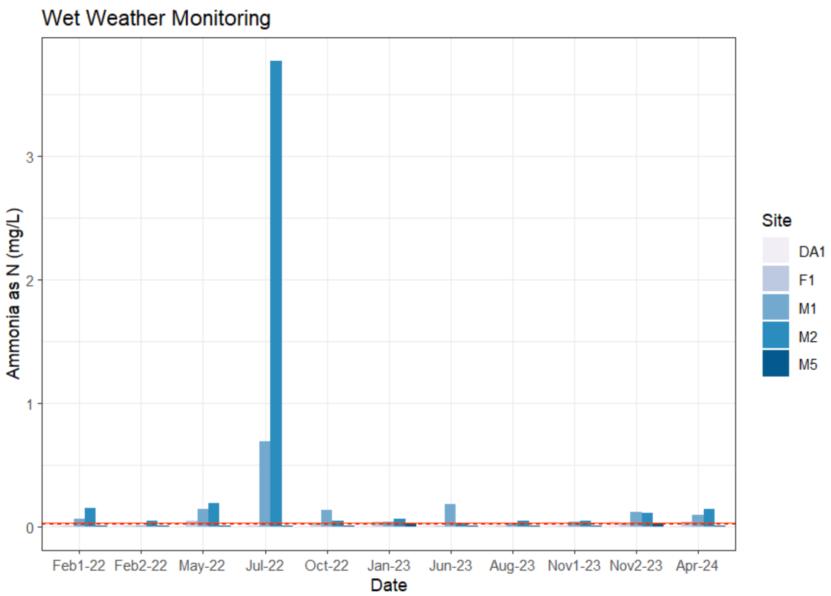

Figure 30: Ammonia (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

NOx

Nitrate and nitrite (NOx) concentrations were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. However, each site (excluding DA1) experienced events where NOx was elevated, as shown by the outliers present, and this was highest at M2 (Figure 31).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at M2 (Figure 32).

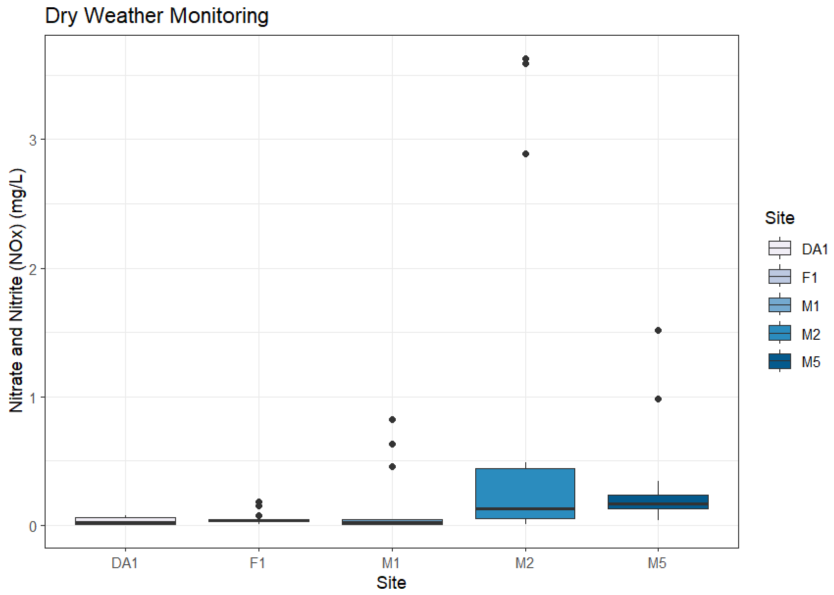

Figure 31: Summary of nitrate and nitrite (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

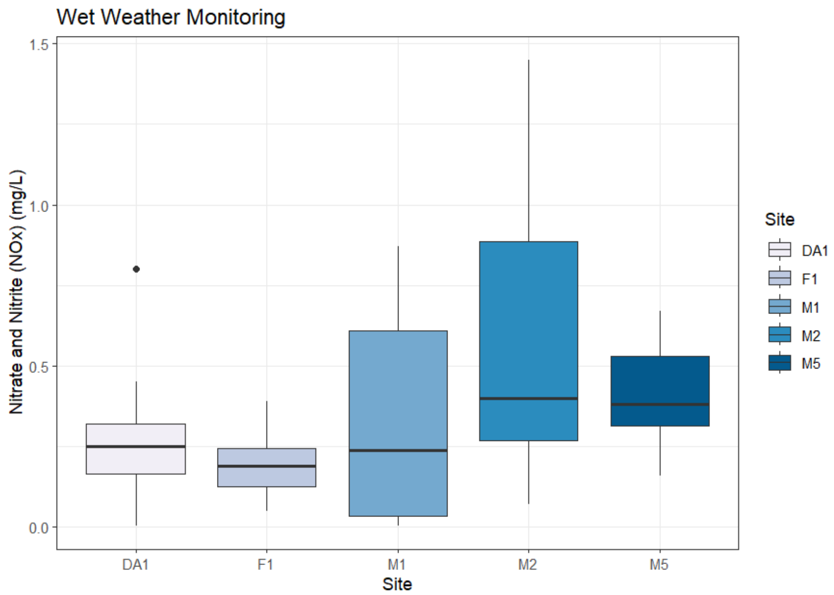

Figure 32: Summary of nitrate and nitrite (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, NOx concentrations at Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 47 occasions (Figure 33). This included at M1 on six occasions (in April 2022 and 2023, June 2022 and 2023, August 2022, and February 2022), on 11 occasions at M2 (excluding in August, October, and December 2023), on six occasions at DA1 (in December 2021, February 2022, April 2022, June 2022 and 2023, and August 2023), on ten occasions at F1 (in January 2022, August, October, and December 2023), and on all occasions at M5. The highest value was recorded at M2 in June 2022 (3.63 mg/L). The median NOx for Mullet Creek sites (0.05 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, NOx concentrations at Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 51 occasions (Figure 34). All sites were non-compliant with the ANZECC (2000) guideline during all sampling events, with the exception of M1 in February 2022, June and August 2023, and DA1 in June 2023. The highest value was recorded at M2 in November 2023 (1.45 mg/L). The median NOx for Mullet Creek sites (0.27 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

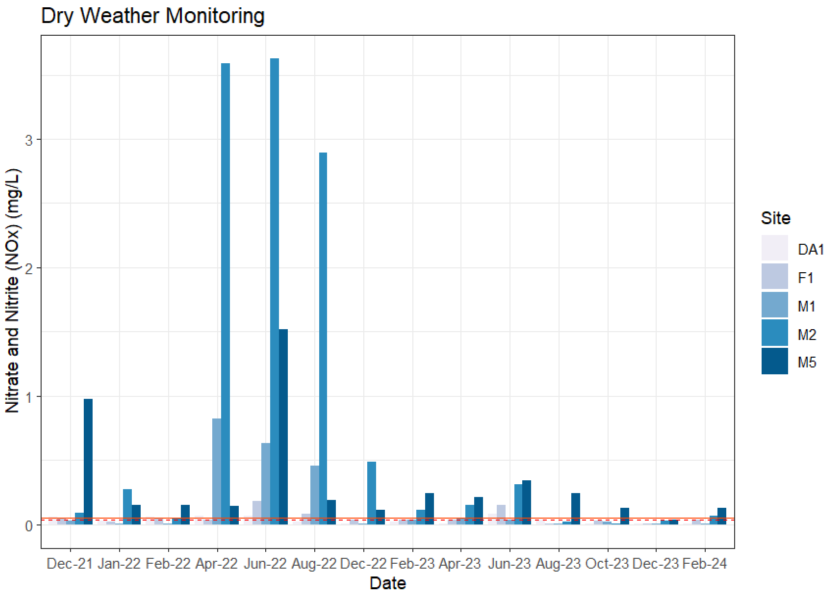

Figure 33: Nitrate and nitrite (NOx) (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

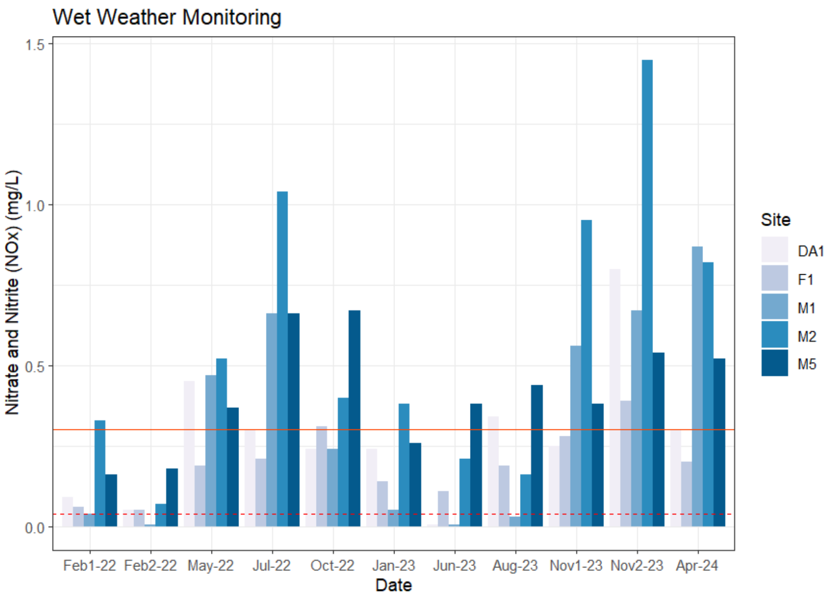

Figure 34: Nitrate and nitrite (NOx) (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Phosphorus

Total phosphorus concentrations were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. However, each site experienced events where total phosphorus was elevated, as shown by the outliers present, and this was highest at DA1 (Figure 35).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at M2 (Figure 36).

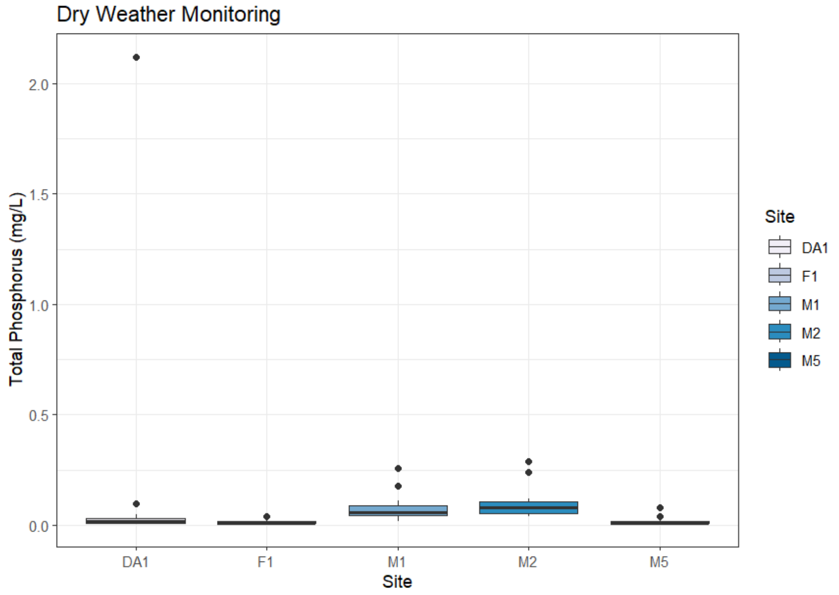

Figure 35: Summary of total phosphorus (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

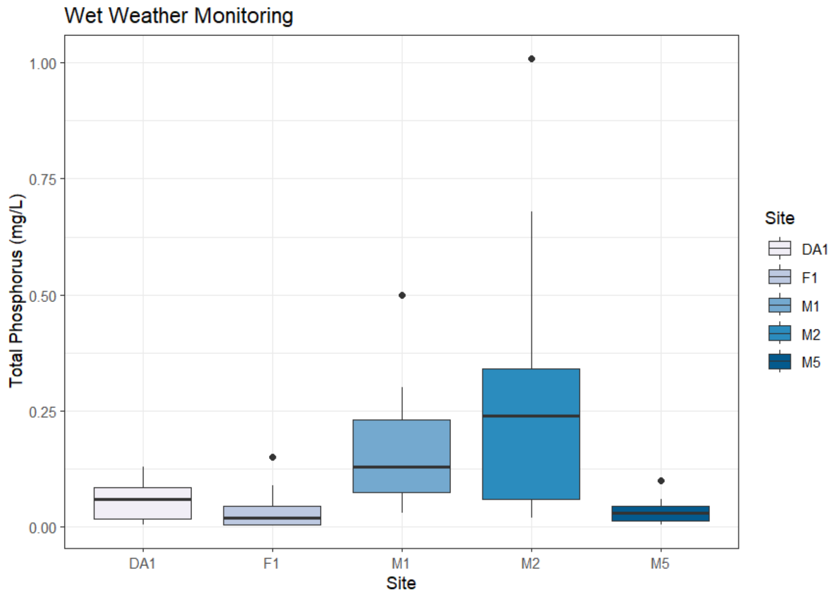

Figure 36: Summary of total phosphorus (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total phosphorus concentrations at Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.05 mg/L on 26 occasions (Figure 37). This included at M1 on ten occasions (excluding in

January 2022, February 2022, April 2022, and June 2023), on 12 occasions at M2 (excluding in August 2022 and 2023), on three occasions at DA1 (in June 2023, August 2023, and October 2023), and on one occasion at M5 (in February 2024). The ANZECC (2000) guidelines were not exceeded at F1. The highest total phosphorus value was recorded at DA1 in October 2023 (2.12 mg/L). The median total phosphorus for Mullet Creek sites (0.03 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, there was slightly higher non-compliance with the ANZECC (2000) guideline for total phosphorus at Mullet Creek sites compared to dry weather monitoring. The guideline was exceeded on 28 occasions (Figure 38). M1 exceeded the guideline on nine occasions (excluding in June and August 2023), and M2 exceeded the guideline on eight occasions (excluding in June, August, and November 2023). DA1 exceeded the total phosphorus guideline on six occasions (in May 2022, July 2022, October 2022, January 2023, and both November 2023 events), concentrations were above the guideline at F1 on three occasions (in May 2022, October 2022, and November 2023), and at M5 on two occasions (in October 2022 and November 2023). The median total phosphorus for Mullet Creek sites (0.07 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

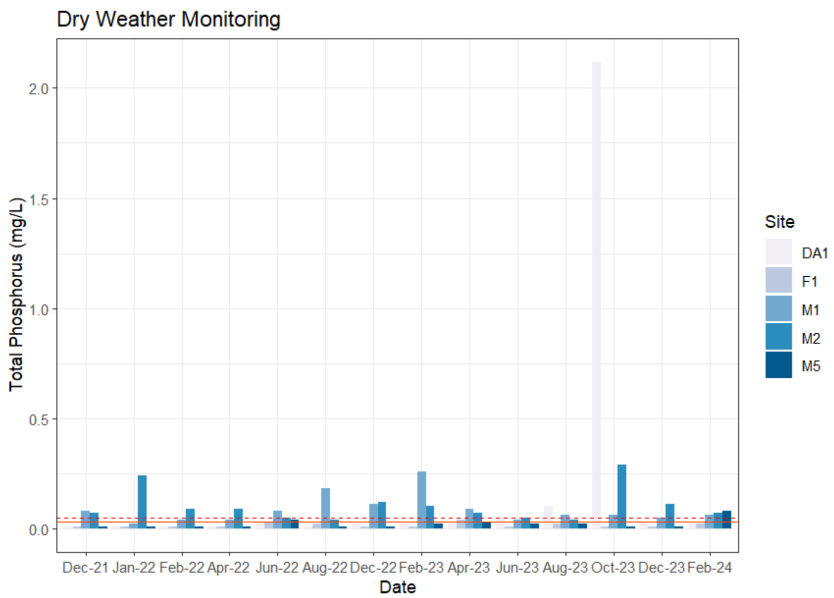

Figure 37: Total phosphorus (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

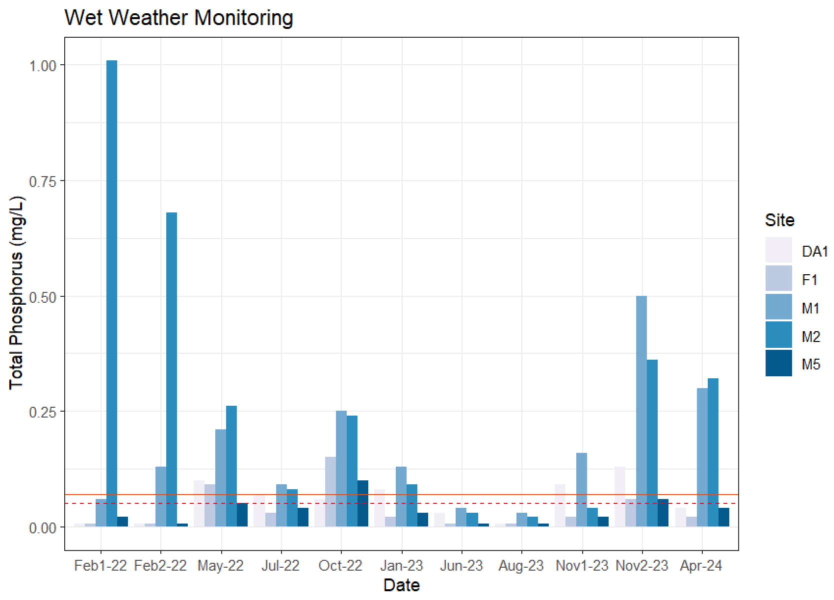

Figure 38: Total phosphorus (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Phosphate

Phosphate concentrations were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period, excluding at M2. However, the remaining four sites experienced events where phosphate was elevated, as shown by the outliers present, and this was highest at DA1 (Figure 39).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at M1 and M2 (Figure 40).

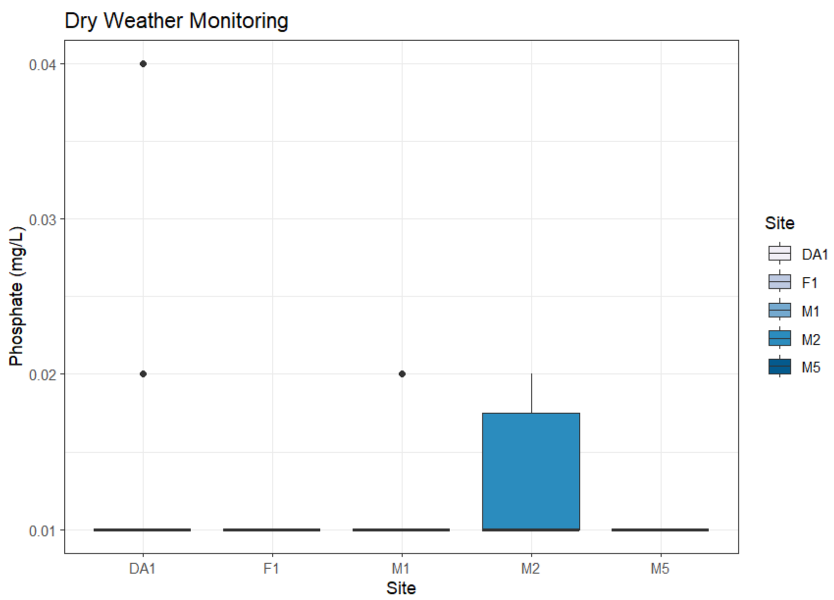

Figure 39: Summary of phosphate (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

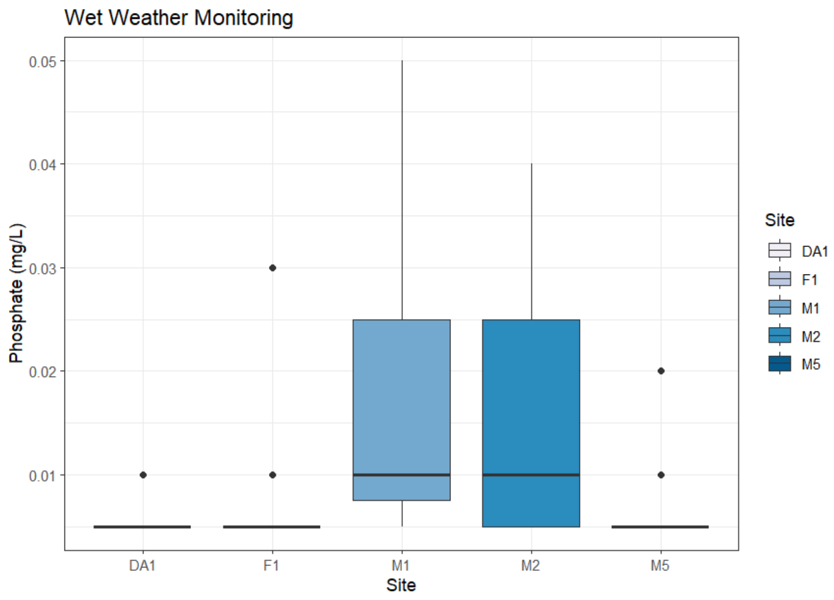

Figure 40: Summary of phosphate (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, phosphate concentrations at Mullet Creek sites were below detection limits (<0.01 mg/L) for the majority of sites and sampling events (Figure 41). This excluded on seven occasions, at M1 in April 2023, at M2 in February 2023, October 2023, December 2023, and February 2024, and at DA1 in October and December 2023. Phosphate levels did not exceed the ANZECC (2000) guideline (0.02 mg/L) at F1 and M5. The median phosphate for Mullet Creek sites (0.01 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, phosphate concentrations at Mullet Creek sites were below detection limits (<0.01 mg/L) for most sites and sampling events (Figure 42). However, the phosphate levels exceeded the ANZECC (2000) guideline (0.02 mg/L) on ten occasions. This included at M1 in February 2022, October 2022, and both November 2023 sampling events, at M2 in May 2022, October 2022, January 2023, and November 2023, at F1 in October 2022, and at M5 in October 2022. Phosphate levels did not exceed the ANZECC (2000) guideline (0.02 mg/L) at DA1 during wet weather monitoring. The median phosphate for Mullet Creek sites (0.01 mg/L) during wet weather monitoring was below the ANZECC (2000) guidelines.

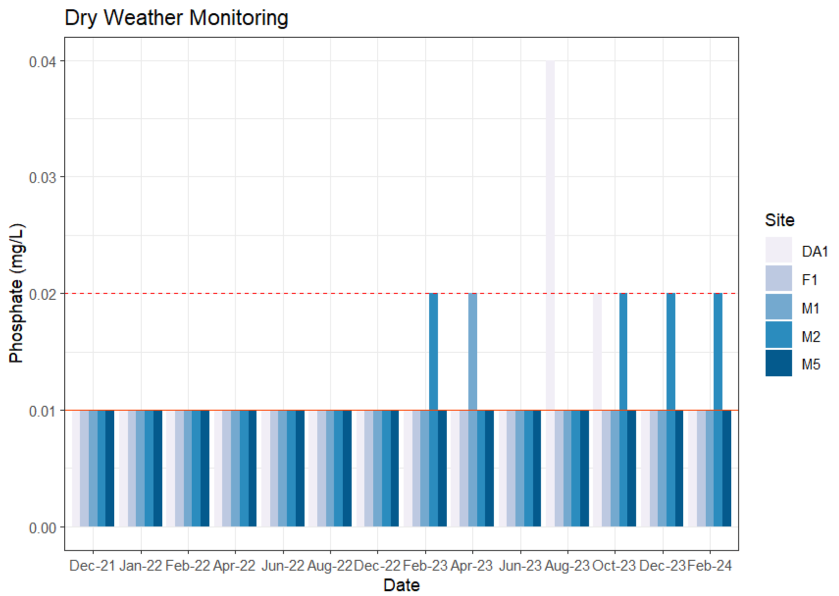

Figure 41: Phosphate (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

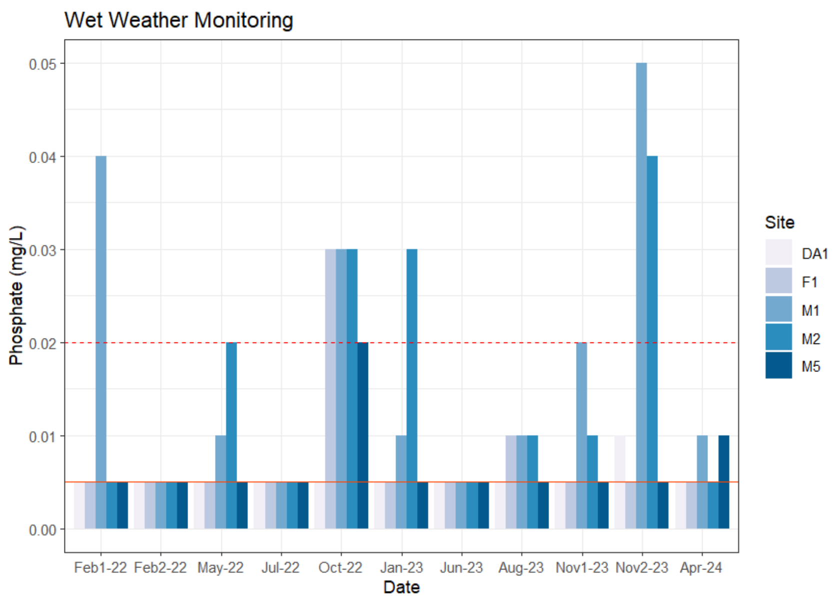

Figure 42: Phosphate (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2023. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Suspended Solids

Total Suspended Solids were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. However, all sites experienced events where levels were elevated, as shown by the outliers present, and this was highest at M2 (Figure 43).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at M2 (Figure 44).

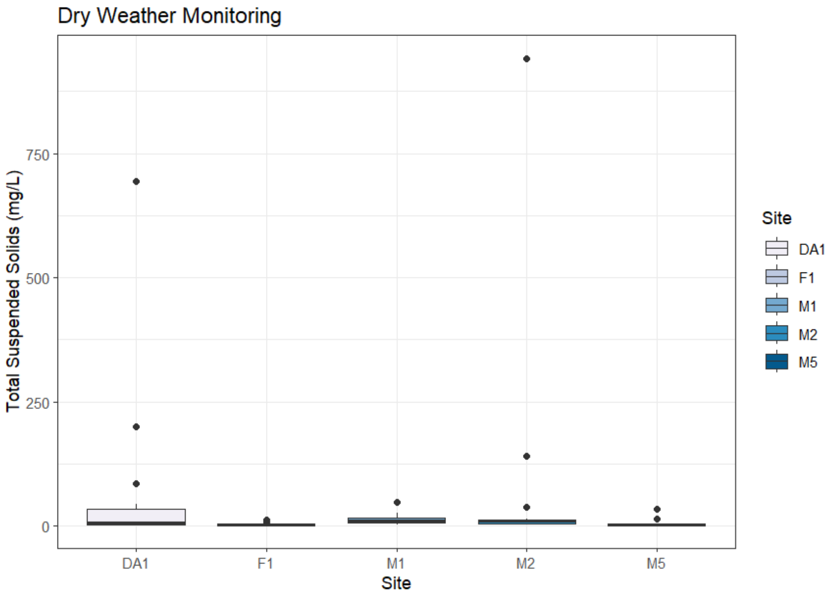

Figure 43: Summary of Total Suspended Solids (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

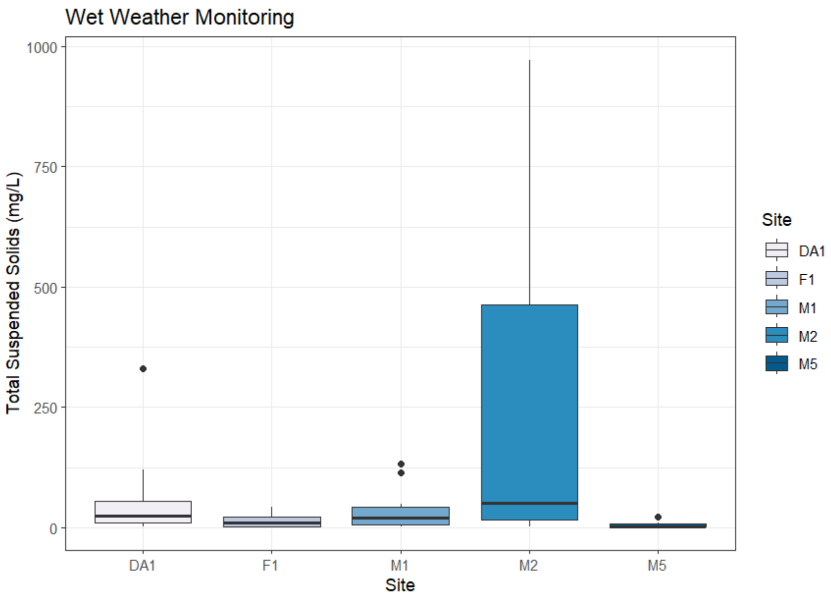

Figure 44: Summary of Total Suspended Solids (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total suspended solids were variable at all Mullet Creek sites, however, higher values were recorded at M2 in April 2022 (942 mg/L) and DA1 in October 2023 (694 mg/L) (Figure 45). The median total suspended solids for Mullet Creek sites was 2.50 mg/L during dry weather monitoring. There are currently no ANZECC (2000) guidelines for total suspended solids.

During wet weather monitoring, total suspended solids showed an increase compared to dry weather monitoring events, particularly at M2 (Figure 46). The highest value was recorded at M2 in February 2022 (972 mg/L). The median total suspended solids for Mullet Creek sites was 13.0 mg/L during wet weather monitoring.

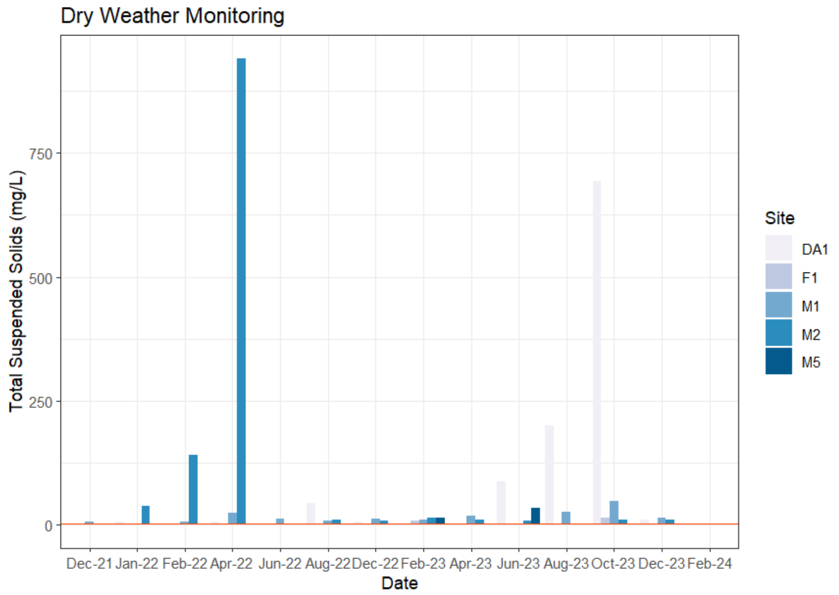

Figure 45: Total Suspended Solids (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024. The solid orange line represents the median for this catchment.

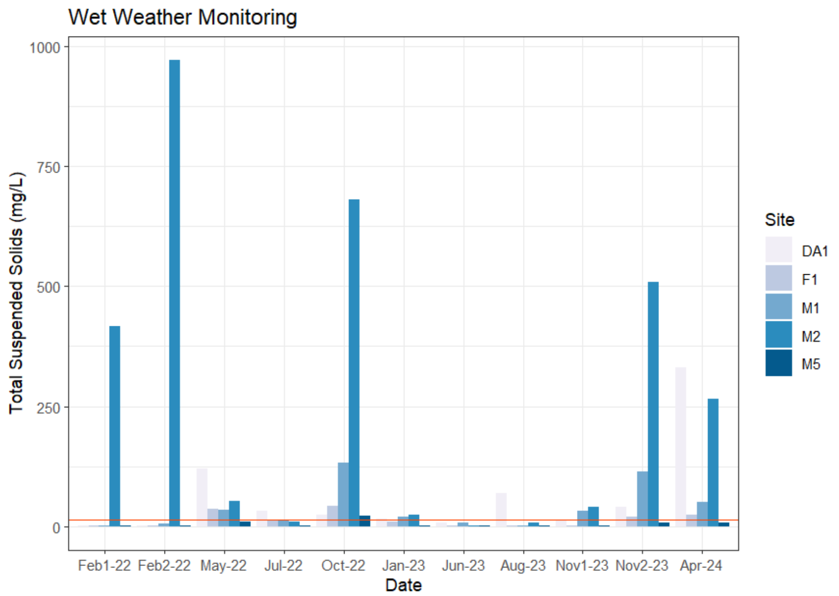

Figure 46: Total Suspended Solids (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Chlorophyll-a

Chlorophyll-*a* concentrations were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. Sites experienced events where chlorophyll-*a* was elevated, as shown by the outliers present (Figure 47). However, at DA1 a significant outlier event occurred where chlorophyll-*a* was 748 mg/L which was much higher relative to the other sites and sampling events, and this is not included in Figure 47 as it masked the trends for the other Mullet Creek sites.

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at M2 (Figure 48).

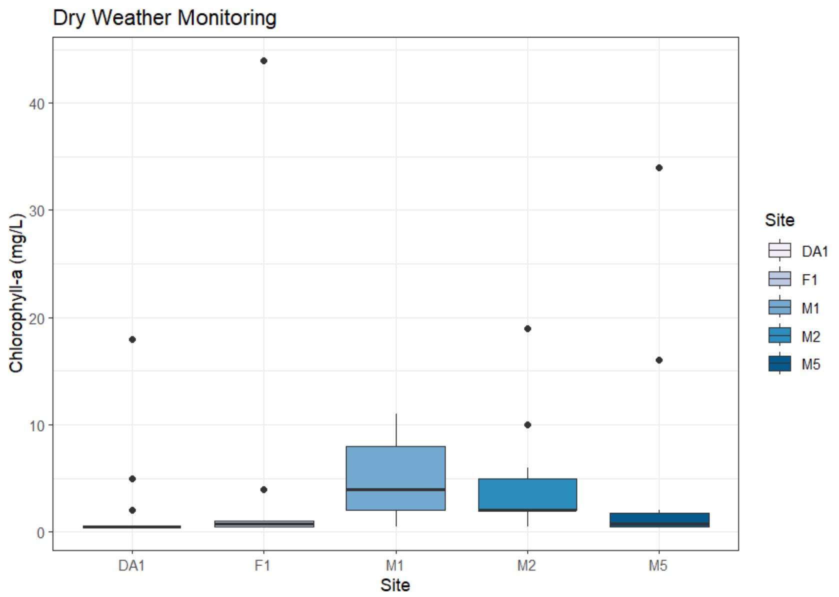

Figure 47: Summary of chlorophyll-*a* (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024. An outlier also occurred at DA1 (not included in this Figure) with a chlorophyll-*a* value of 748 mg/L.

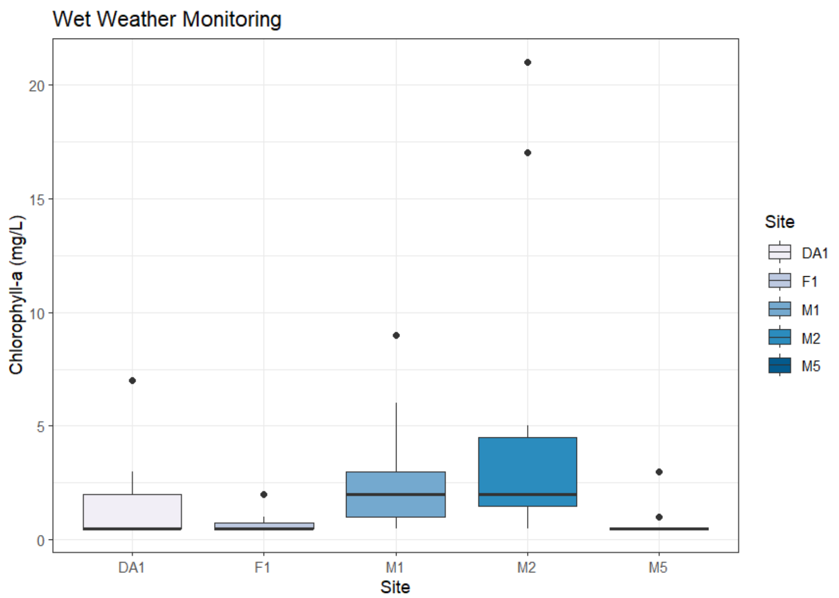

Figure 48: Summary of chlorophyll-*a* (mg/L) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, chlorophyll-*a* levels at all Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 49). Chlorophyll-*a* levels were highest at DA1 in October 2023 (748 mg/L) (not included in Figure 49 as it masked the trends of the other sites). The median chlorophyll-*a* for Mullet Creek sites (1.00 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, chlorophyll-*a* levels at all Mullet Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events but were lower than dry weather monitoring events. Chlorophyll-*a* levels were highest at M2 in February 2022 (21 mg/L). The median chlorophyll-*a* for Mullet Creek sites (1.00 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

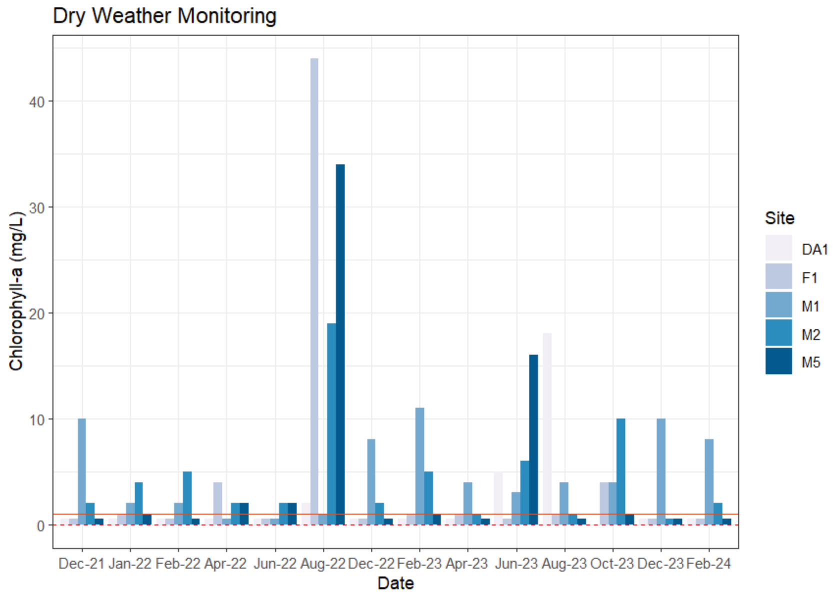

Figure 49: Chlorophyll-*a* (mg/L) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment. An outlier also occurred at DA1 in October 2023 (not included in this Figure) with a chlorophyll-*a* value of 748 mg/L.

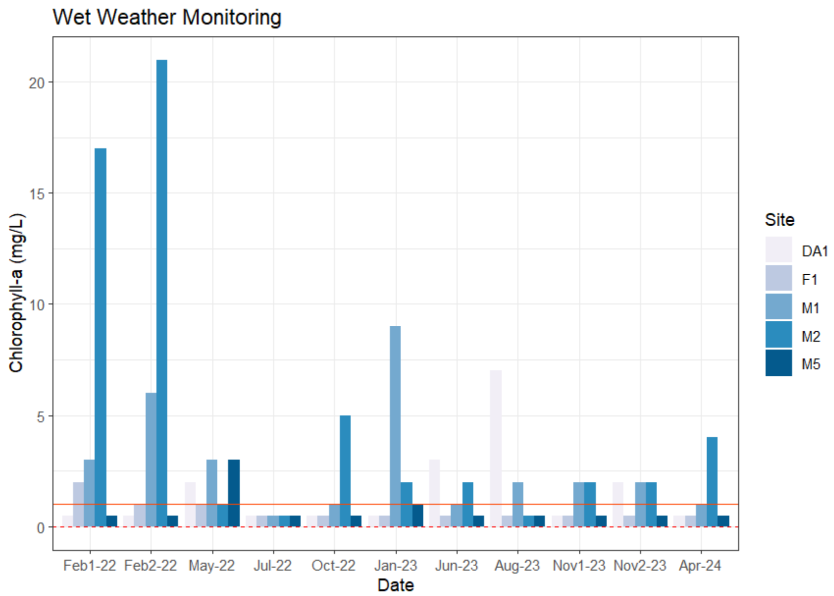

Figure 50: Chlorophyll-*a* (mg/L) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Enterococci

Enterococci concentrations were within a narrow range across all Mullet Creek sites during dry weather monitoring for the 2021-24 period. However, sites experienced events where *Enterococci* was elevated, as shown by the outliers present, and this occurred at M1 (Figure 51).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and like dry weather monitoring the highest range was recorded at M1 (Figure 52).

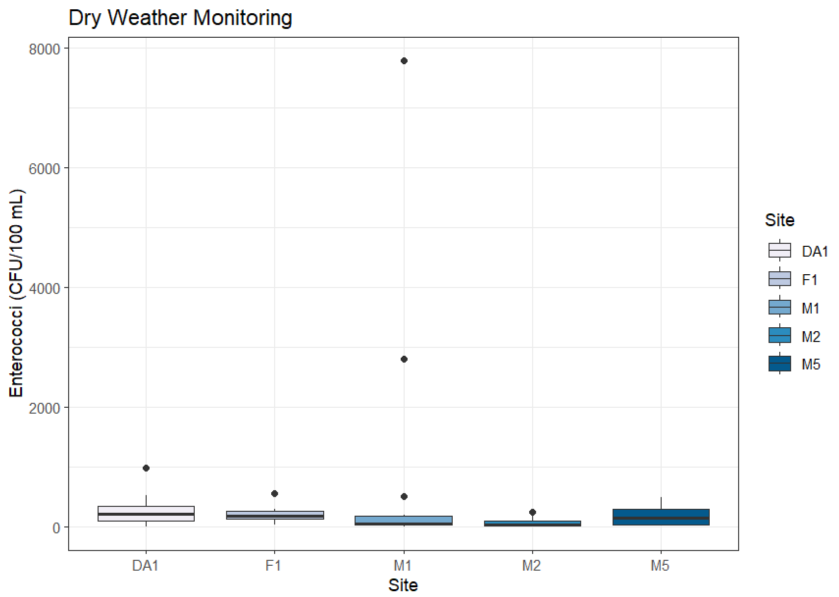

Figure 51: Summary of *Enterococci* (CFU/100 mL) at Mullet Creek sites during dry weather monitoring events from December 2021 to April 2024.

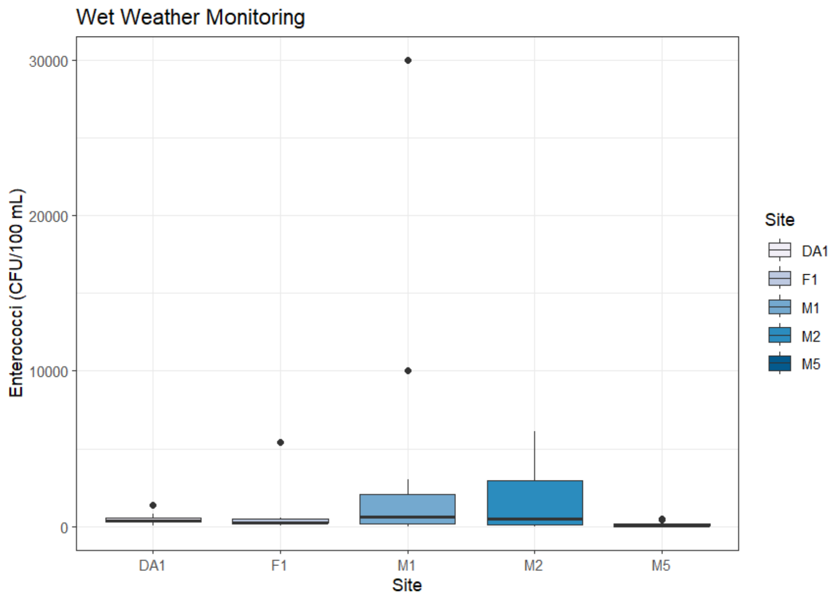

Figure 52: Summary of *Enterococci* (CFU/100 mL) at Mullet Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, *Enterococci* levels at Mullet Creek sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 32 occasions (Figure 53). This included at M1 on seven occasions (in December 2021, 2022, and 2023, January 2022, August 2022, April 2023, and June 2023), and at M2 on six occasions (in February 2022, April 2023, August 2023, October 2023, December 2023, and February 2024). DA1 was above the primary guideline on five occasions (in December 2021 and 2022, January 2022, April 2023, and June 2023). For site F1, the primary guideline was exceeded on ten occasions (in December 2021, 2022, and 2023, April 2022, and 2023, June 2022 and 2023, August 2022 and 2023, and February 2023). At M5, Enterococci levels were in excess of the primary guideline in December 2021, January 2022, April 2023, and February 2024.

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 21 occasions. This included at M1 on three occasions (in February 2022, 2023, and 2024), and at M2 in February 2023. For site DA1, the secondary guideline was exceeded on eight occasions (in February 2022, 2023, and 2024, April 2022, December 2022 and 2023, August 2023, and October 2023), and on three occasions at F1 (in October 2023, and February 2022 and 2023). At M5, Enterococci levels were in excess of the secondary guideline on six occasions (in February, April, and December in 2022 and 2023).

The median *Enterococci* for Mullet Creek sites (125 CFU/100 mL) during dry weather monitoring was above the primary contact ANZECC (2000) guidelines, but did not exceed the secondary contact guidelines.

During wet weather monitoring, *Enterococci* levels at Mullet Creek sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 17 occasions (Figure 54). This included at M1 on three occasions (for both February 2022 events and in July 2022), at M2 on three occasions (in February 2022, July 2022, and June 2023), at F1 on four occasions (for both events in February 2022, July 2022, and June 2023), and at M5 on seven occasions (for both events in February 2022, May 2022, January 2023, August 2023, and both November 2023 events).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 32 occasions. This included at M1 on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). At M2, the secondary guideline was exceeded on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). At DA1, levels were above the secondary guideline on nine occasions (for both events in February 2022, May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). For site F1, the secondary guideline was exceeded on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). At M5, the secondary guideline was exceeded in October 2022 and April 2024.

The median *Enterococci* for Mullet Creek sites (500 CFU/100 mL) during wet weather monitoring was above the ANZECC (2000) primary and secondary contact guidelines.

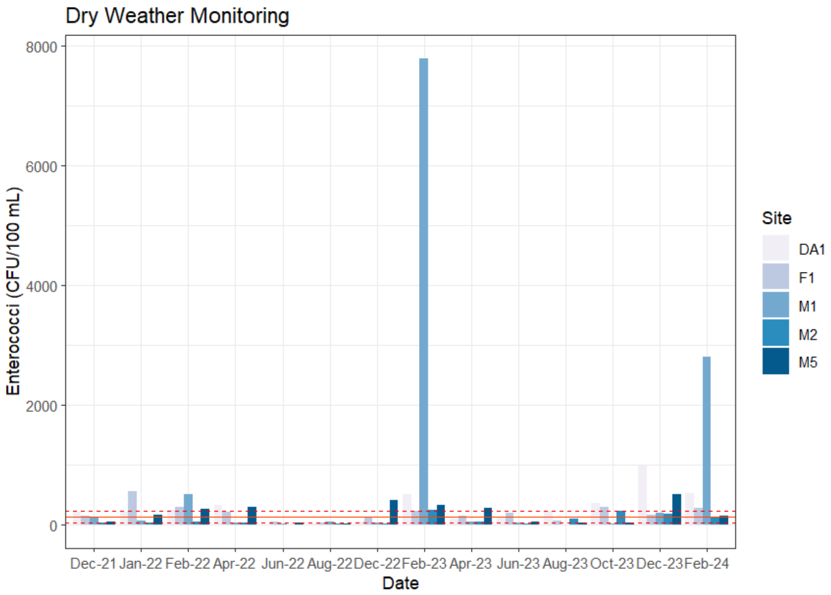

Figure 53: *Enterococci* (CFU/100 mL) at Mullet Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

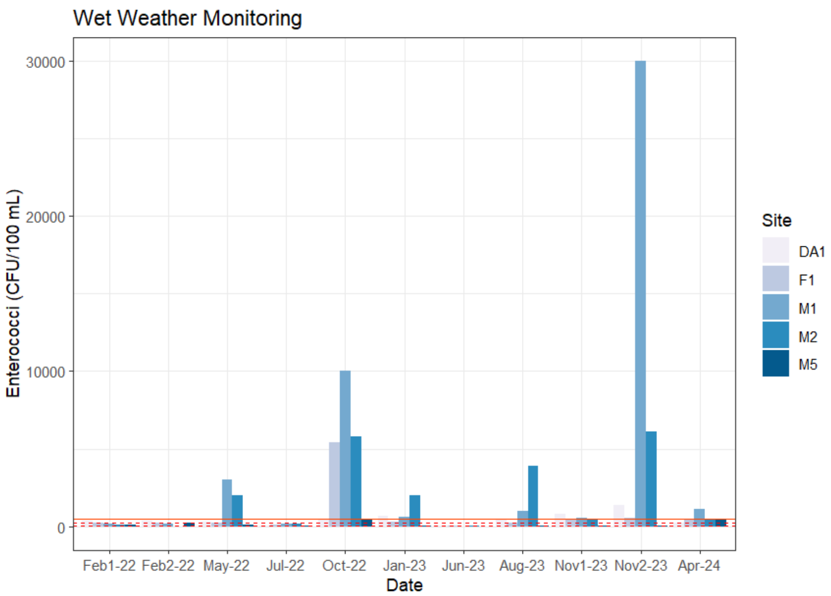

Figure 54: *Enterococci* (CFU/100 mL) at Mullet Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

Macquarie Rivulet

Six sites (SCC1, SCC2, SCC3, SCC4, SCC5, and SCC6) were sampled within the Macquarie Rivulet catchment on 25 occasions between December 2021 and April 2024, with 14 dry weather monitoring events and 11 wet weather monitoring events. A summary of findings for each water quality parameter is outlined below.

pH

Overall, pH remained similar across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period (Figure 55). Recorded values within the upper and lower quartiles of data largely overlapped between sites and outlier values were observed at SCC1, SCC2, and SCC5.

During wet weather monitoring, there was more variability in pH at Macquarie Rivulet sites, however, ranges still largely overlapped and SCC1 maintained the highest pH values recorded (Figure 56).

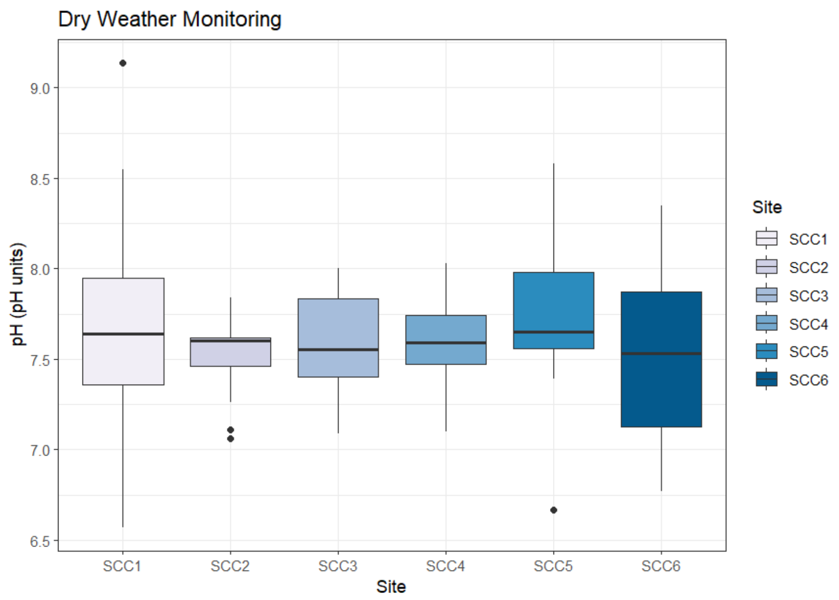

Figure 55: Summary of pH (pH units) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

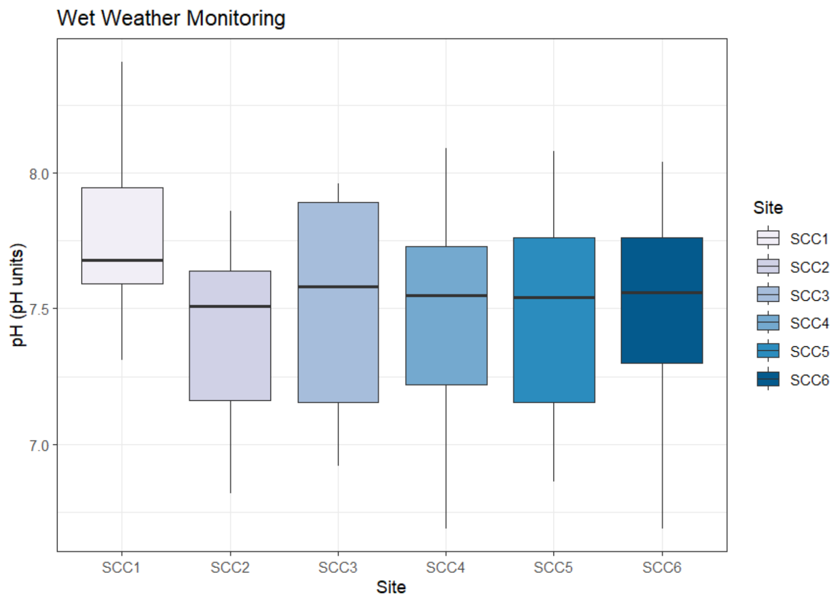

Figure 56: Summary of pH (pH units) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, pH at Macquarie Rivulet sites was predominantly within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units. However, the upper guideline limit was exceeded on ten occasions (Figure 57). This included at SCC1 on three occasions (in December 2021, February and June 2023), at SCC4 in January 2022, at SCC5 on three occasions (in December 2021, April and June 2023), and at SCC6 on three occasions (in December 2021, April and June 2023). The median pH for Macquarie Rivulet sites (7.61 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

During wet weather monitoring, pH at Macquarie Rivulet sites was predominantly within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units. The upper guideline limit was exceeded on five occasions, at SCC1 in May 2022 and June 2023, at SCC4 in February 2022, at SCC5 in January 2023, and SCC6 in June 2023. Recorded pH was similar during wet weather monitoring events compared to dry weather monitoring. The median pH for Macquarie Rivulet sites (7.59 pH units) during wet weather monitoring was within the ANZECC (2000) guidelines.

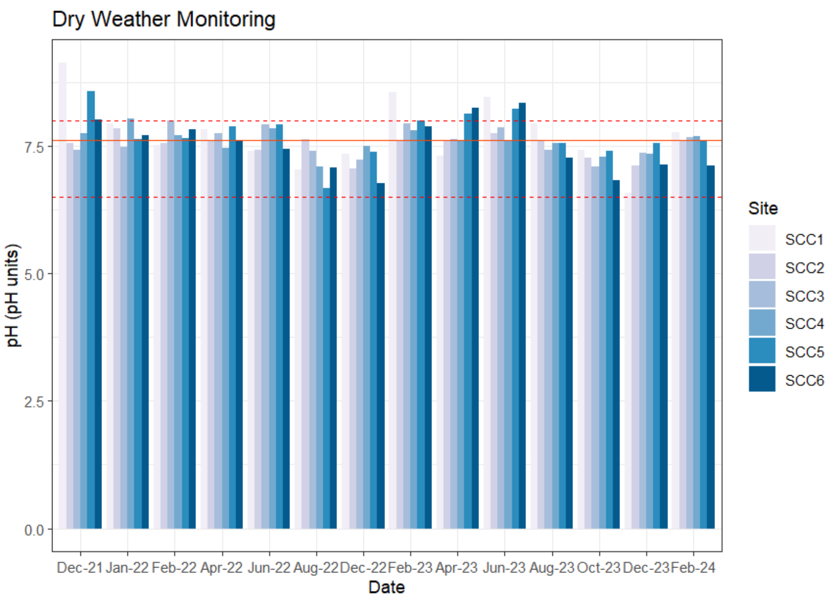

Figure 57: pH (pH units) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

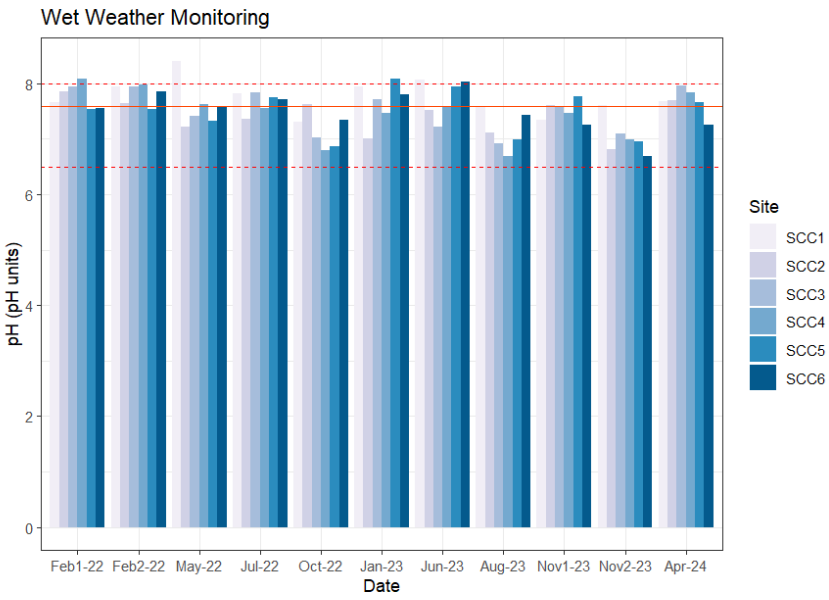

Figure 58: pH (pH units) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2023. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Electrical conductivity

Electrical conductivity experienced a wide range at SCC3 and SCC4 compared to the other Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period (Figure 59). All other sites had a narrow range of observed values that largely overlapped, and outlier values were observed at SCC2.

During wet weather monitoring, this trend was maintained, with a wide range of variability in electrical conductivity at SCC2, SCC3, and SCC3. Ranges still largely overlapped for all sites (Figure 60).

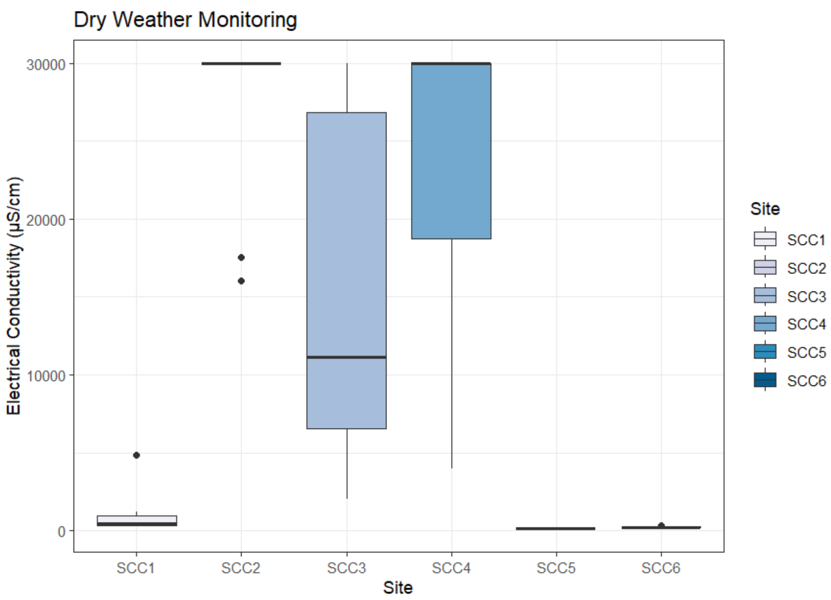

Figure 59: Summary of electrical conductivity (µS/cm) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

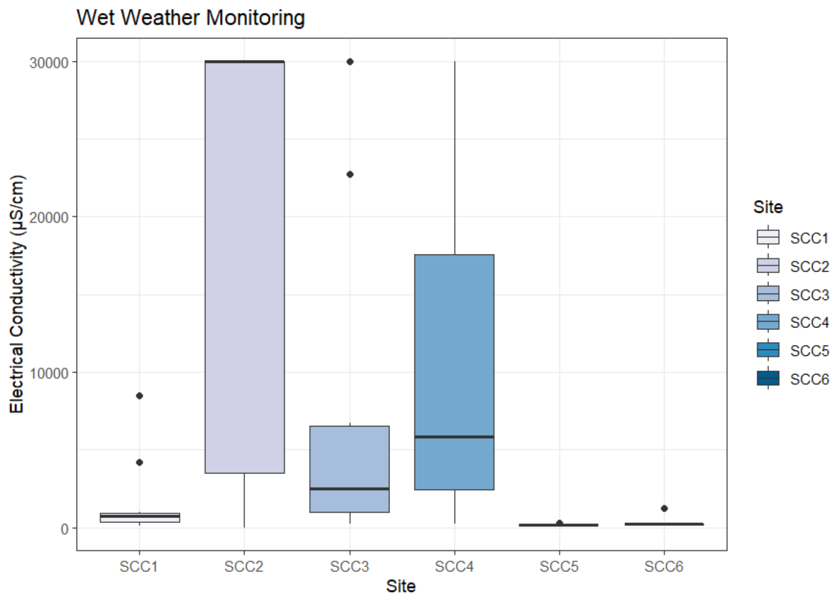

Figure 60: Summary of electrical conductivity (µS/cm) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, electrical conductivity at Macquarie Rivulet sites frequently exceeded the upper ANZECC (2000) guideline of 300 µS/cm for all sites. This excluded at SCC5 and SCC6 (except for October 2023 sampling), which were consistently within or below the guideline across the monitoring period (Figure 61). Electrical conductivity at SCC1 also was below the ANZECC (2000) guideline in April 2022, December 2022 and 2023. Electrical conductivity exceeded the maximum limit of detection of the in-situ probe (30,000 µS/cm) on a total of 24 occasions, 12 times at SCC2, four times at SCC3, and eight times at SCC4. This occurred due to the effects of saline water at these sites as the estuary is brackish. The median electrical conductivity for Macquarie Rivulet sites (2209.50 µS/cm) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, electrical conductivity at Macquarie Rivulet sites was overall lower compared to dry weather monitoring. However, the upper ANZECC (2000) guideline was still exceeded on 39 occasions at SCC1, SCC2, SCC3, SCC4, and SCC6 (Figure 62). The maximum limit of detection of the in-situ probe (30,000 µS/cm) was also exceeded on a total of nine occasions, six times at SCC2, once at SCC3, and twice at SCC4. Sites SCC5 and SCC6 were compliant (within or below the limits) with the ANZECC (2000) guidelines across the monitoring period, excluding in July 2022 at SCC5 and June 2023 at SCC6. The median electrical conductivity for Macquarie Rivulet sites (343.50 µS/cm) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

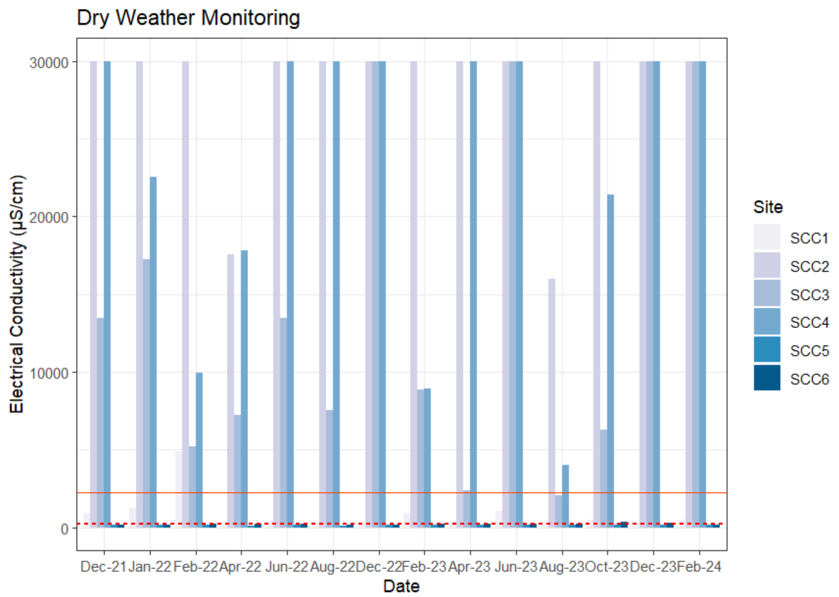

Figure 61: Electrical conductivity (µS/cm) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

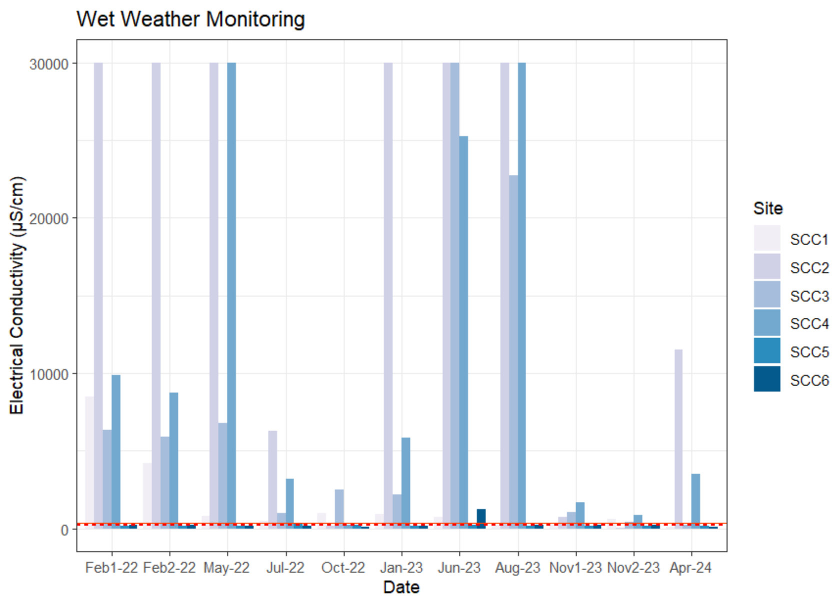

Figure 62: Electrical conductivity (µS/cm) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Temperature

Temperature remained consistent between the Macquarie Rivulet sites throughout the 2021-2024 dry weather monitoring period (Figure 63), with the range of all sites overlapping.

During wet weather monitoring, temperature at all sites also remained consistent across all sites (Figure 64).

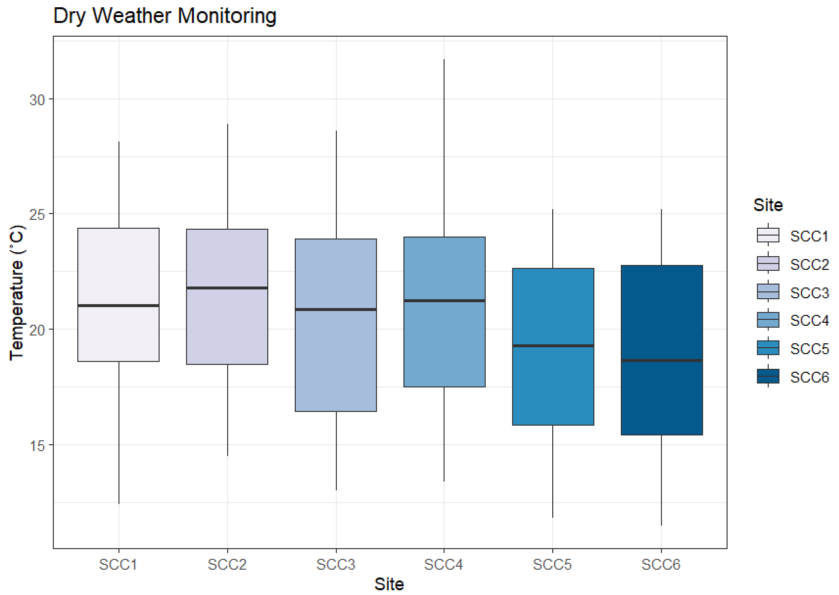

Figure 63: Summary of temperature (˚C) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

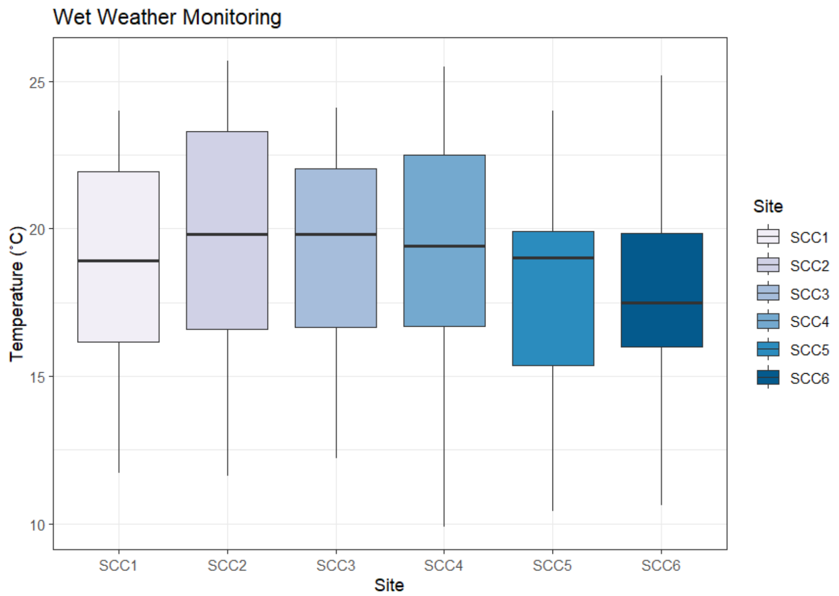

Figure 64: Summary of temperature (˚C) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, temperature ranged from a maximum of 31.7˚C at SCC2 in January 2022 and a minimum of 11.5˚C at SCC6 in June 2022 (Figure 65). Macquarie Rivulet sites all showed similar temperature trends. The median temperature for Macquarie Rivulet sites was 20.45˚C during dry weather monitoring.

During wet weather monitoring, temperature ranged from a maximum of 25.7˚C at SCC2 in February 2022 and a minimum of 9.9˚C at SCC4 in August 2023 (Figure 66). Macquarie Rivulet sites all showed similar temperature trends. The median temperature for Macquarie Rivulet sites was 18.5˚C during dry weather monitoring. There are currently no ANZECC (2000) guidelines for temperature for lowland rivers and temperature can also experience temporal and diurnal changes at sites.

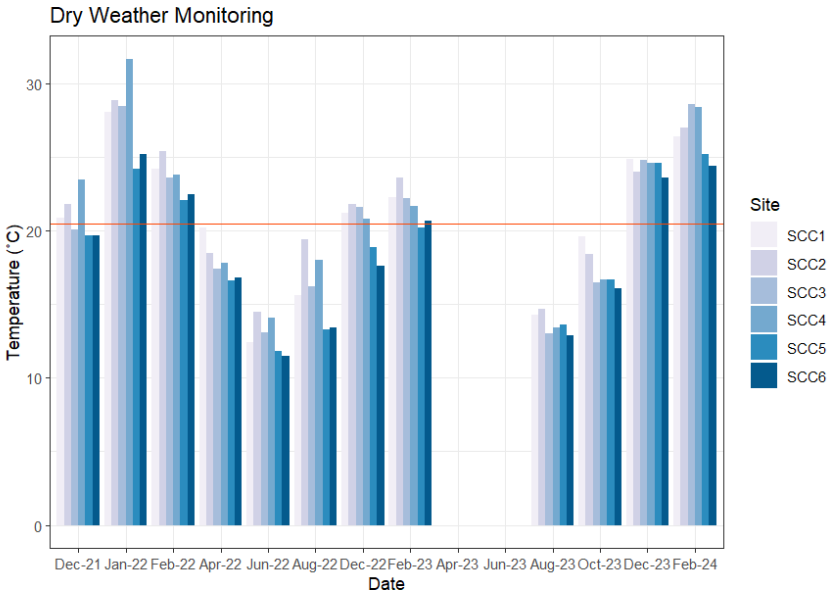

Figure 65: Temperature (˚C) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

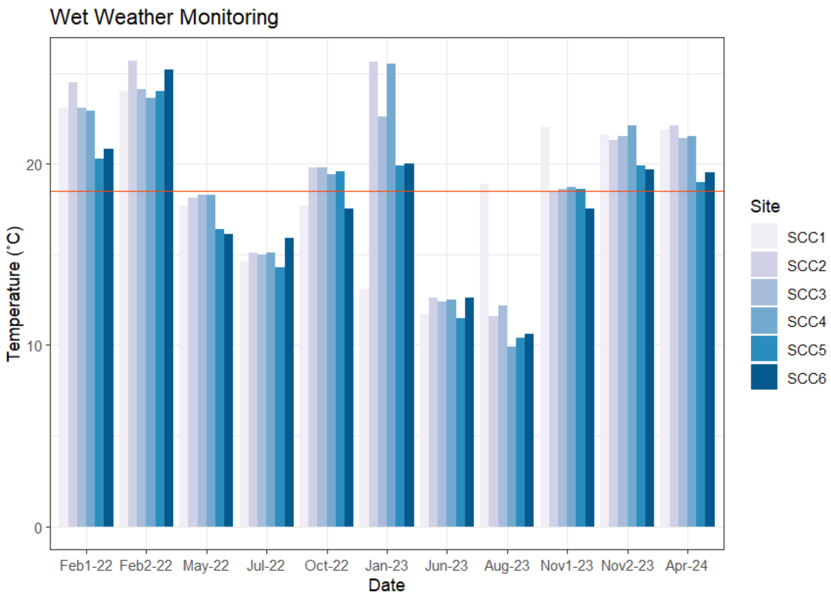

Figure 66: Temperature (˚C) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Dissolved oxygen

Dissolved oxygen was variable between Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period (Figure 67). Whilst there was some overlap between the ranges of each site, SCC5 and SCC6 had the highest recorded values, whereas dissolved oxygen was consistently low at SCC1 to SCC4.

During wet weather monitoring, dissolved oxygen remained similar to dry weather monitoring, as ranges still largely overlapped, however, SCC5 and SCC6 maintained higher dissolved oxygen (Figure 68). Conversely, dissolved oxygen was consistently low at SCC1 to SCC4

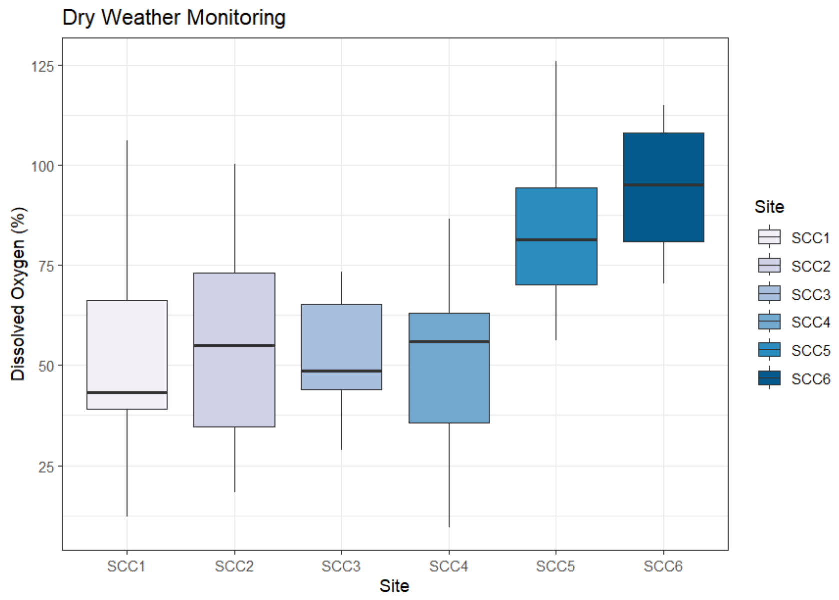

Figure 67: Summary of dissolved oxygen (%) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

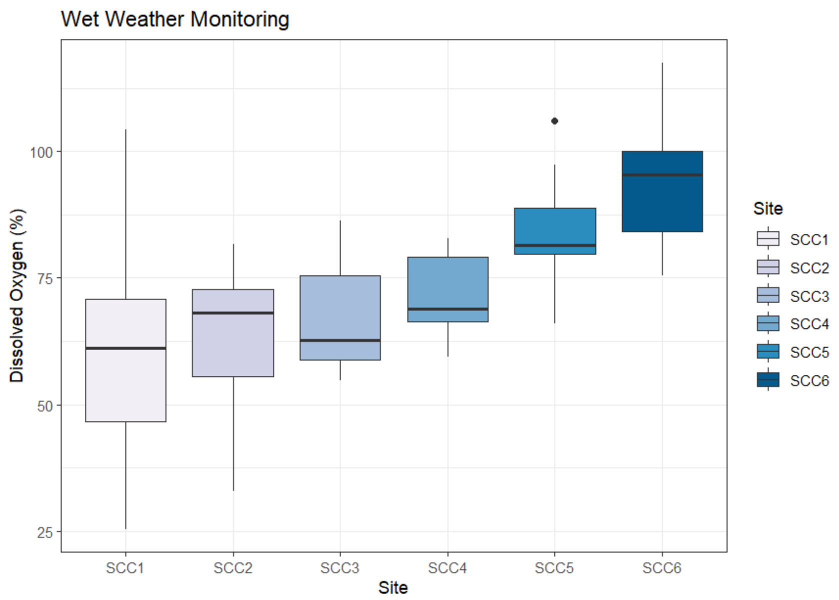

Figure 68: Summary of dissolved oxygen (%) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, dissolved oxygen levels at Macquarie Rivulet sites were compliant with the ANZECC (2000) guidelines of 85-110% on 20 occasions (Figure 69). This included at SCC1 on three occasions (in December 2021, January 2022, and August 2022), at SCC2 in August 2022, at SCC4 in February 2023, at SCC5 on five occasions (in December 2021 and 2022, January 2022, August 2022, and February 2023), and on ten occasions at SCC6 (in December 2021 and 2022, January 2022, June 2022, August 2022, February 2023, April 2023, June 2023, August 2023, and February 2024). The median dissolved oxygen for Macquarie Rivulet sites (65.10%) during dry weather monitoring was well below the ANZECC (2000) guidelines.

During wet weather monitoring, dissolved oxygen levels at Macquarie Rivulet sites were compliant with the ANZECC (2000) guidelines on 14 occasions (Figure 70). This included at SCC1 on two occasions (in May and

October 2022), at SCC3 in August 2023, at SCC5 on four occasions (in February 2022, May 2022, January 2023, and November 2023), on seven occasions at SCC6 (in February 2022, May 2022, October 2022, January 2023, June 2023, August 2023, and November 2023). The median dissolved oxygen for Macquarie Rivulet sites (75.86%) during wet weather monitoring was well below the ANZECC (2000) guidelines.

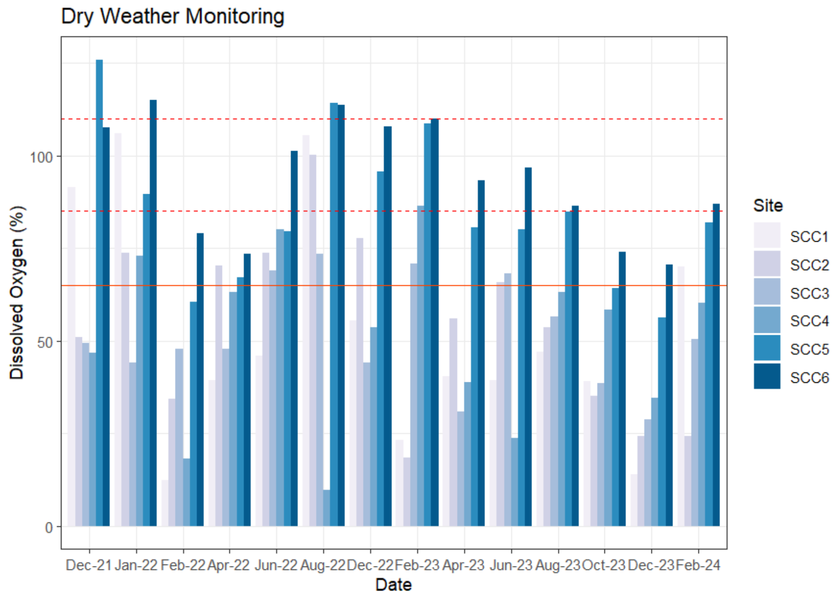

Figure 69: Dissolved oxygen (%) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

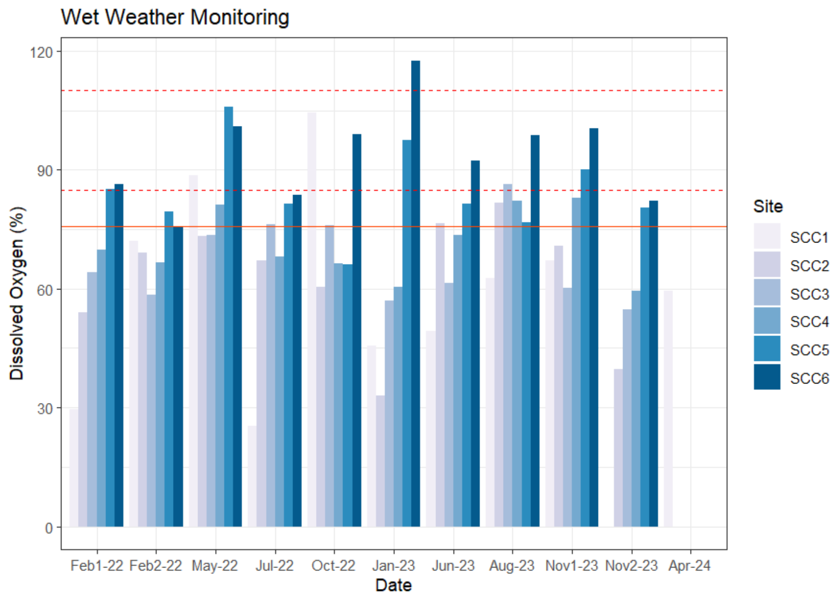

Figure 70: Dissolved oxygen (%) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Turbidity

Turbidity was variable between Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period (Figure 71). Whilst the ranges of each site largely overlapped and the medians were similar, outliers were present at all sites (excluding SCC1), with high values observed at SCC2 and SCC3.

During wet weather monitoring, the range of turbidity values largely overlapped between all sites and outliers occurred at all sites (Figure 72).

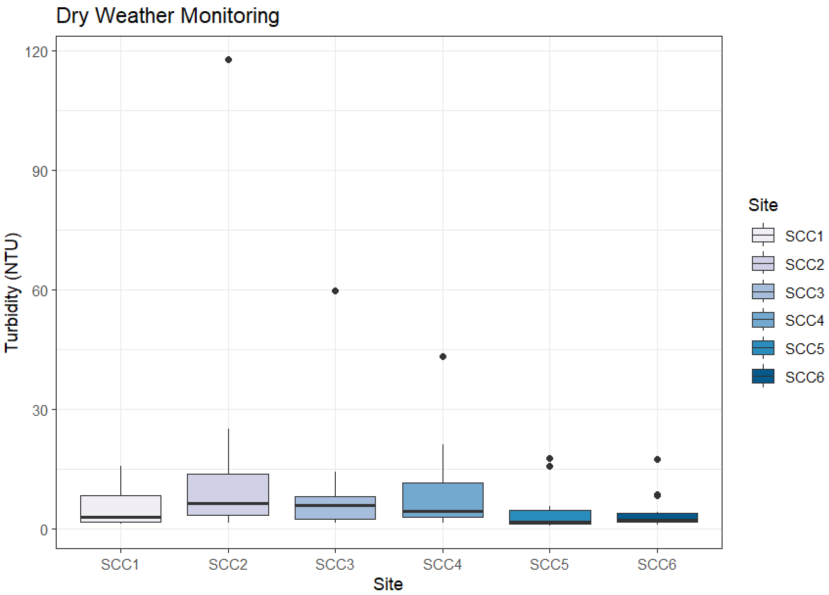

Figure 71: Summary of turbidity (NTU) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

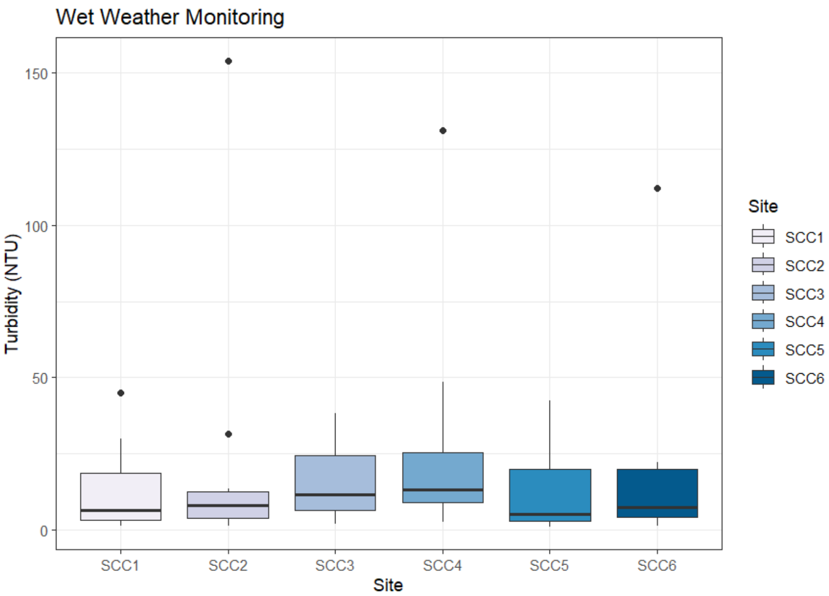

Figure 72: Summary of turbidity (NTU) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, turbidity at Macquarie Rivulet sites remained within the ANZECC guideline range of 6 – 50 NTU for all monitoring events (Figure 73). This excluded at SCC3 in December 2023 (59.9 NTU) and SCC2 in February 2024 (118.0 NTU), which was the maximum turbidity recorded. The median turbidity for Macquarie Rivulet sites (3.82 NTU) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, turbidity at Macquarie Rivulet sites remained within the ANZECC guideline range of 6 – 50 NTU, excluding on three occasions (Figure 74). This included at SCC2, SCC4, and SCC6 in

November 2023. Turbidity levels were higher compared to dry weather monitoring. Maximum turbidity was recorded at SCC2 (154.0 NTU) in November 2023. The median turbidity for Macquarie Rivulet sites (11.40 NTU) during wet weather monitoring was below the ANZECC (2000) guidelines. Results below 6 NTU should not be considered as non-compliant, instead is representative of very low suspended sediments, which is a positive result.

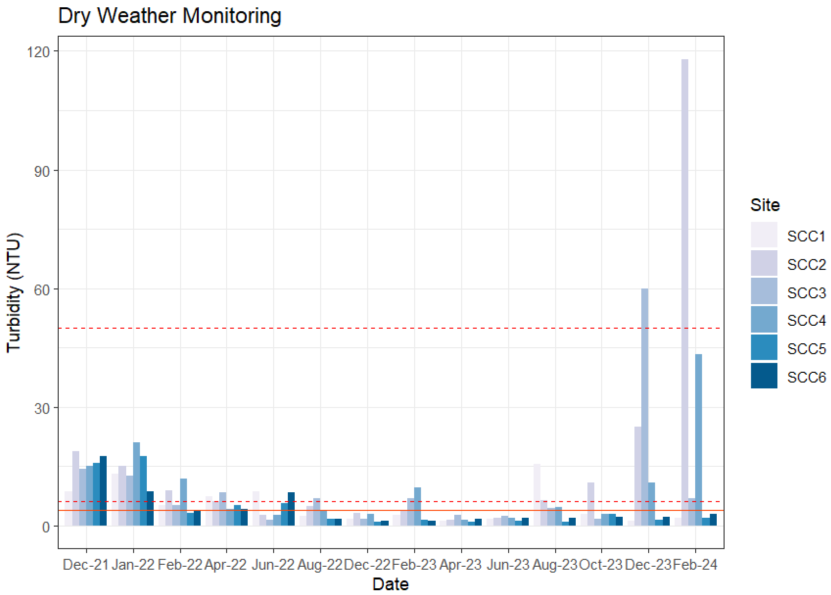

Figure 73: Turbidity (NTU) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

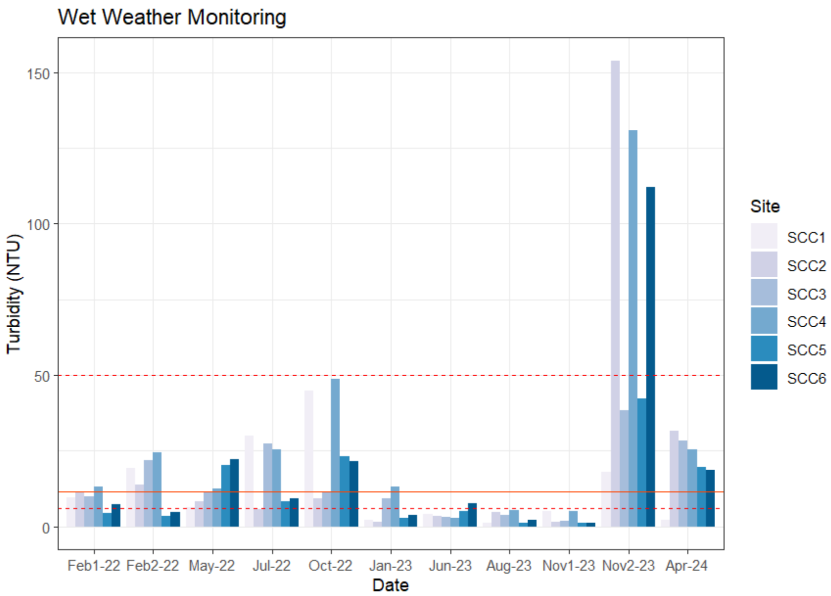

Figure 74: Turbidity (NTU) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Total Nitrogen

Total nitrogen remained consistent between Macquarie Rivulet sites SCC1, SCC2, SCC3, and SCC4 during dry weather monitoring for the 2021-24 period. However, the range of SCC5 and SCC6 was lower compared to the other sites (Figure 75).

During wet weather monitoring, the ranges of all sites overlapped, however, outlier values were higher across all sites compared to dry weather monitoring (Figure 76).

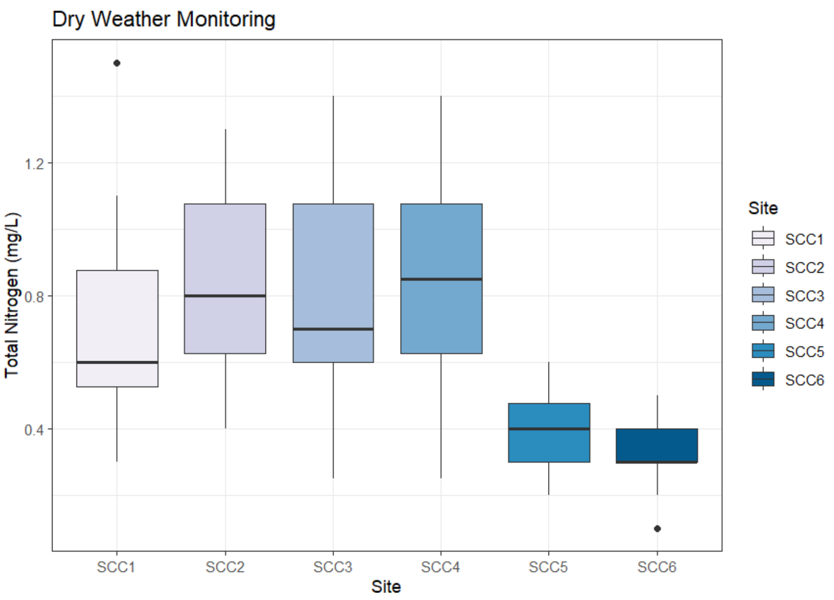

Figure 75: Summary of total nitrogen (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

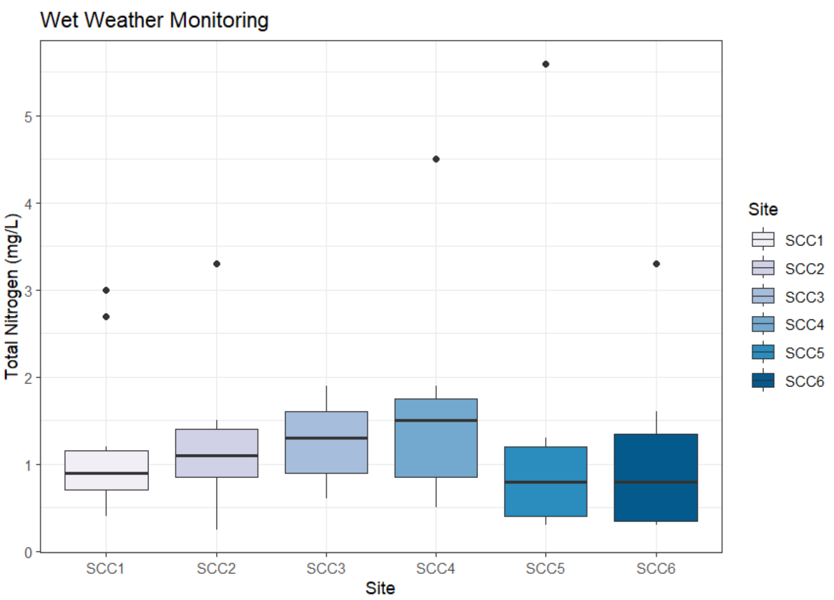

Figure 76: Summary of total nitrogen (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total nitrogen concentrations at Macquarie Rivulet sites exceeded the ANZECC (2000) guideline of 0.5 mg/L on 52 occasions (Figure 77). Compliant events only occurred on four occasions at SCC1 (in December 2021, February 2022, and April 2022), and on one occasion at SCC2 (in

February 2022). The upper guideline was also exceeded on two occasions at SCC3 (in December 2021 and June 2022), and on two occasions at SCC4 (in December 2021 and June 2022). The ANZECC (2000) guideline was not compliant at SCC5 in April 2022 and February 2023, and at SCC6 in June 2022. The median total nitrogen for Macquarie Rivulet sites (0.60 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, compliance with the ANZECC (2000) guideline for total nitrogen occurred on 11 occasions (Figure 78). This included at SCC1 in February 2022, at SCC2 in February 2022 and June 2023, at SCC4 in June 2023 (0.5 mg/L), at SCC5 and SCC6 on four occasions (including both February 2022 events, and in June and November 2023 respectively). The median total nitrogen for Macquarie Rivulet sites (0.80 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

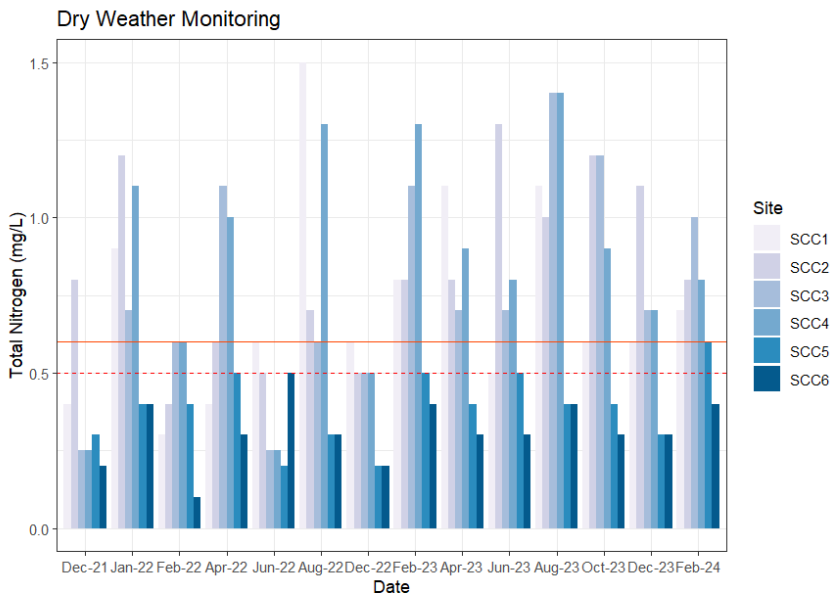

Figure 77: Total nitrogen (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

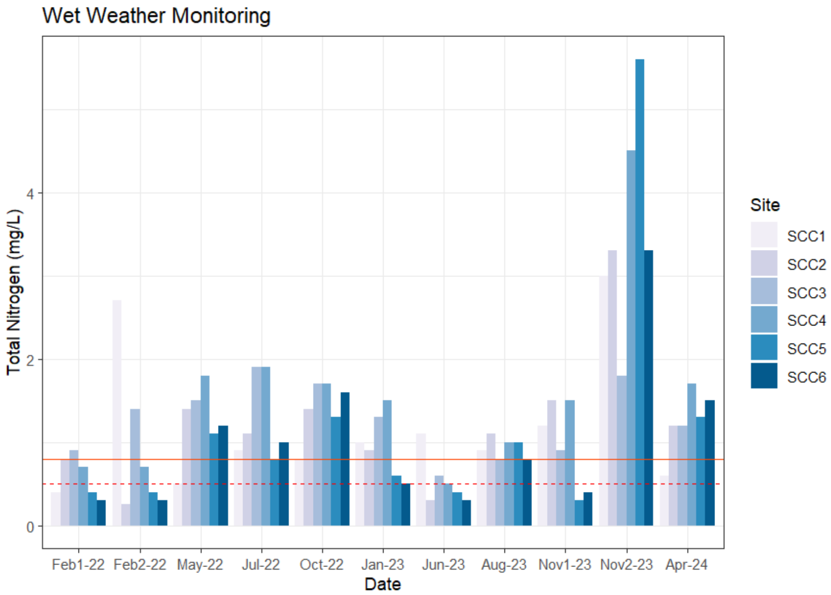

Figure 78: Total nitrogen (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Ammonia

Ammonia was variable across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. However, ammonia ranges were highest for SCC2 and SCC4, as shown by the outliers present (Figure 79).

During wet weather monitoring, the ranges for ammonia concentrations largely overlapped for all sites, however, outliers were present for all sites (Figure 80).

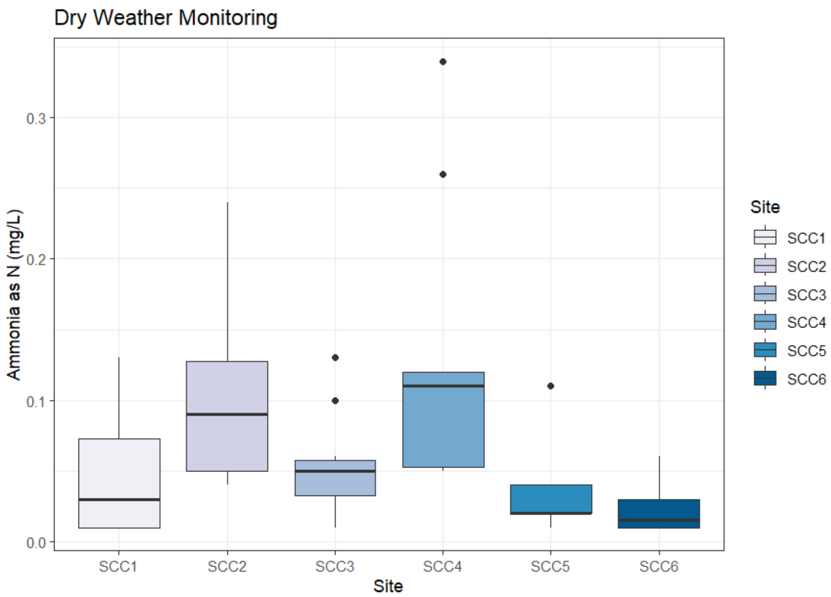

Figure 79: Summary of ammonia (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

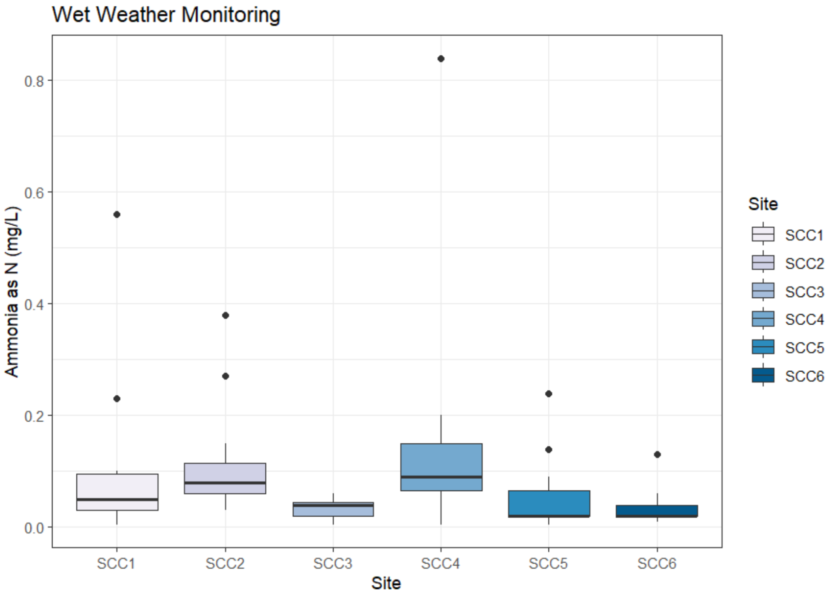

Figure 80: Summary of ammonia (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, ammonia concentrations at Macquarie Rivulet sites were compliant with the ANZECC (2000) guideline of 0.02 mg/L on 17 occasions (Figure 81). Sites that were compliant included at SCC1 on five occasions (in December 2021 and 2023, January 2022, and February 2022 and 2024), at SCC3 in December 2023, at SCC5 on four occasions (in January 2022, August 2022 and 2023, and February 2023), and on seven occasions at SCC6 (in December 2021, 2022, and 2023, April 2022, February 2023, August 2023, and October 2023). The highest ammonia value of 0.34 mg/L was recorded at SCC4 in April 2022. The median ammonia for Macquarie Rivulet sites (0.05 mg/L) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, ammonia concentrations at Macquarie Rivulet sites were compliant with the ANZECC (2000) guideline of 0.02 mg/L on eight occasions (Figure 82). This included at SCC1 on three occasions (including both February 2022 events and August 2023), at SCC3 and SCC4 in February 2022, at SCC5 on two occasions (in July 2022 and November 2023), and at SCC6 in July 2022. The highest value was recorded at SCC4 in November 2023 (0.84 mg/L), and this was higher than the observed maximum during dry weather monitoring. The median ammonia for Macquarie Rivulet sites (0.03 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

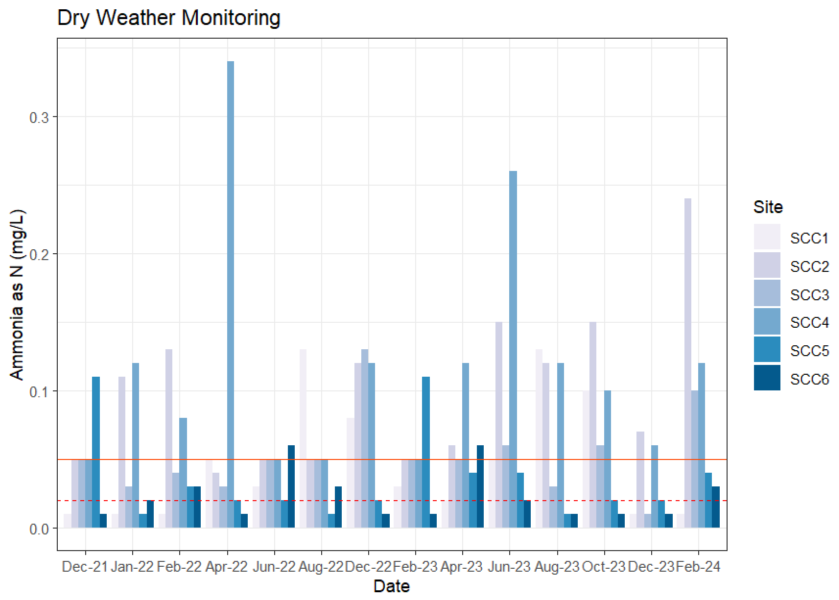

Figure 81: Ammonia (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

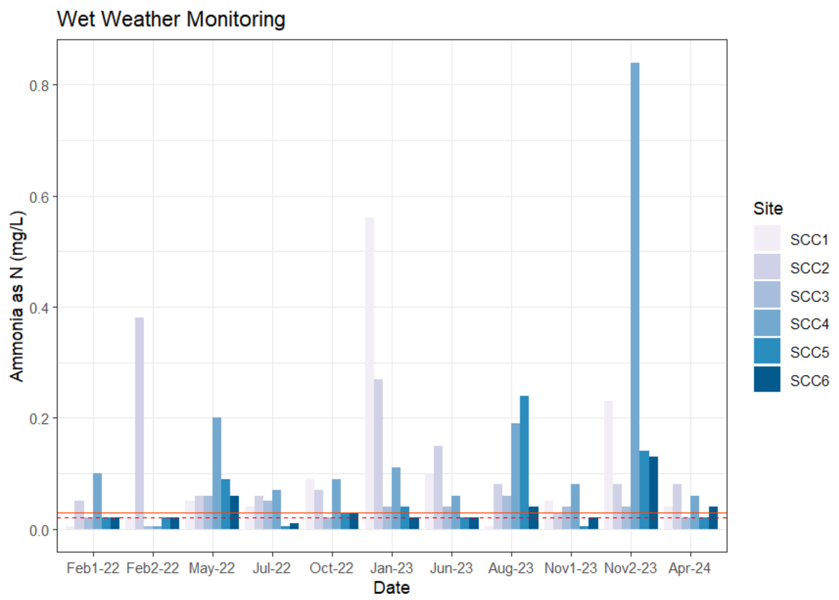

Figure 82: Ammonia (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

NOx

Nitrate and nitrite (NOx) concentrations showed high variability across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. Sites with the lowest range of recorded values were SCC5 and SCC6 (Figure 83).

During wet weather monitoring, the range of NOx values was greater across all sites, however, ranges still largely overlapped for all sites (Figure 84).

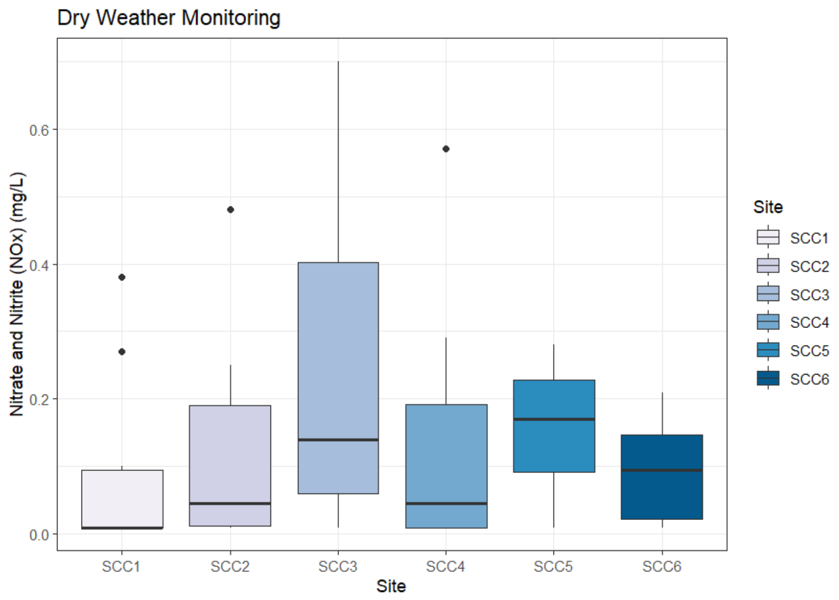

Figure 83: Summary of nitrate and nitrite (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

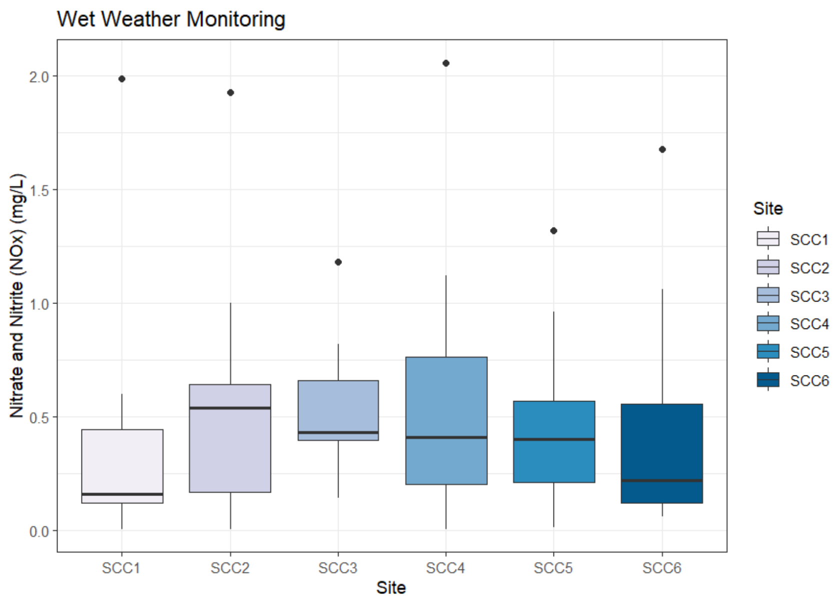

Figure 84: Summary of nitrate and nitrite (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, NOx concentrations at Macquarie Rivulet sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 50 occasions (Figure 85). SCC1 was non-compliant on five occasions (in June 2022 and 2023, August 2022 and 2023, and April 2023), and SCC2 exceeded the guidelines on eight occasions (in April 2022 and 2023, August 2022 and 2023, February 2023, June 2023, October 2023, and December 2023). Sites that were compliant included SCC3 on three occasions (in December 2021 and 2022, and February 2024), SCC4 on seven occasions (in December 2021 and 2022, January 2022, February 2022 and 2024, June 2022, and August 2022), SCC5 on four occasions (in October 2023, and December 2021, 2022, and 2023), and SCC6 on five occasions (in December 2021, 2022, and 2023, February 2023, and October 2023). Non-compliance was consistent across the monitoring period. The highest value was recorded at SCC3 in August

2023 (0.70 mg/L). The median NOx for Macquarie Rivulet sites (0.08 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, NOx concentrations at Macquarie Rivulet sites frequently exceeded the ANZECC (2000) guideline of 0.04 mg/L (Figure 86). This excluded at SCC1 during both February 2022 events, at SCC2 in February 2022 and June 2023, at SCC4 in February 2022, and at SCC5 in November 2023. The highest value was recorded at SCC4 in November 2023 (2.06 mg/L). The median NOx for Macquarie Rivulet sites (0.34 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

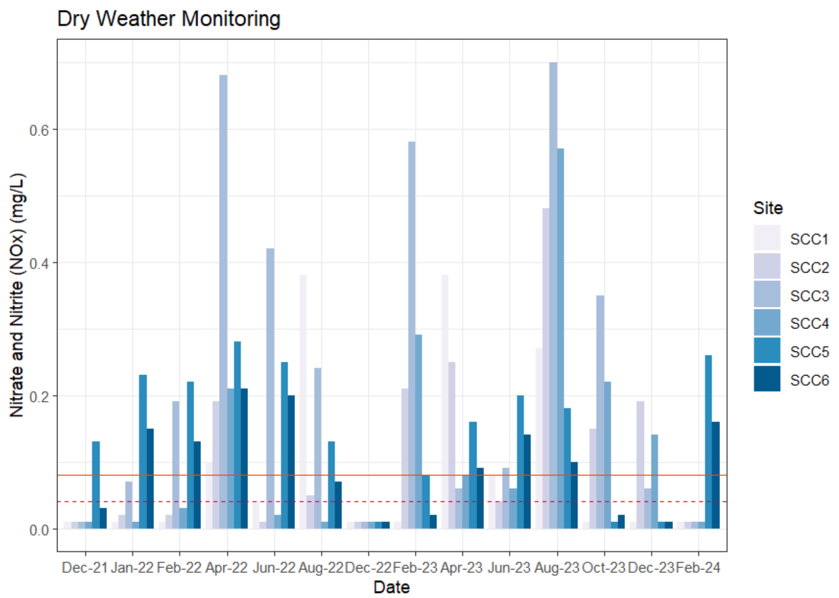

Figure 85: Nitrate and nitrite (NOx) (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

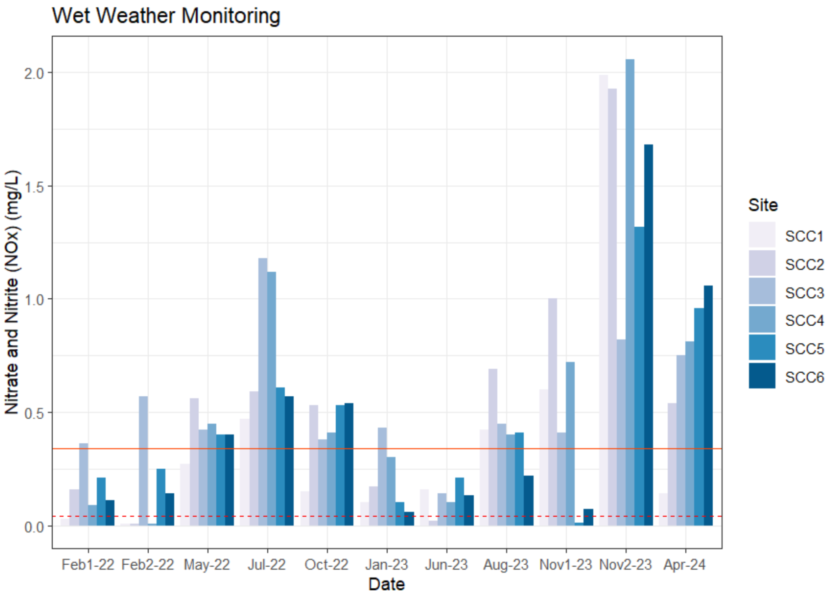

Figure 86: Nitrate and nitrite (NOx) (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Phosphorus

Total phosphorus concentrations were predominantly within a narrow range across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. However, each site experienced events where total phosphorus was elevated, as shown by the outliers present, and this was highest at SCC2 and SCC4 (Figure 87).

During wet weather monitoring, there was slightly more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at SCC4 and SCC5 (Figure 88).

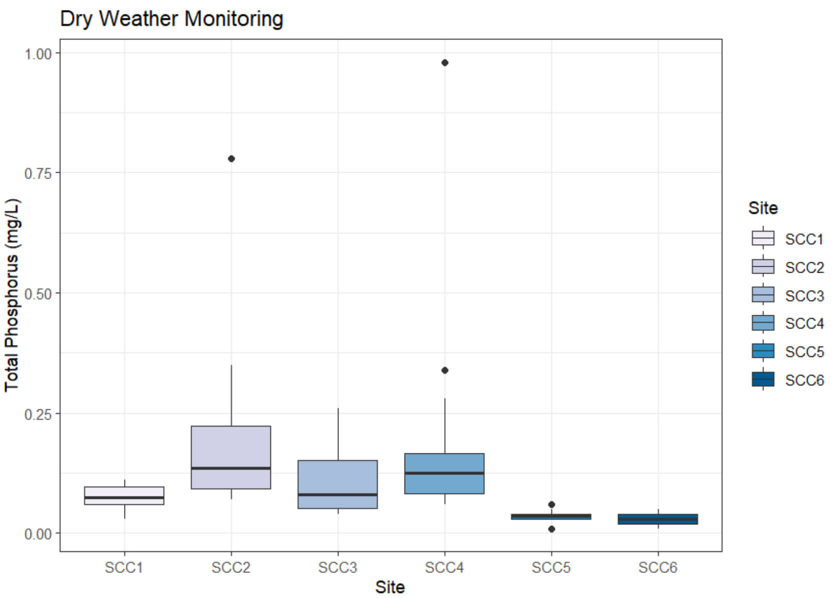

Figure 87: Summary of total phosphorus (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

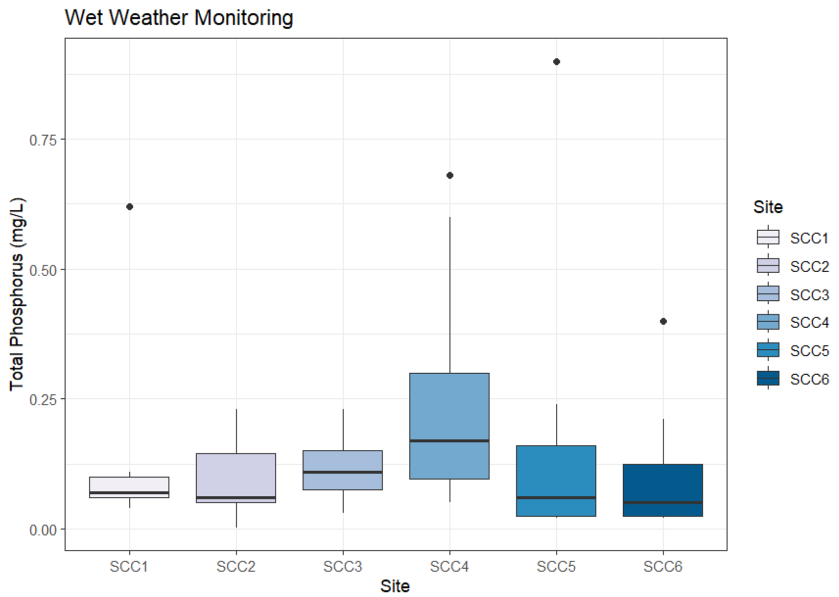

Figure 88: Summary of total phosphorus (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total phosphorus concentrations at Macquarie Rivulet sites exceeded the ANZECC (2000) guideline of 0.05 mg/L on 55 occasions (Figure 89). The sites that were compliant were SCC1 on three occasions (in December 2021, April 2022, and June 2023), and SCC3 on two occasions (in February 2022 and August 2022). SCC2 and SCC4 did not comply with the ANZECC guidelines during the 2021-24 monitoring period. However, total phosphorus concentrations were consistently below the ANZECC guideline for SCC5 and SCC6. Exceedance of the guidelines occurred on three occasions at SCC5 (in August 2023, October 2023, and February 2024), and in August 2023 at SCC6. The highest total phosphorus value was recorded at SCC4 in January 2022 (0.98 mg/L). The median total phosphorus for Macquarie Rivulet sites (0.07 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, the ANZECC (2000) guideline for total phosphorus at Macquarie Rivulet sites was exceeded on 53 occasions (Figure 90). SCC1 was compliant with the guideline in May 2022, as was SCC2 on two occasions (in February 2022 and August 2022), at SCC3 in August 2023, and at SCC4 in August 2023. SCC5 was compliant on four occasions (during both February 2022 events, June 2023, and November 2023), and SCC6 was compliant with the guideline on five occasions (during both February 2022 events, January 2023, June 2023, and August 2023). The median total phosphorus for Macquarie Rivulet sites (0.08 mg/L) during wet weather monitoring was exceeded the ANZECC (2000) guidelines.

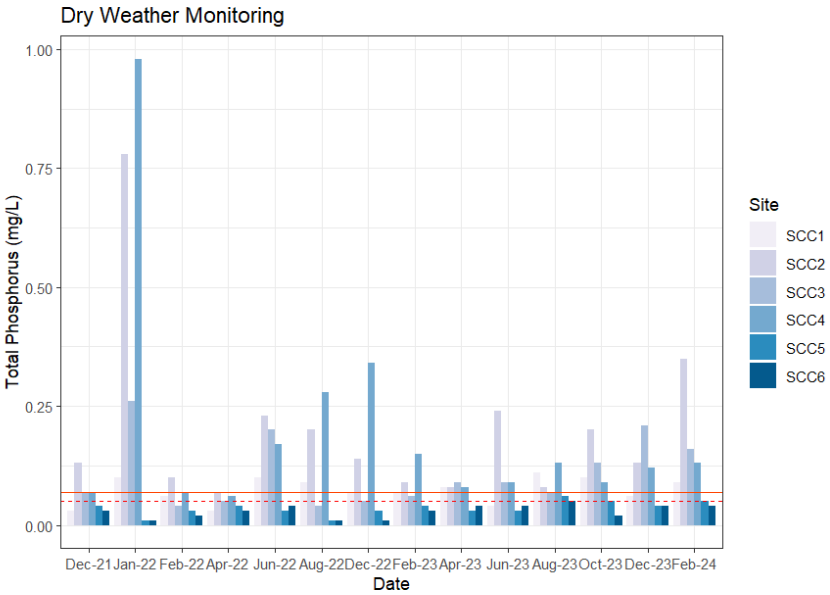

Figure 89: Total phosphorus (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

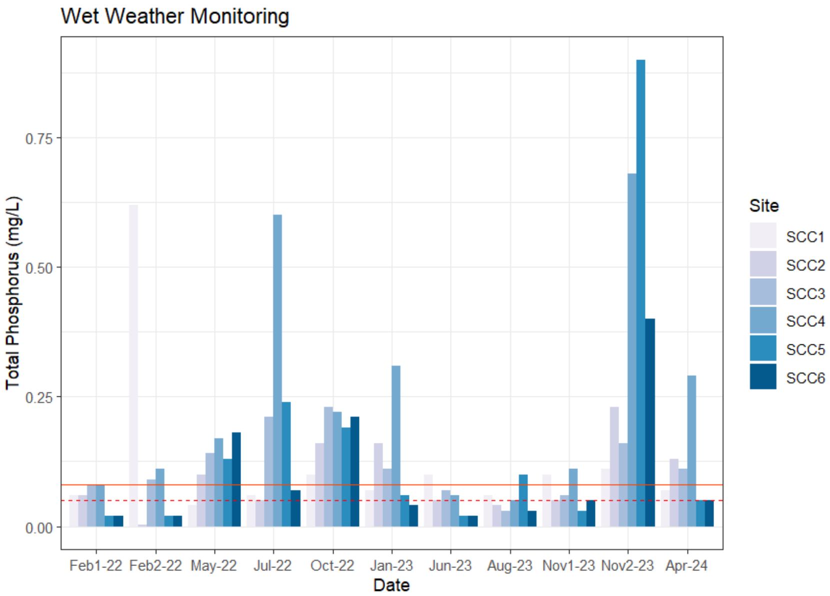

Figure 90: Total phosphorus (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Phosphate

Phosphate concentrations were within a narrow range across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period, excluding at SCC2. However, outliers were also present at SCC1 and SCC6 (Figure 91).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at SCC4 (Figure 92).

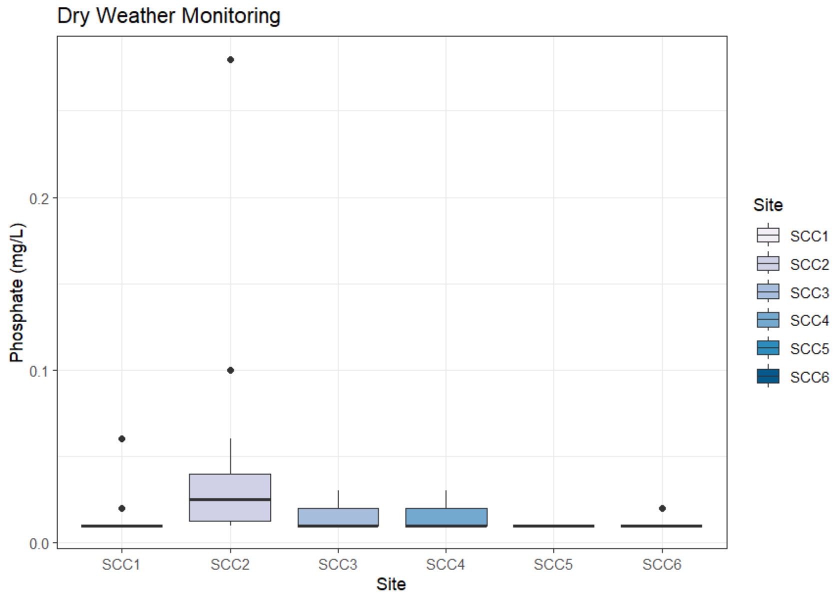

Figure 91: Summary of phosphate (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

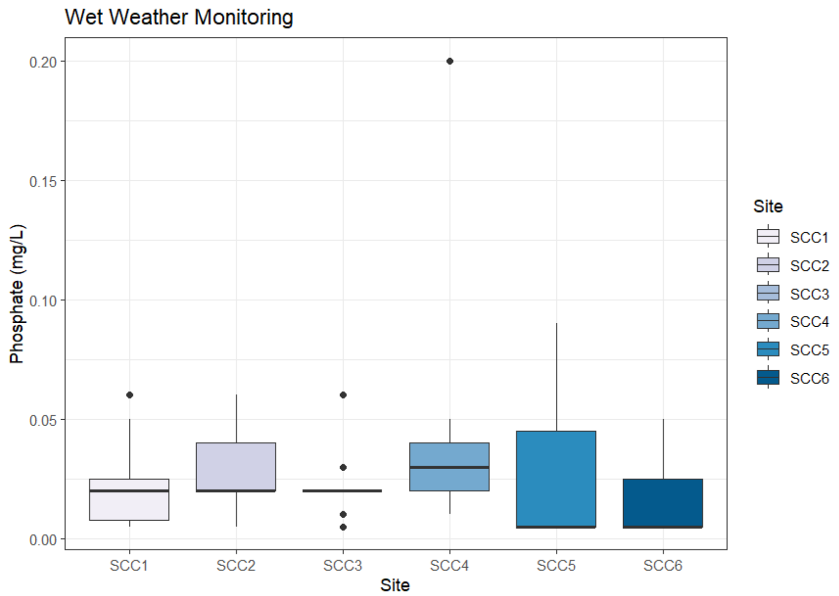

Figure 92: Summary of phosphate (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, phosphate concentrations at Macquarie Rivulet sites exceeded the ANZECC (2000) guideline (0.02 mg/L) on 25 occasions (Figure 93). This included on three occasions at SCC1 (in February, April, and October 2023), on ten occasions at SCC2 (in December 2021, 2022, and 2023, January 2022, February 2022, 2023, and 2024, April 2023, June 2023, and October 2023), and on five occasions at SCC3 (in December 2022 and 2023, June 2022, October 2023, and February 2024). The guideline was also exceeded on six occasions at SCC4 (in February 2022, December 2022 and 2023, June 2023, August 2023, and October 2023), and on one occasion at SCC6 (in August 2023). The median phosphate for Macquarie Rivulet sites (0.01 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, phosphate concentrations at Macquarie Rivulet sites were non-compliant with the ANZECC (2000) guidelines on 43 occasions (Figure 94). This included at SCC1 on seven occasions (excluding for both February 2022 events, January 2023, and August 2023), at SCC2 on ten occasions (excluding in February 2022), at SCC3 on two occasions (excluding in February 2022 and August 2023), and at SCC4 on ten occasions (in February 2022). The ANZECC (2000) guidelines were exceeded at SCC5 on four occasions (in May 2022, October 2022, August 2023, and November 2023) and at SCC6 on three occasions (in May 2022, October 2022, and November 2023). The median phosphate for Macquarie Rivulet sites (0.005 mg/L) during wet weather monitoring was below the ANZECC (2000) guidelines.

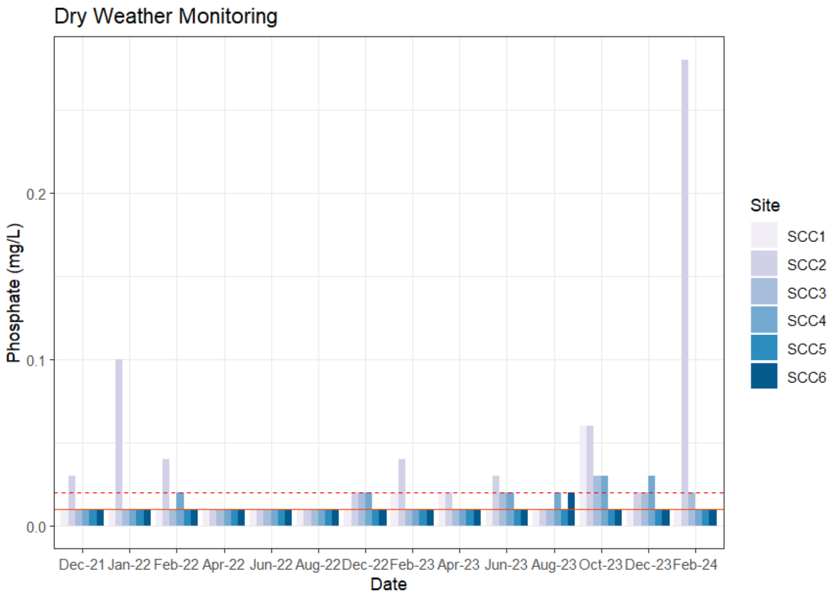

Figure 93: Phosphate (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

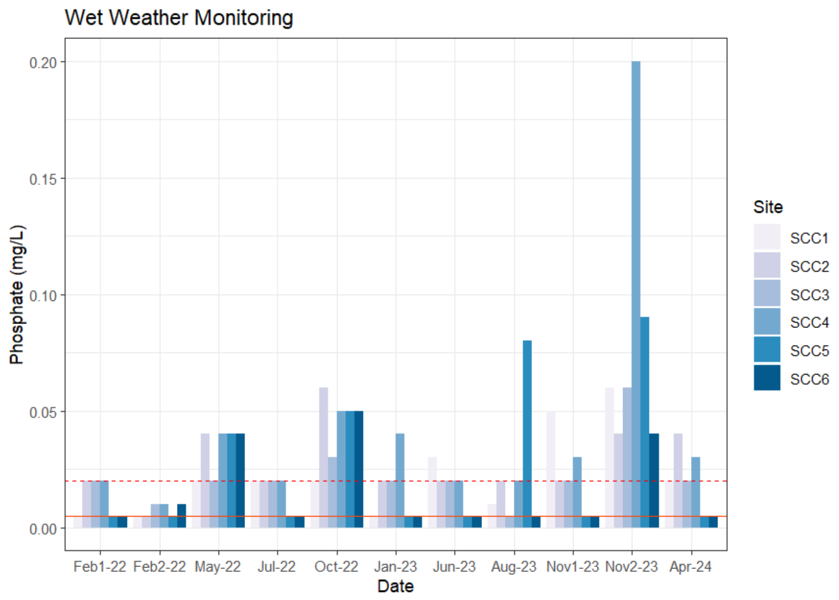

Figure 94: Phosphate (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Suspended Solids

Total Suspended Solids were within a narrow range across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. However, all sites experienced events where levels were elevated, as shown by the outliers present, and this was highest at SCC2 (Figure 95).

During wet weather monitoring, trends for all Macquarie Rivulet sites were similar to dry weather monitoring. However, ranges still largely overlapped for all sites, and the highest range was recorded at SCC2 (Figure 96).

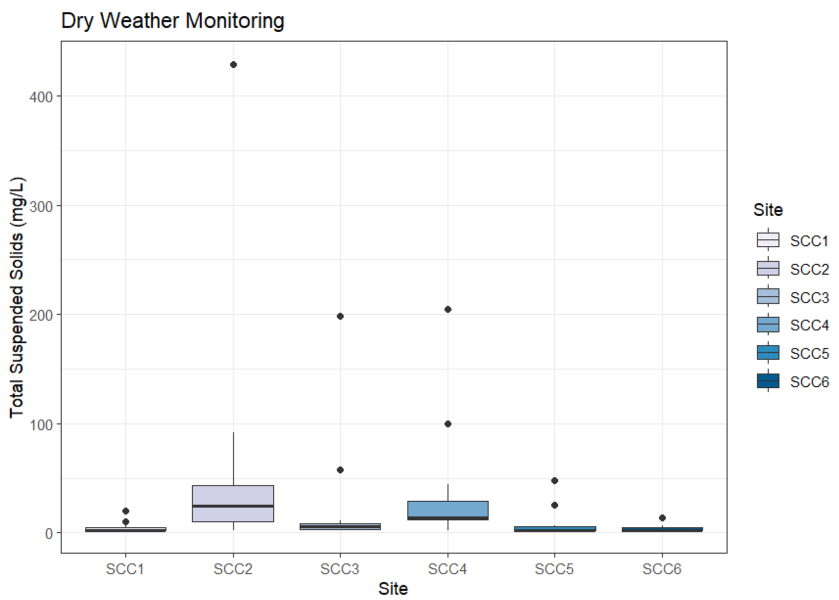

Figure 95: Summary of Total Suspended Solids (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

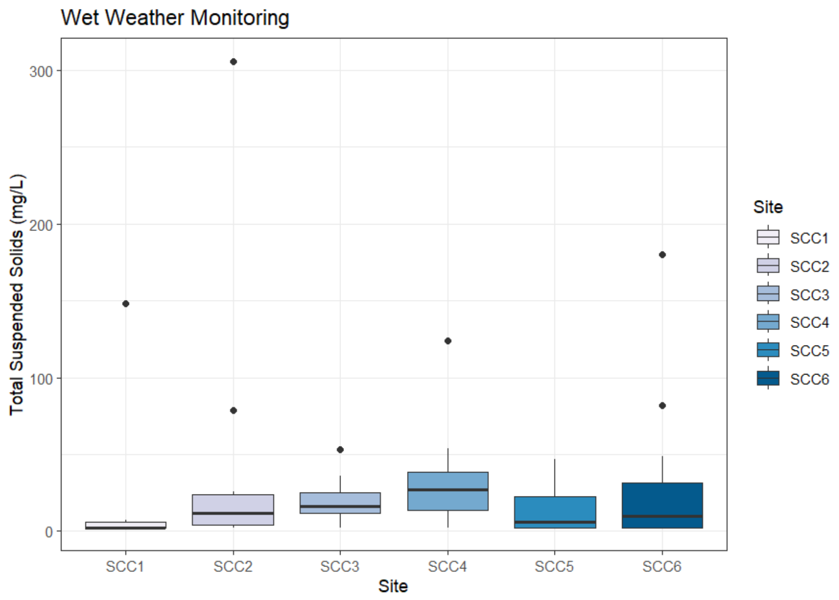

Figure 96: Summary of Total Suspended Solids (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total suspended solids remained low to moderate at all Macquarie Rivulet sites. The maximum total suspended solids value was recorded at SCC2 (429 mg/L) in February 2024 (Figure 97). The median total suspended solids for Macquarie Rivulet sites was 6.00 mg/L during dry weather monitoring. There are currently no ANZECC (2000) guidelines for total suspended solids.

During wet weather monitoring, total suspended solids showed an overall increase compared to dry weather monitoring events (Figure 98). The highest value was recorded at SCC2 in November 2023 (306 mg/L). The median total suspended solids for Macquarie Rivulet sites was 11.00 mg/L during wet weather monitoring.

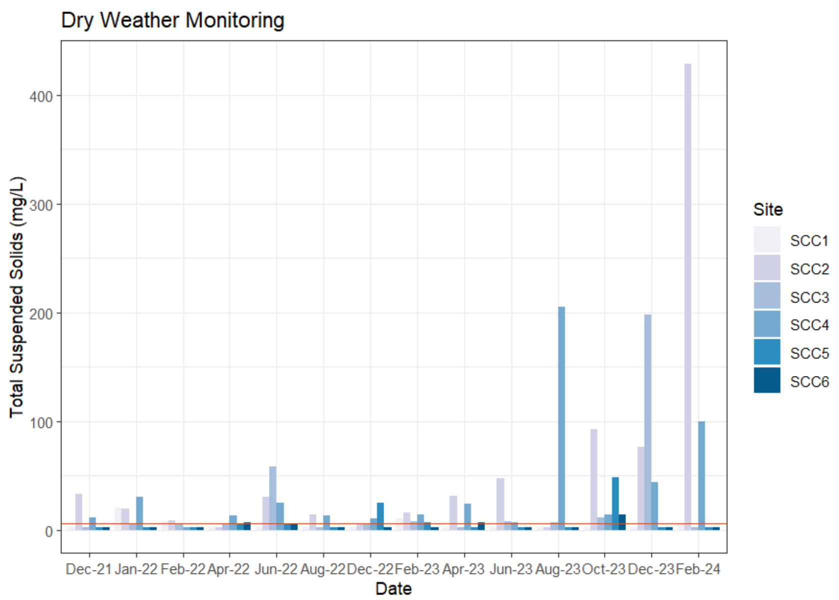

Figure 97: Total Suspended Solids (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

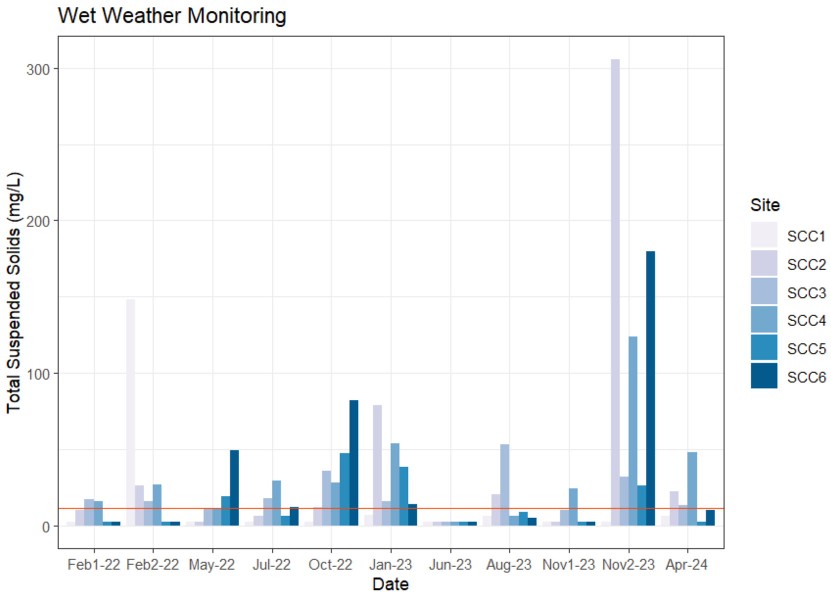

Figure 98: Total Suspended Solids (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Chlorophyll-a

Chlorophyll-*a* concentrations were variable across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. However, sites experienced events where chlorophyll-*a* was elevated, as shown by the outliers present, and this was highest at SCC1 (Figure 99).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at SCC4 (Figure 100).

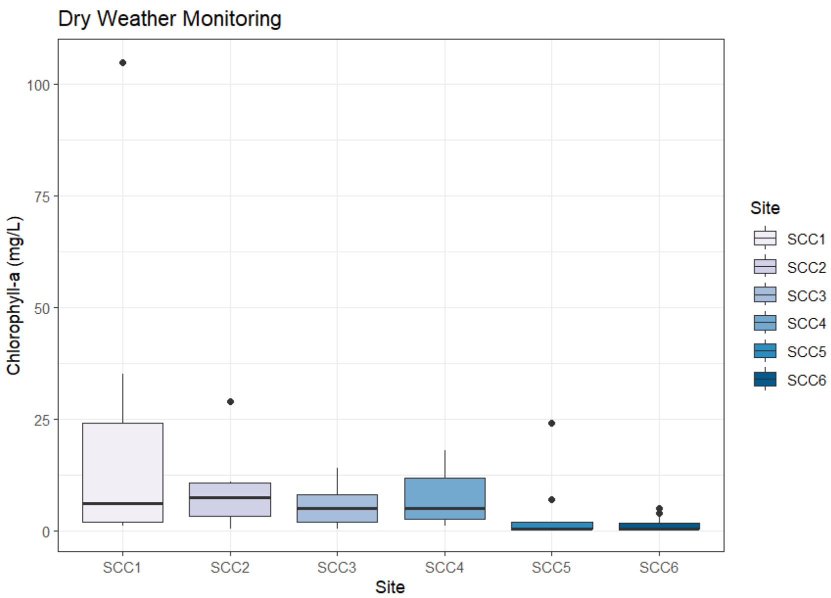

Figure 99: Summary of chlorophyll-*a* (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

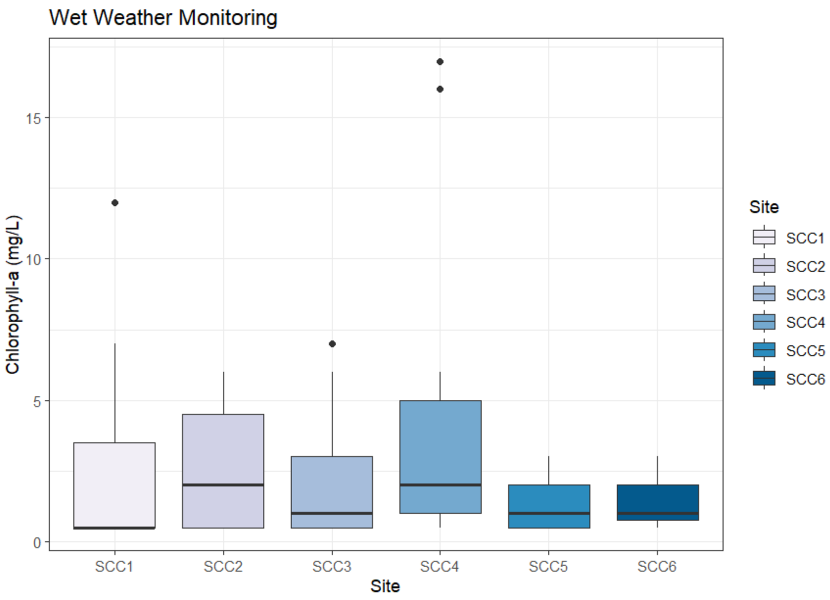

Figure 100: Summary of chlorophyll-*a* (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, chlorophyll-*a* levels at all Macquarie Rivulet sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 101). Chlorophyll-*a* levels were consistently elevated at all sites and were highest at SCC1 in January 2022 (105 mg/L). The median chlorophyll-*a* for Macquarie Rivulet sites (4.00 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, chlorophyll-*a* levels at all Macquarie Rivulet sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 102). Overall values were lower compared to dry weather monitoring. Chlorophyll-*a* levels were highest at SCC4 in January 2023 (17.0 mg/L). The median chlorophyll-*a* for Macquarie Rivulet sites (0.75 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

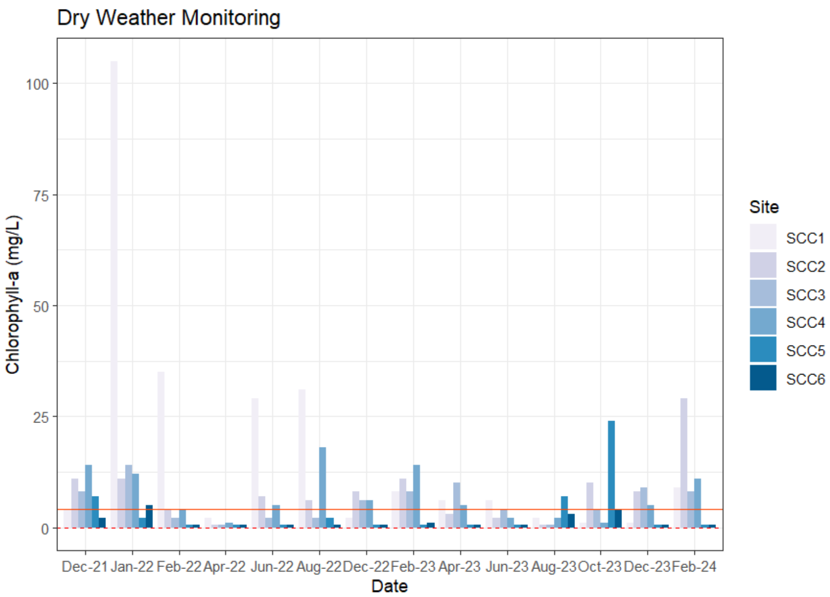

Figure 101: Chlorophyll-*a* (mg/L) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

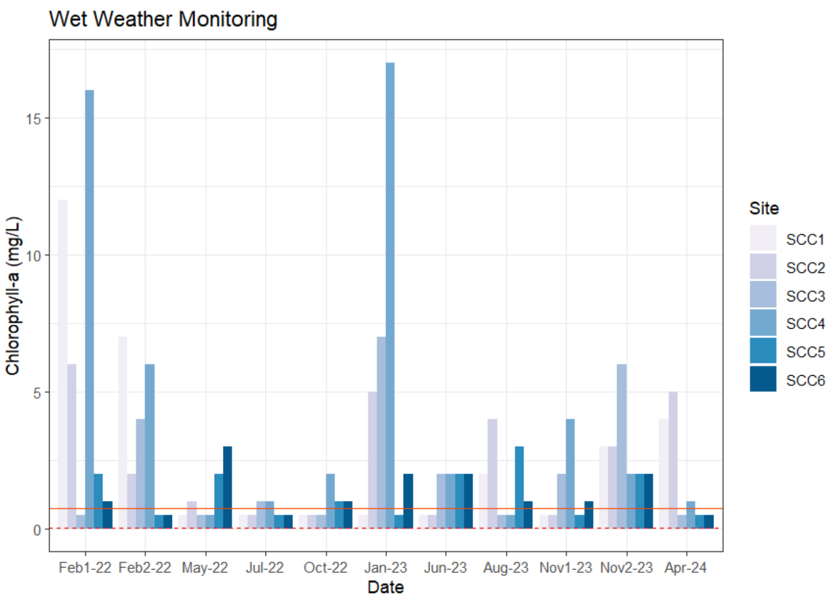

Figure 102: Chlorophyll-*a* (mg/L) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Enterococci

Enterococci concentrations were variable across all Macquarie Rivulet sites during dry weather monitoring for the 2021-24 period. However, all sites experienced events where *Enterococci* was elevated, as shown by the outliers present, particularly at SCC4 (Figure 103).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and like dry weather monitoring the highest range was recorded at SCC4 with a maximum value of 31,000 CFU/100 mL (Figure 104).

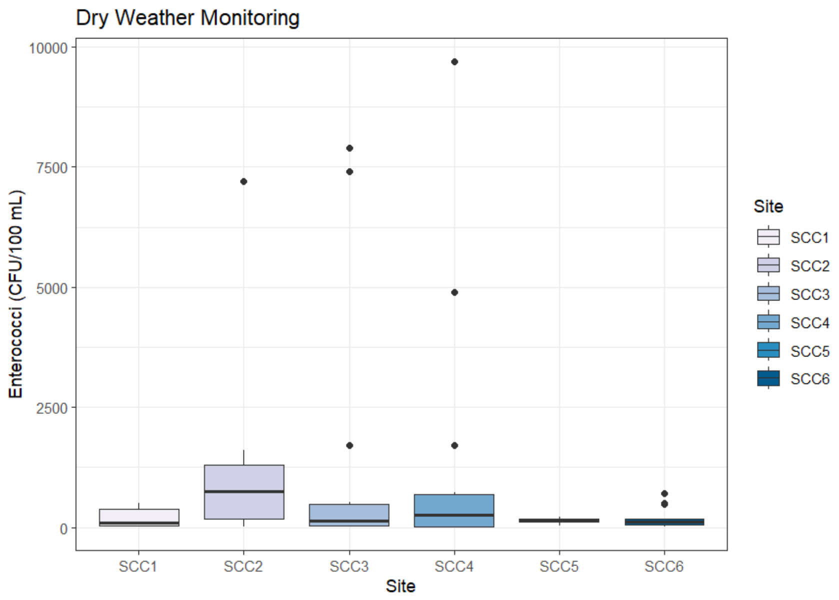

Figure 103: Summary of *Enterococci* (CFU/100 mL) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to April 2024.

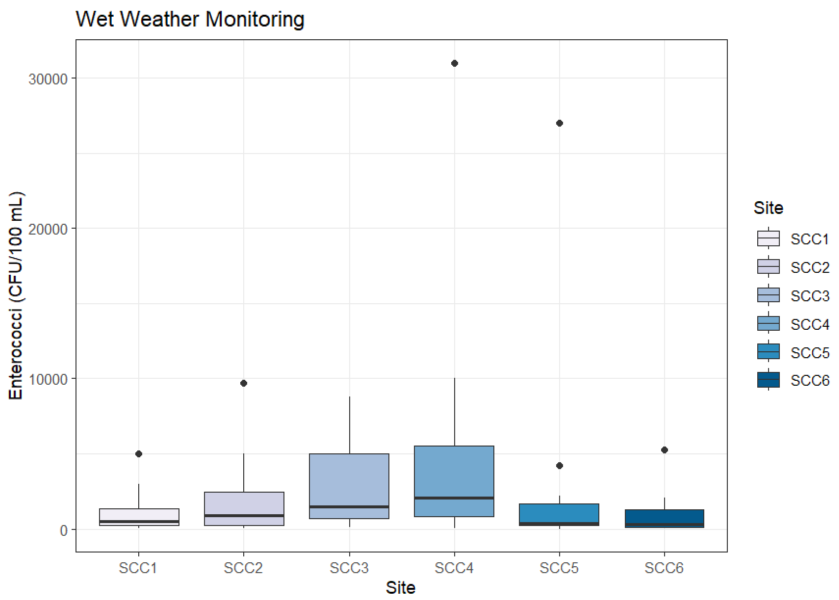

Figure 104: Summary of *Enterococci* (CFU/100 mL) at Macquarie Rivulet sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, *Enterococci* at Macquarie Rivulet sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 33 occasions (Figure 105). This included at SCC1 on four occasions (in December 2021, February 2022, June 2023, and October 2023), at SCC2 on four occasions (in February 2022 and 2024, June 2022, and December 2022), at SCC3 on four occasions (in December 2021, February 2022, June 2022, and August 2022), and at SCC4 on two occasions (in January 2022 and February 2024). The primary contact was also exceeded on 12 occasions at SCC5 (in December 2021, 2022, and 2023, February 2022, 2023, and 2024, April 2022 and 2023, June 2022 and 2023, August 2023, and October 2023), and at SCC6 on seven occasions (in December 2021 and 2023, February 2022, 2023, and 2024, April 2022, and June 2023).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 31 occasions. This included at SCC1 on six occasions (in January 2022, April 2022, December 2022, April 2023, August 2023, and February 2024), and at SCC2 on nine occasions (in December 2021 and 2023, January 2022, April 2022 and 2023, February 2023, June 2023, August 2023, and October 2023). For site SCC3, the secondary guideline was exceeded on six occasions (in April 2022 and 2023, February 2023, August 2023, October 2023, and December 2023). At SCC4, non-compliance occurred on seven occasions (in February 2022 and 2023, April 2022 and 2023, August 2023, October 2023, and December 2023). The secondary guideline was exceeded on three occasions at SCC6 (in April, August, and October 2023).

The median *Enterococci* for Macquarie Rivulet sites (150 CFU/100 mL) during dry weather monitoring was above the primary contact ANZECC (2000) guidelines, but did not exceed the secondary contact guidelines.

During wet weather monitoring, *Enterococci* levels at Macquarie Rivulet sites were non-compliant with the ANZECC (2000) guidelines across all sites and monitoring events. The primary guideline was exceeded on 15 occasions (Figure 106). This included at SCC1 on three occasions (in February 2022, January 2023, and Augst 2023), at SCC2 on two occasions (in February 2022 and June 2023), at SCC3 on two occasions (in February 2022 and July 2022), and at SCC4 on one occasion (in February 2022). The primary contact was also exceeded on two occasions at SCC5 (during both February 2022 sampling events), and at SCC6 on five occasions (during both February 2022 sampling events, July 2022, June 2023, and November 2023).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 50 occasions. This included at SCC1 on eight occasions (in February 2022, May 2022, July 2022, October 2022, June 2023, both November 2023 events, and April 2024), and at SCC2 on nine occasions (in February 2022, May 2022, July 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). For site SCC3, the secondary guideline was exceeded on nine occasions (in February 2022, May 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024). At SCC4, non-compliance occurred on ten occasions (during all sampling events excluding February 2022). The secondary guideline was exceeded on eight occasions at SCC5 (in May 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024), and on six occasions at SCC6 (in May 2022, October 2022, January 2023, August 2023, November 2023, and April 2024).

The median *Enterococci* for Macquarie Rivulet (380 CFU/100 mL) during wet weather monitoring was above the ANZECC (2000) primary and secondary contact guidelines. Levels were particularly elevated across all sites in August and October 2023, however, low rainfall was recorded in the week prior to sampling (as shown in Table 3).

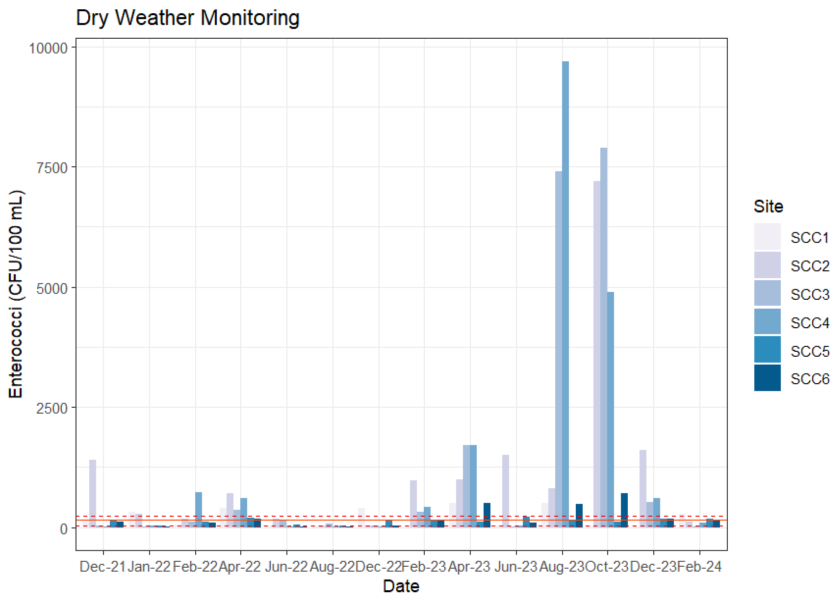

Figure 105: *Enterococci* (CFU/100 mL) at Macquarie Rivulet sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

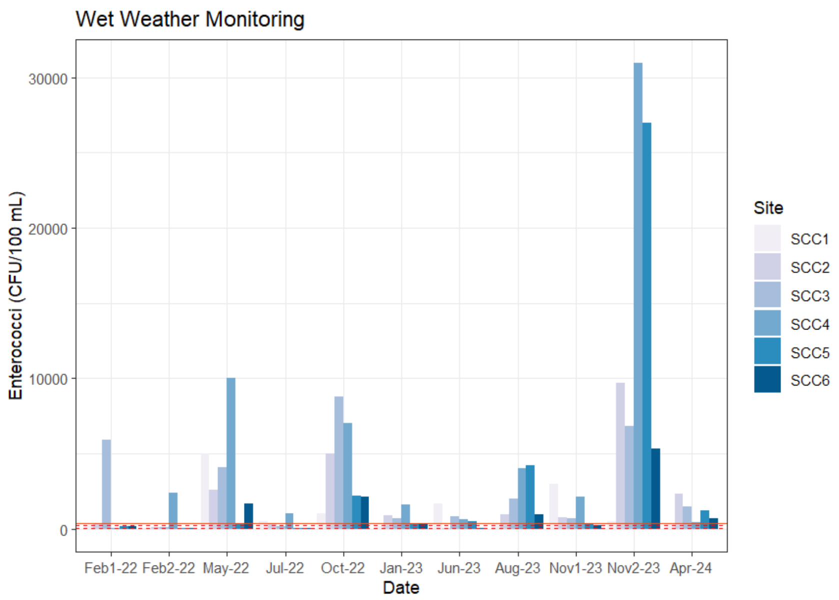

Figure 106: *Enterococci* (CFU/100 mL) at Macquarie Rivulet sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

Robins Creek

Two sites (R1 and R2) were sampled within the Robins Creek catchment on 25 occasions between December 2021 and April 2024, with 14 dry weather monitoring events and 11 wet weather monitoring events. A summary of findings for each water quality parameter is outlined below.

pH

Overall, pH remained similar across the Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 107), as recorded values within the upper and lower quartiles of data largely overlapped between sites.

During wet weather monitoring, ranges still largely overlapped in line with dry weather monitoring (Figure 108).

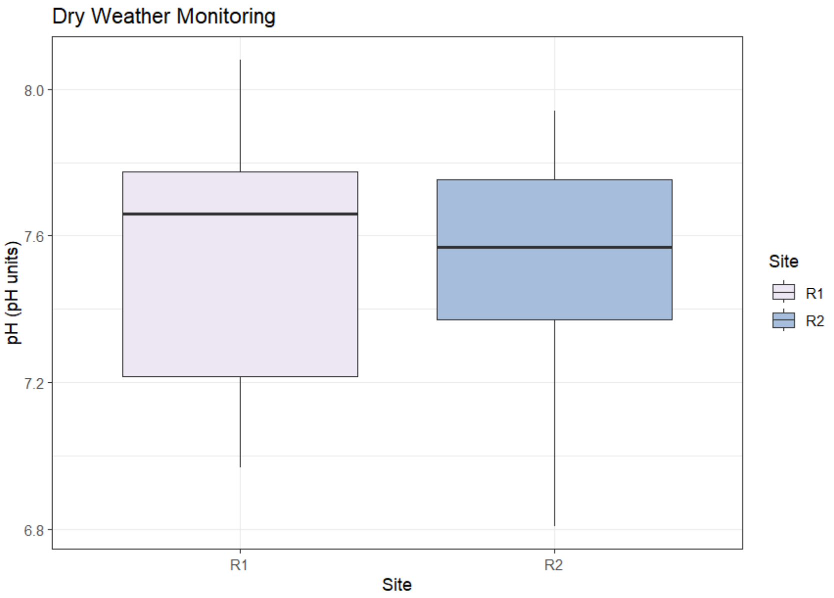

Figure 107: Summary of pH (pH units) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

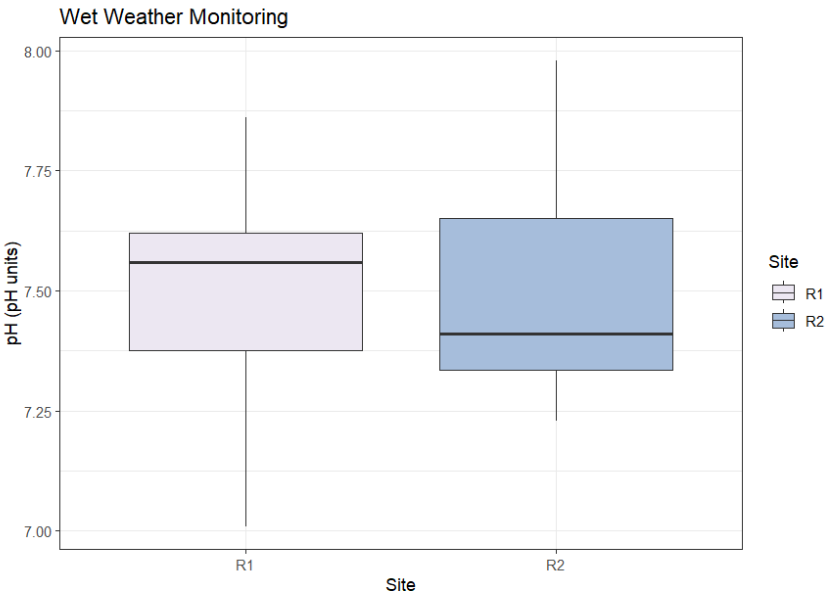

Figure 108: Summary of pH (pH units) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, pH at Robins Creek sites remained within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units for all sites, excluding at R1 in February 2023 (8.08 pH units, which was the highest pH recorded) and August 2023 (8.03 pH units) (Figure 109). The median pH for Robins Creek sites (7.61 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

During wet weather monitoring, pH at Robins Creek sites remained within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units for all sampling events (Figure 110). pH was similar to dry weather monitoring, with a maximum of 7.98 pH units at R2 in February 2022. The median pH for Robins Creek sites (7.55 pH units) during wet weather monitoring was within the ANZECC (2000) guidelines.

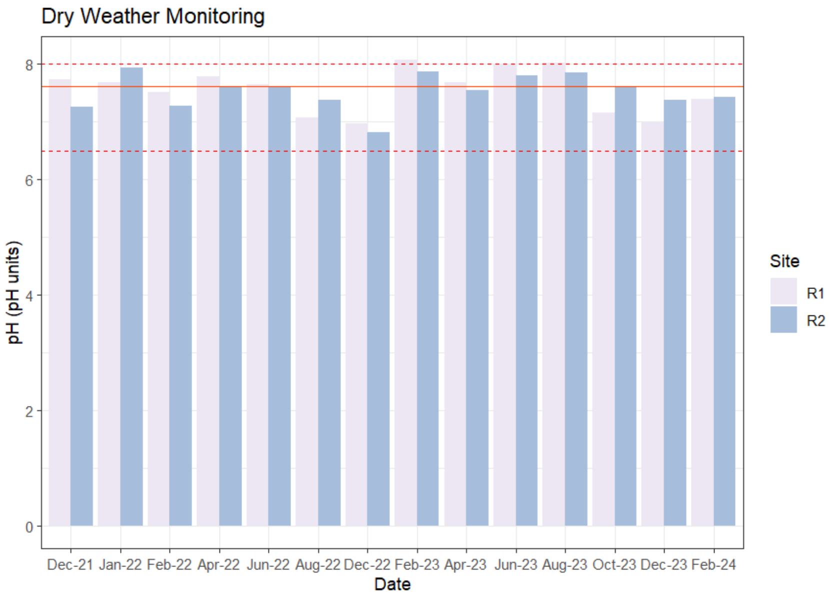

Figure 109: pH (pH units) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

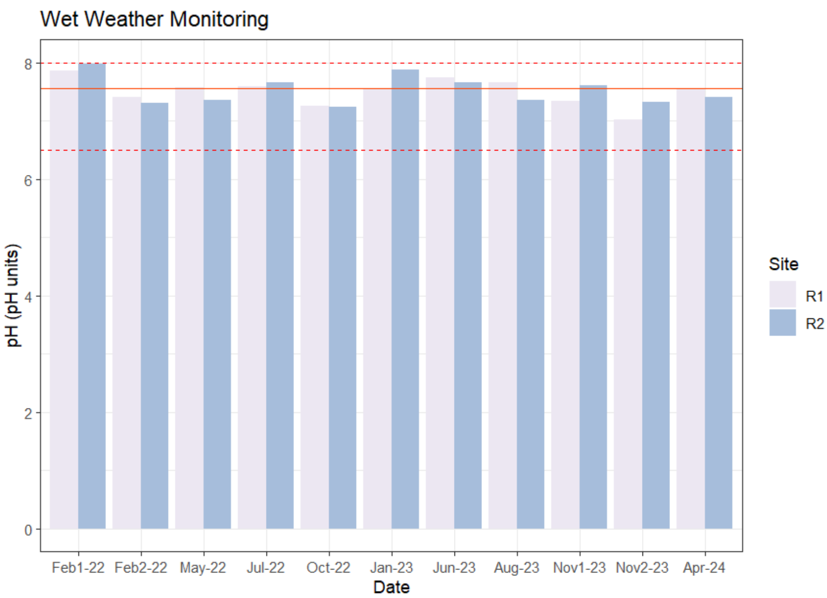

Figure 110: pH (pH units) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Electrical conductivity

Electrical conductivity experienced a wide range at R1, whereas the median was higher at R2 during dry weather monitoring for the 2021-24 period (Figure 111).

During wet weather monitoring, this trend was maintained, with a wide range of variability in electrical conductivity at both Robins Creek sites (Figure 112).

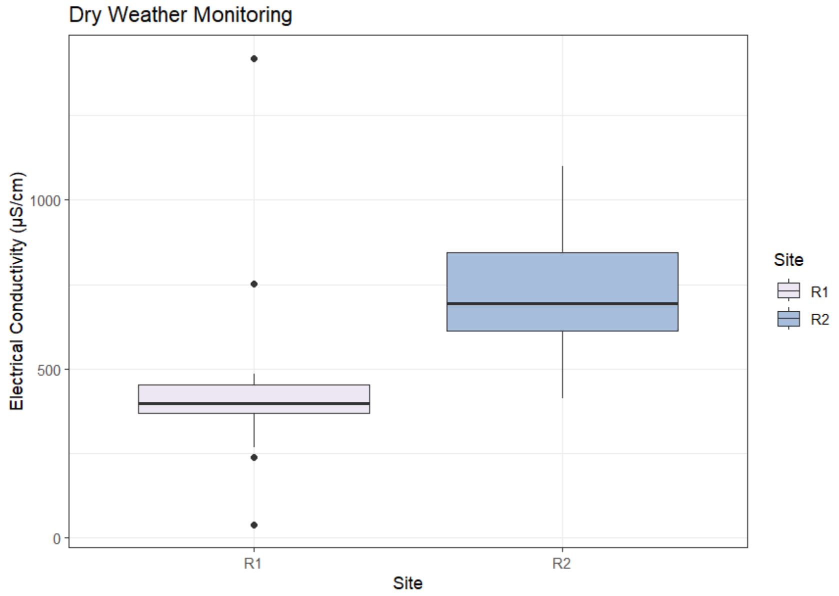

Figure 111: Summary of electrical conductivity (µS/cm) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

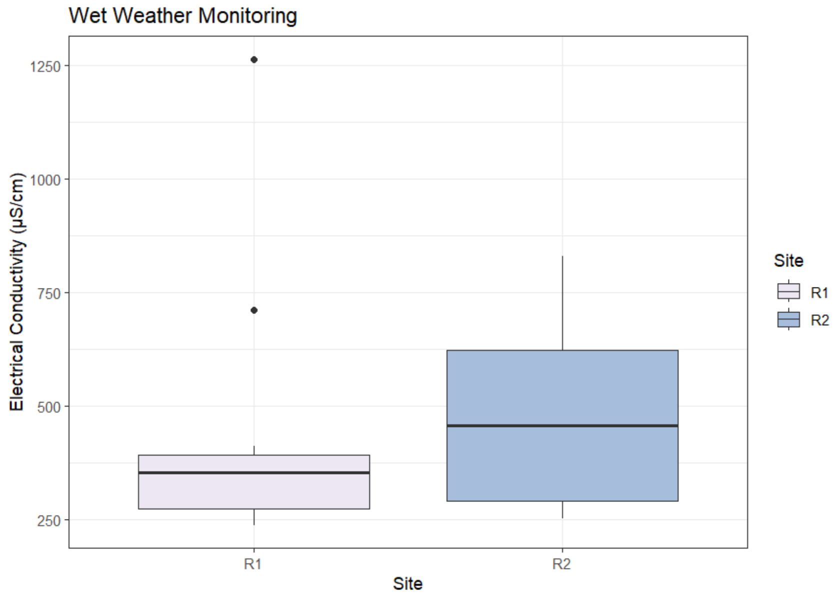

Figure 112: Summary of electrical conductivity (µS/cm) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, electrical conductivity at Robins Creek sites exceeded the upper ANZECC (2000) guideline of 300 µS/cm for both sites on all occasions, excluding at R1 in December 2021 and June 2023. High electrical conductivity is influenced by saline water within the Lake Illawarra catchment as the estuary is brackish. R1 had the highest electrical conductivity, with a maximum of 1420 µS/cm in August 2023 (Figure 113). The median electrical conductivity for Robins Creek sites (500.50 µS/cm) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, the upper ANZECC (2000) guideline for electrical conductivity was exceeded at Robins Creek at both sites across all monitoring events, excluding on four occasions at R1 (in February 2022, July 2022, October 2022, and April 2024) and on three occasions at R2 (in May 2022, July 2022, and April 2024) (Figure 114). Maximum electrical conductivity was recorded at R1 in June 2023 (1264 µS/cm). The median electrical conductivity for Robins Creek sites (167.00 µS/cm) during wet weather monitoring was below the ANZECC (2000) guidelines.

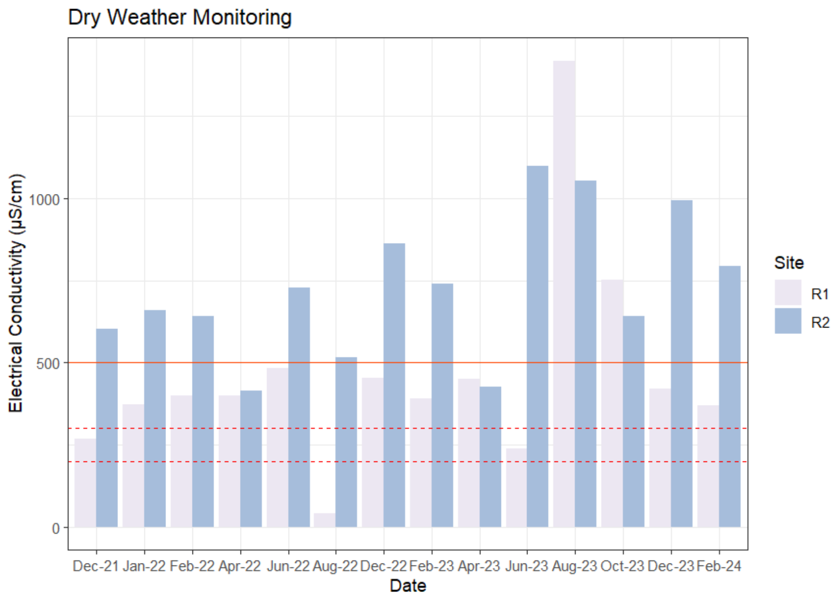

Figure 113: Electrical conductivity (µS/cm) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

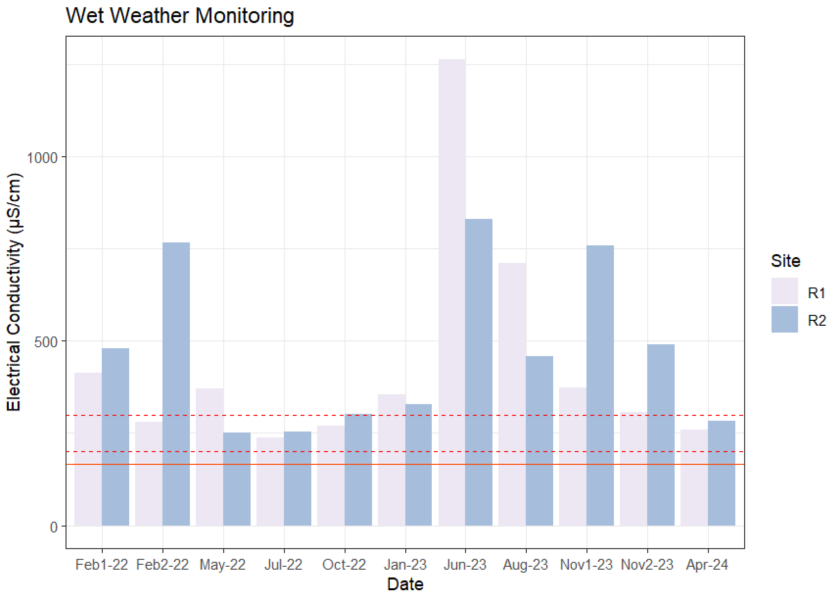

Figure 114: Electrical conductivity (µS/cm) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Temperature

Temperature remained consistent between the Robins Creek sites throughout the 2021-2024 dry weather monitoring period (Figure 115), with the range of all sites overlapping.

During wet weather monitoring, temperature at all sites also remained consistent across all sites (Figure 116).

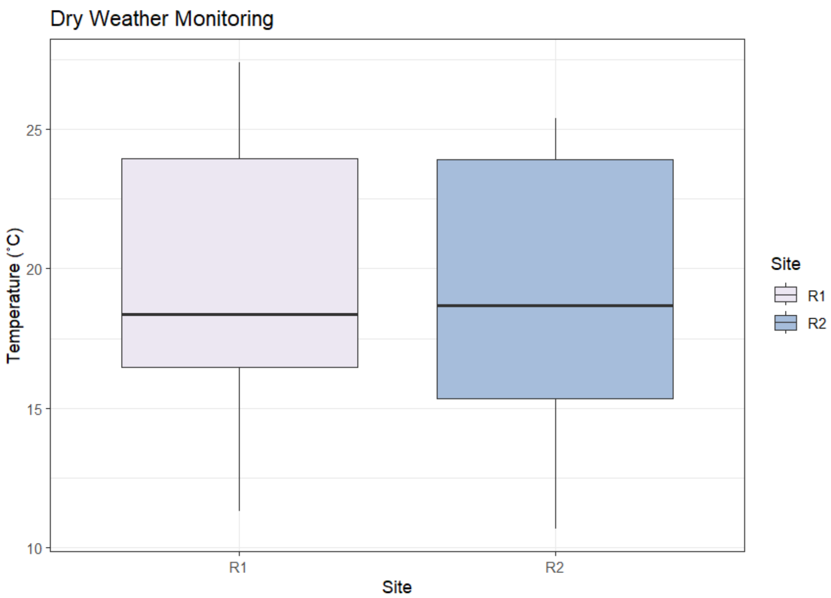

Figure 115: Summary of temperature (˚C) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

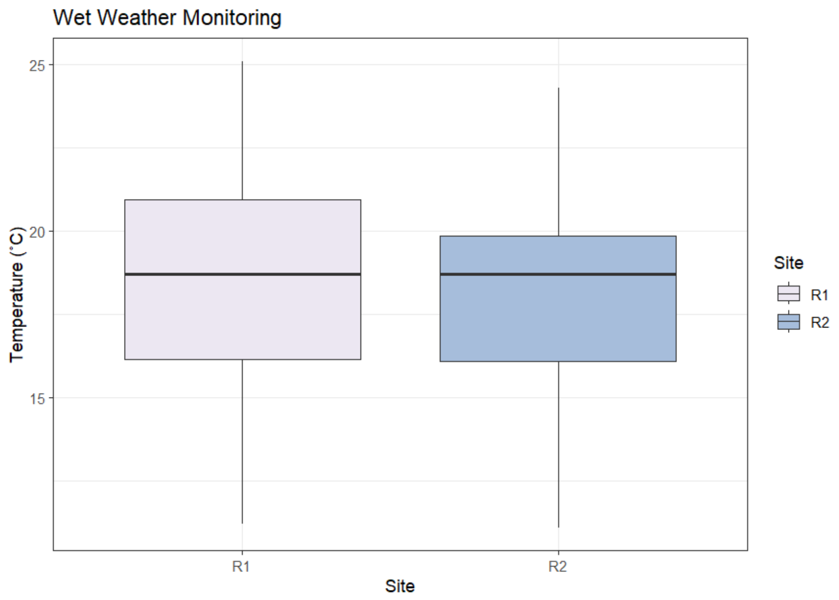

Figure 116: Summary of temperature (˚C) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, temperature ranged from a maximum of 27.4˚C at R1 in February 2024 and a minimum of 10.7˚C at R2 in June 2022 (Figure 117). Robins Creek sites all showed similar temperature trends. The median temperature for Robins Creek sites was 18.35˚C during dry weather monitoring.

During wet weather monitoring, temperature ranged from a maximum of 25.1˚C at R1 in February 2022 and a minimum of 11.1˚C at R2 in August 2023 (Figure 118). Robins Creek sites all showed similar temperature trends. The median temperature for Robins Creek sites was 18.80˚C during wet weather monitoring. There are currently no ANZECC (2000) guidelines for temperature for lowland rivers and temperature can also experience temporal and diurnal changes at sites.

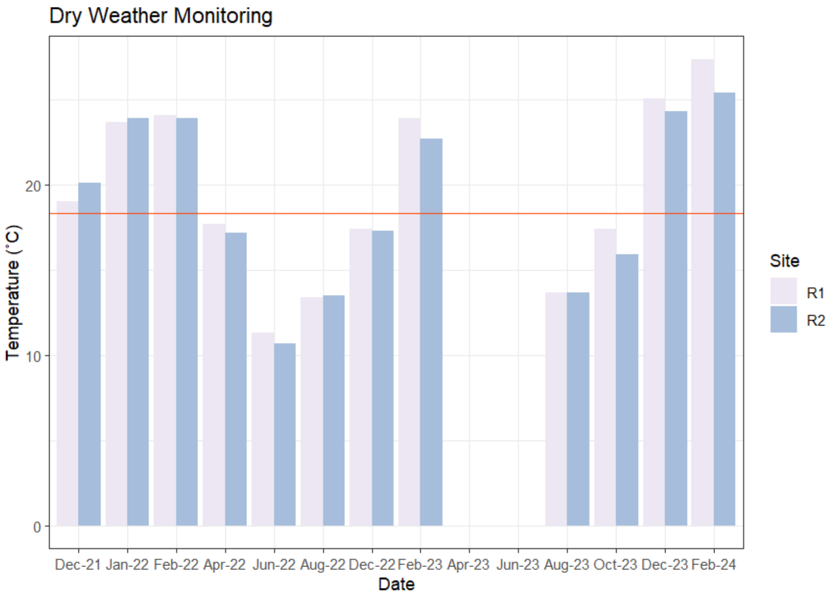

Figure 117: Temperature (˚C) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment. Temperature was not recorded in April and June 2023 due to equipment error.

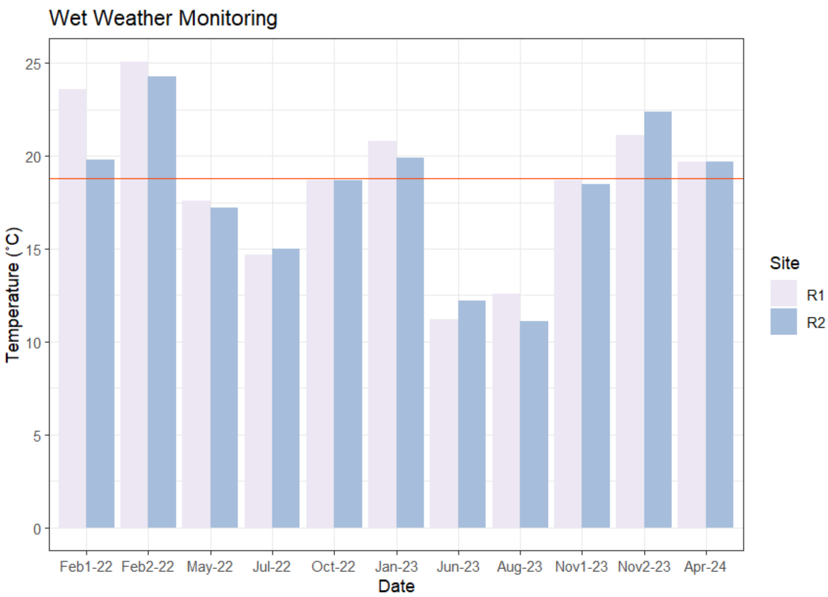

Figure 118:Temperature (˚C) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Dissolved oxygen

Dissolved oxygen, including the median and range of values, remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 119).

During wet weather monitoring, dissolved oxygen remained similar to dry weather monitoring, as ranges still largely overlapped, however, the median for R2 was slightly higher (Figure 120).

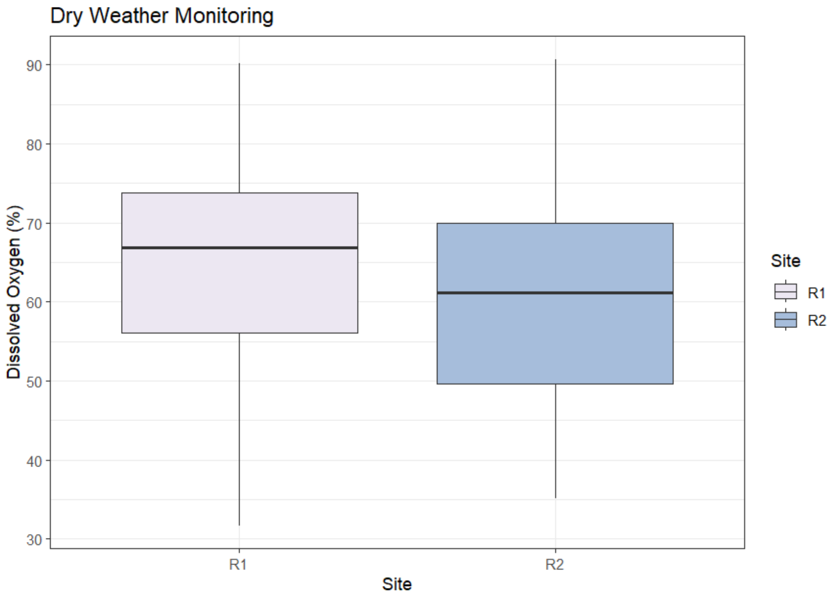

Figure 119: Summary of dissolved oxygen (%) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

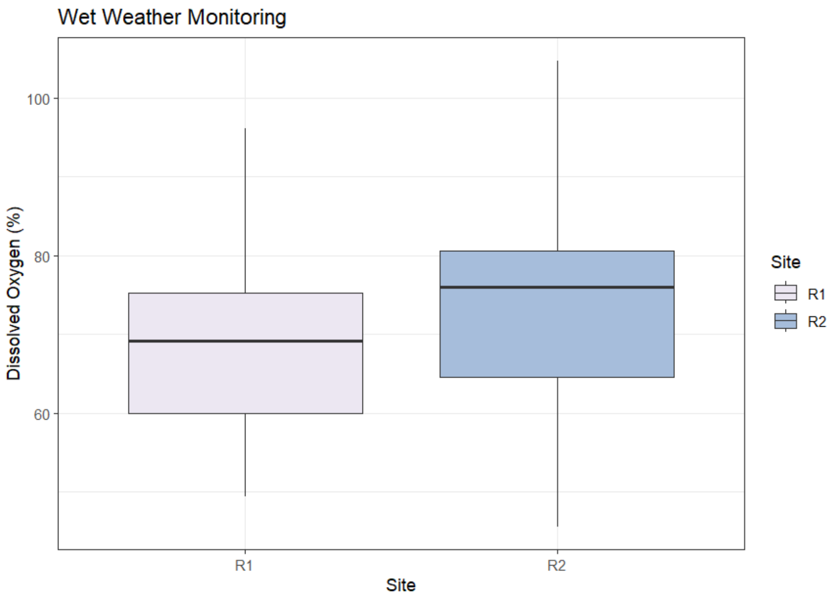

Figure 120: Summary of dissolved oxygen (%) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, dissolved oxygen levels at Robins Creek sites were consistently below the lower ANZECC (2000) guidelines of 85-110%, excluding at both sites in August 2022 (Figure 121). The highest dissolved oxygen was recorded at R2 in August 2022 (90.7%) and the lowest was at R1 in December 2022 (50.9%). The median dissolved oxygen for Robins Creek sites (63.75%) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, dissolved oxygen levels at Robins Creek sites remained low similar to dry weather monitoring (Figure 122). Dissolved oxygen was compliant with the ANZECC (2000) guidelines on one occasion at both sites in October 2022 (96.1% at R1 and 104.8% at R2 respectively), and at R2 in May 2022 (94.8%). The lowest dissolved oxygen was recorded at R2 in February 2022 (45.7%). The median dissolved oxygen for Robins Creek sites (87.5%) during wet weather monitoring was just above the ANZECC (2000) guidelines.

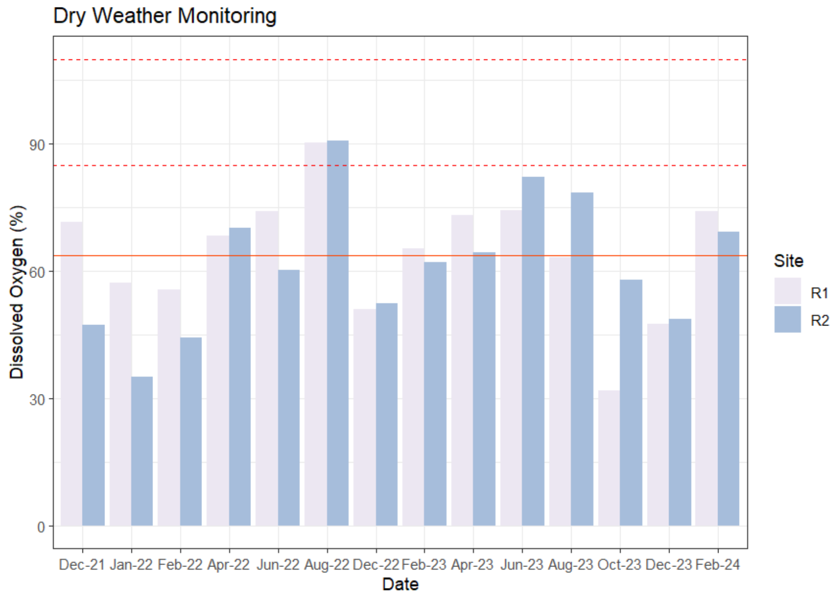

Figure 121: Dissolved oxygen (%) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

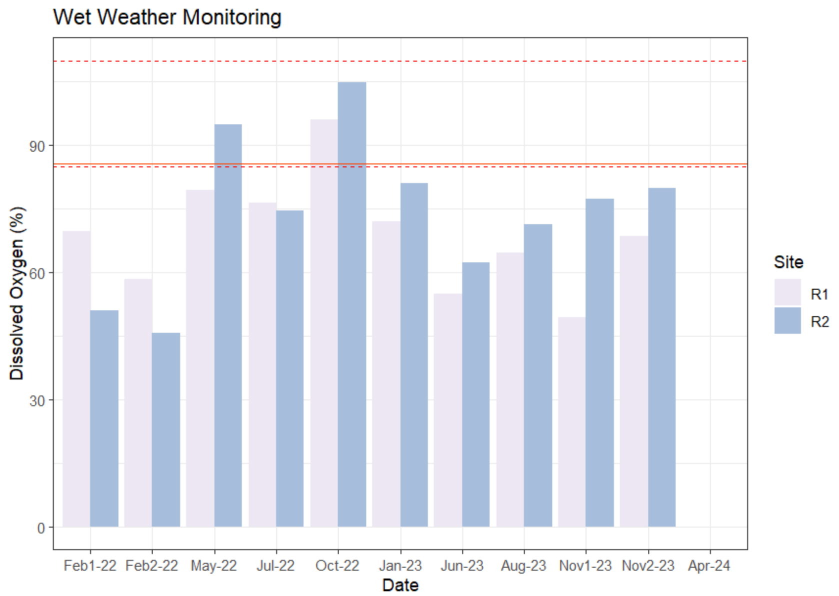

Figure 122: Dissolved oxygen (%) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Turbidity

Turbidity, including the median and range of values, remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 123). However, outliers were observed at R2.

During wet weather monitoring, turbidity remained similar to dry weather monitoring, as ranges still largely overlapped, however, turbidity was overall higher and outliers occurred at R1 (Figure 124).

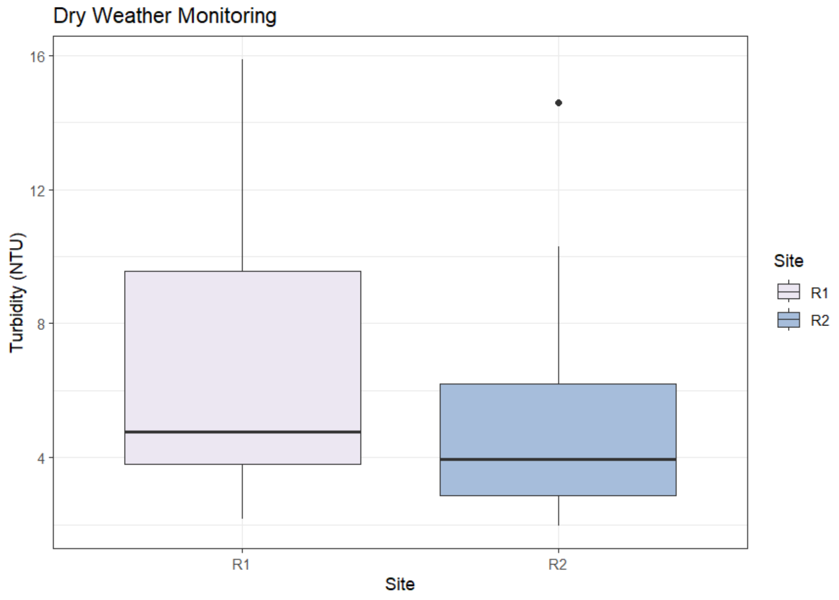

Figure 123: Summary of turbidity (NTU) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

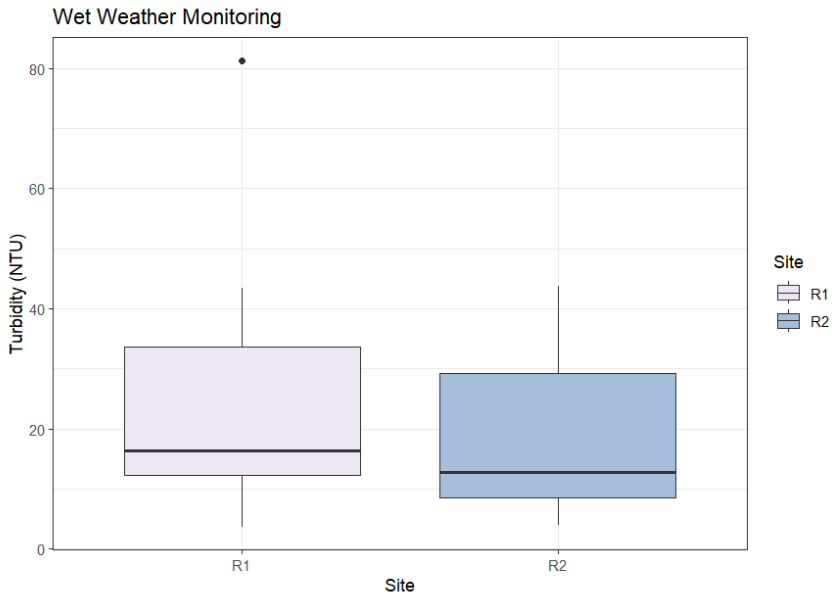

Figure 124: Summary of turbidity (NTU) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, turbidity at Robins Creek sites remained within or below the ANZECC guideline range of 6 – 50 NTU (Figure 125). Maximum turbidity was recorded at R1 (15.9 NTU) in December 2023. The median turbidity for Robins Creek sites (4.54 NTU) during dry weather monitoring was below the ANZECC (2000) guidelines. Results below 6 NTU should not be considered as non-compliant, instead is representative of very low suspended sediments, which is a positive result.

During wet weather monitoring, turbidity at Robins Creek sites remained within the ANZECC guideline range of 6 – 50 NTU (Figure 126). However, this excluded at R1 in November 2023 (81.3 NTU). Turbidity levels were also higher compared to dry weather monitoring. The median turbidity for Robins Creek sites (7.46 NTU) during wet weather monitoring was below the ANZECC (2000) guidelines.

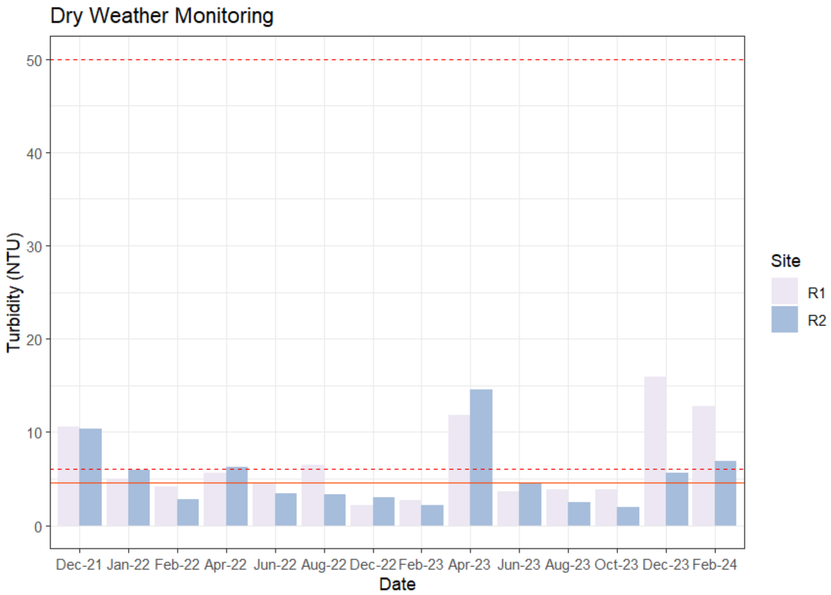

Figure 125: Turbidity (NTU) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

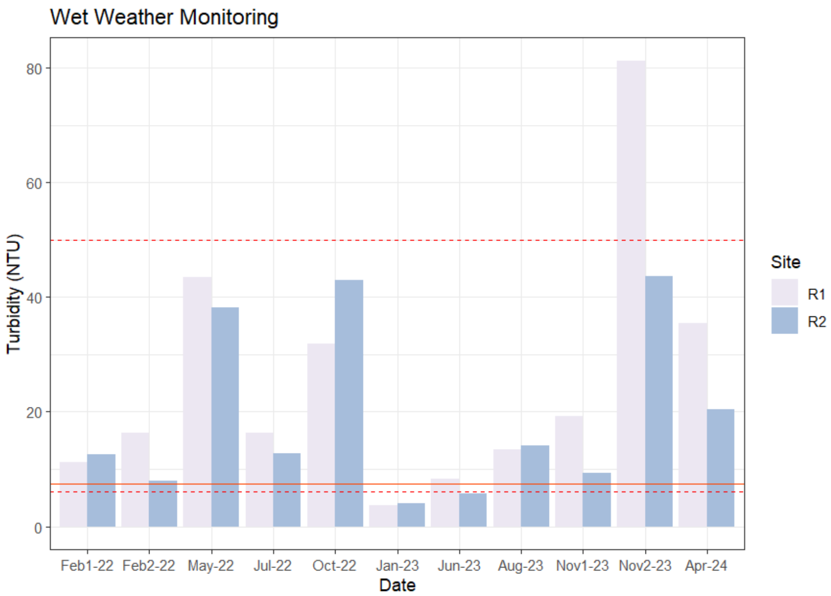

Figure 126: Turbidity (NTU) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Total nitrogen

Total nitrogen, including the median and range of values, remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 127). However, outliers were observed at R2.

During wet weather monitoring, total nitrogen remained similar to dry weather monitoring, as ranges still largely overlapped, however, values were overall higher and outliers occurred at R2 (Figure 128).

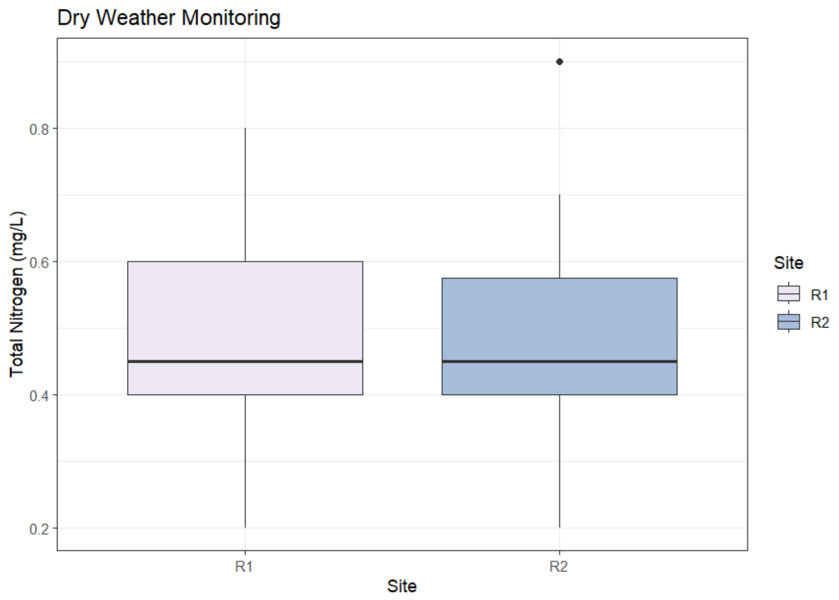

Figure 127: Summary of total nitrogen (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

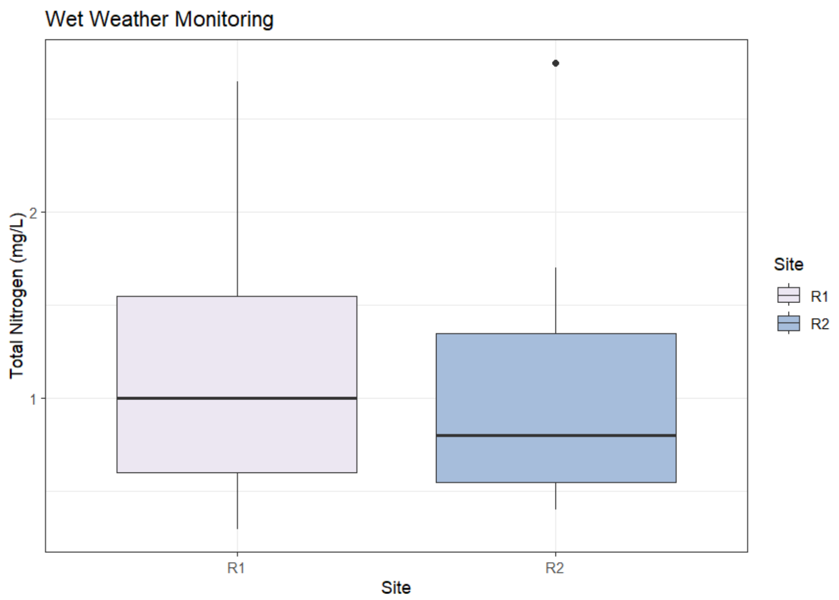

Figure 128: Summary of total nitrogen (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total nitrogen concentrations at Robins Creek sites exceeded the ANZECC (2000) guideline of 0.5 mg/L on 14 occasions (Figure 129). This included at R1 on seven occasions (in August 2022, April 2023, June 2023, August 2023, October 2023, December 2023, and February 2024), and at R3 on seven occasions (in January 2022, February 2023, April 2023, June 2023, August 2023, October 2023, and December 2023). The median total nitrogen for Robins Creek sites (0.45 mg/L) during dry weather monitoring was just below the ANZECC (2000) guidelines.

During wet weather monitoring, compliance with the ANZECC (2000) guideline for total nitrogen was low at Robins Creek sites (Figure 130). Total nitrogen concentrations complied with the ANZECC (2000) guideline on four occasions. This included on three occasions at R1 (in February 2022, June 2023, and August 2023), and in February 2022 at R2. The median total nitrogen for Robins Creek sites (0.80 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

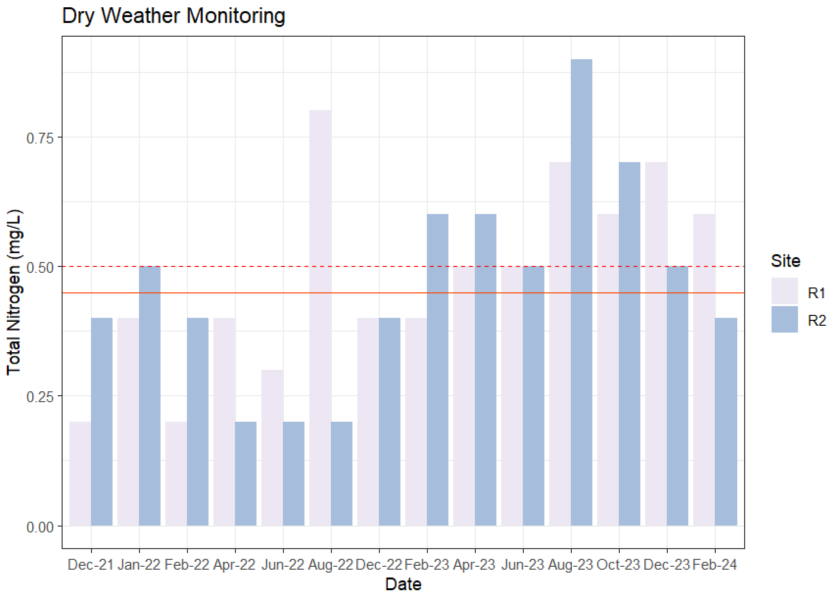

Figure 129: Total nitrogen (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

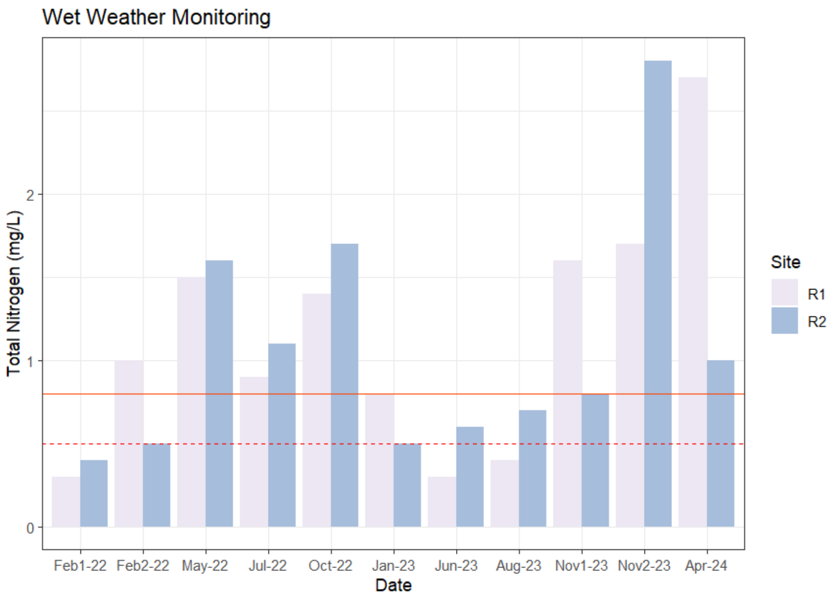

Figure 130: Total nitrogen (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Ammonia

Ammonia, including the median and range of values, remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 131). However, outliers were observed at R1.

During wet weather monitoring, ammonia remained similar to dry weather monitoring, as ranges still largely overlapped, however, the median was higher at R2 and outliers occurred at R1 (Figure 132).

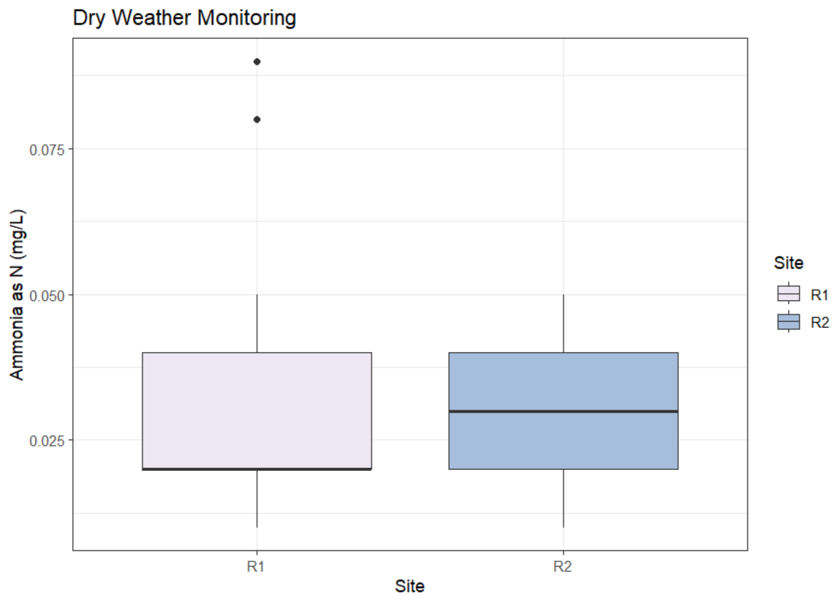

Figure 131: Summary of ammonia (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

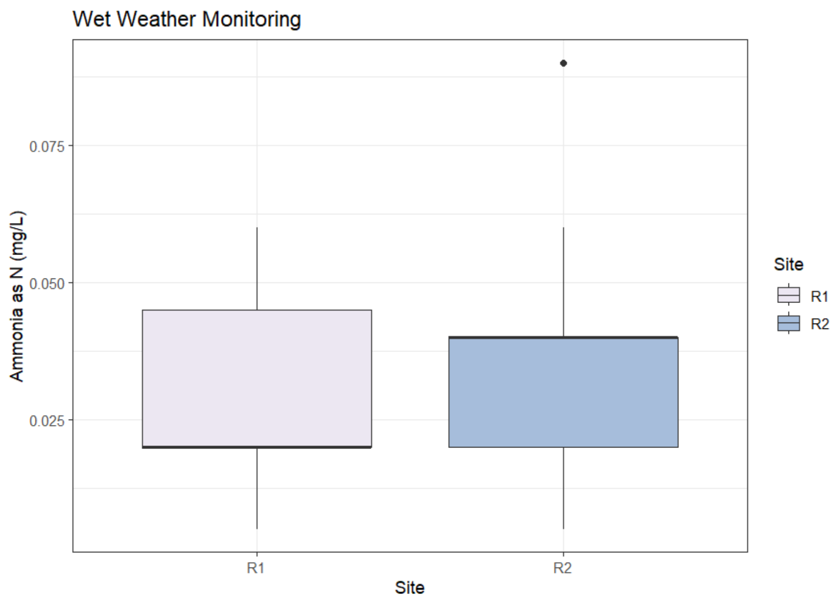

Figure 132: Summary of ammonia (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, ammonia concentrations at Robins Creek sites were compliant with the ANZECC (2000) guideline of 0.02 mg/L on four occasions (Figure 133). This included on two occasions at R1 (in December 2021 and August 2023), and on two occasions at R2 (in August 2022 and April 2023). The median ammonia for Robins Creek sites (0.03 mg/L) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, ammonia concentrations at Robins Creek sites also complied with the ANZECC (2000) guideline of 0.02 mg/L on four occasions (Figure 134). This included on two occasions at R1 (in June 2023 and November 2023), and on two occasions at R2 (in February 2022 and November 2023). The maximum recorded ammonia value for wet weather monitoring (0.09 mg/L at R2 in January 2023) was in line with dry weather monitoring (0.09 mg/L at R1 in October 2023). The median ammonia for Robins Creek sites (0.02 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

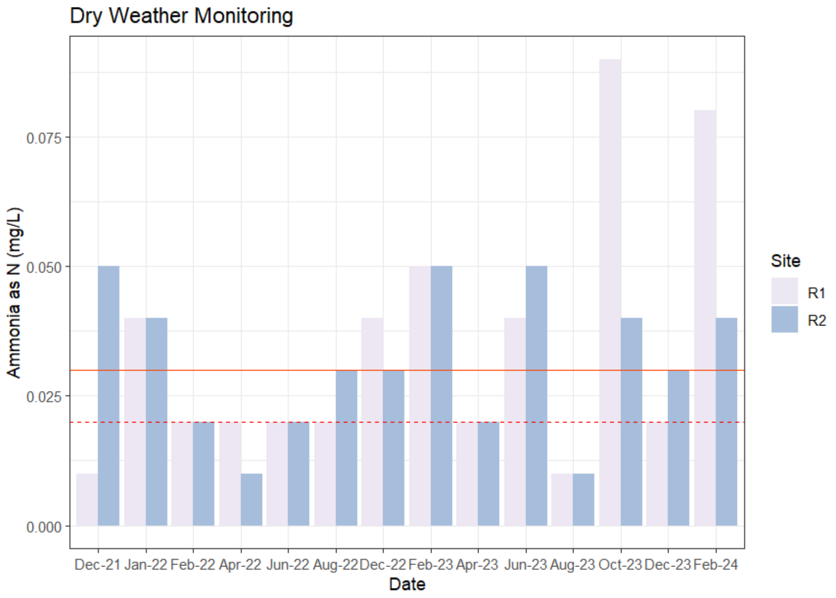

Figure 133: Ammonia (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

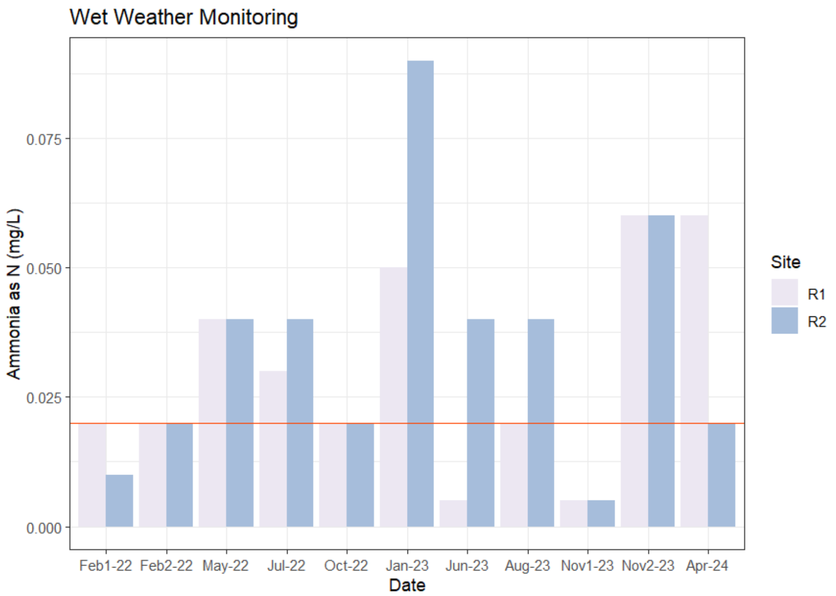

Figure 134: Ammonia (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

NOx

Nitrate and nitrite (NOx) concentrations remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 135). However, outliers were observed at R2 and the median was higher at R1.

During wet weather monitoring, NOx remained similar to dry weather monitoring, as ranges still largely overlapped, however, the median was higher at R2 (Figure 136).

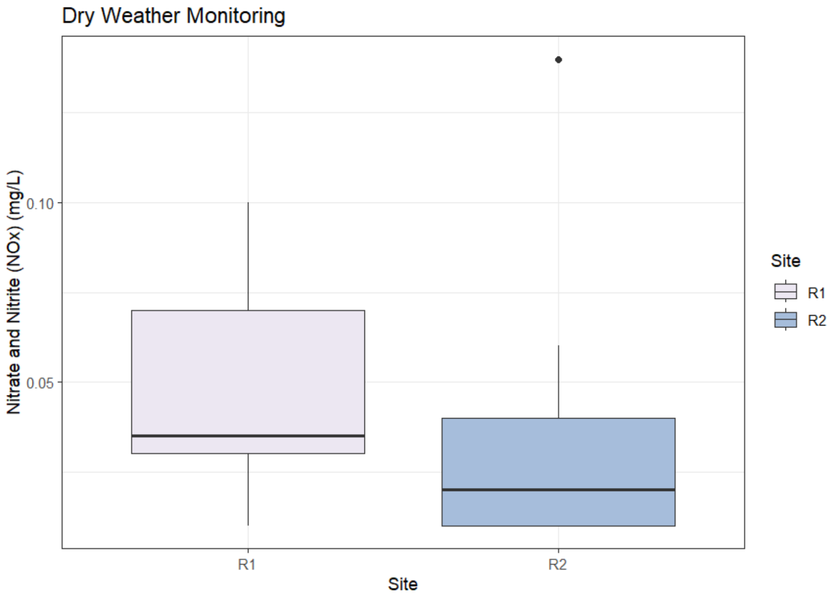

Figure 135: Summary of nitrate and nitrite (NOx) (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

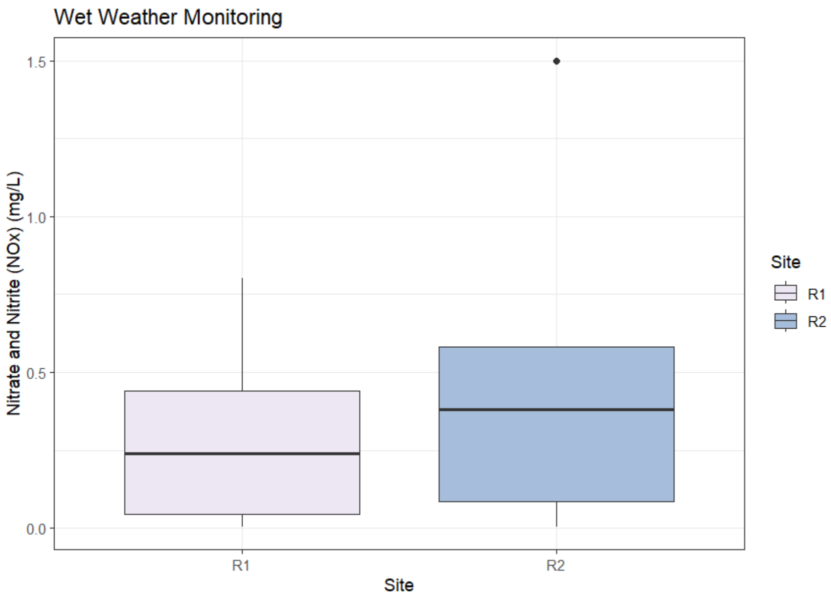

Figure 136: Summary of nitrate and nitrite (NOx) (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, NOx concentrations at Robins Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 12 occasions (Figure 137). This occurred at R1 on seven occasions (in January 2022, April 2022 and 2023, June 2022 and 2023, and August 2022), and at R2 on five occasions (in August 2022 and 2023, April 2022, June 2023, and October 2023). The median NOx for Robins Creek sites (0.03 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, NOx concentrations at Robins Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 18 occasions (Figure 138). This reflects an increase in NOx concentrations compared to dry weather monitoring. Non-compliant events occurred at R1 on nine occasions (in February 2022, May 2022, July 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024), and at R2 on nine occasions (in May 2022, July 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024). The highest NOx value was recorded at R2 in November 2023 (1.50 mg/L). The median NOx for Robins Creek sites (0.33 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

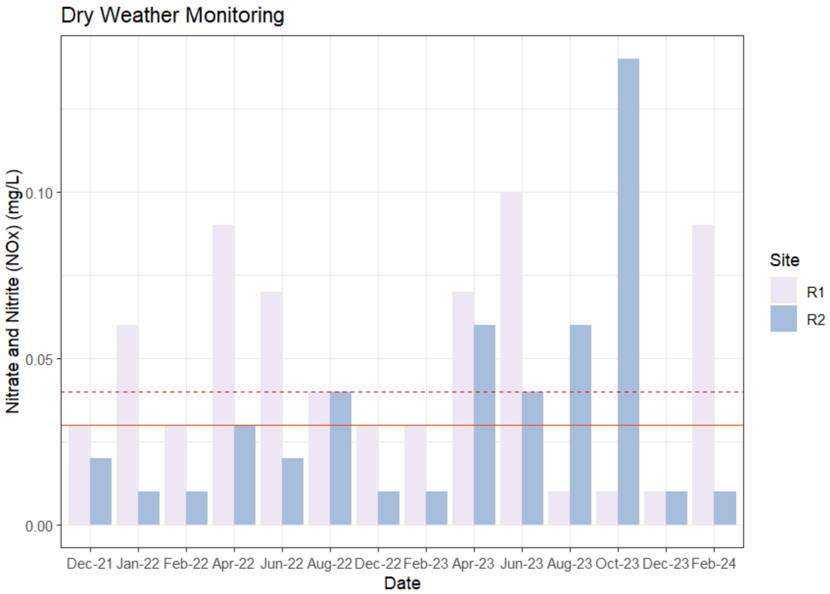

Figure 137: Nitrate and nitrite (NOx) (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

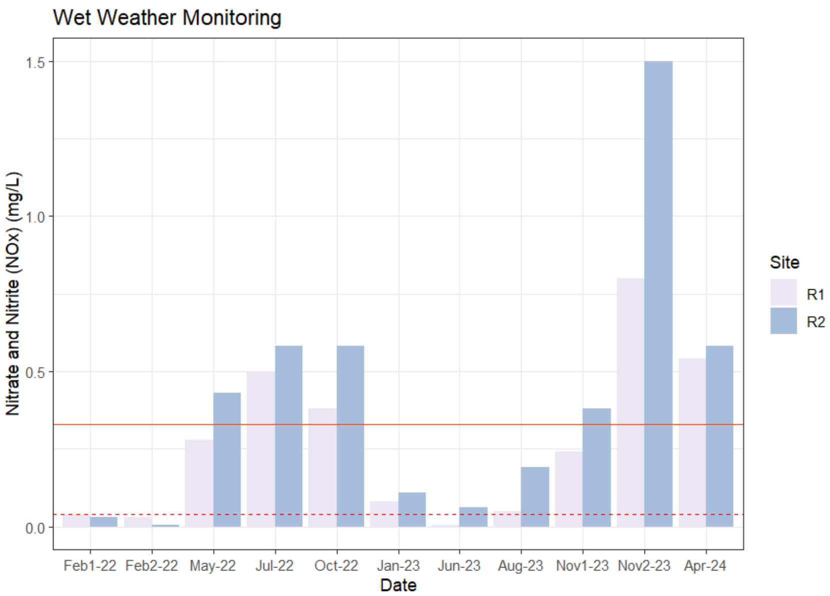

Figure 138: Nitrate and nitrite (NOx) (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Phosphorus

Total phosphorus concentrations remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 139). However, each site experienced events where total phosphorus was elevated, as shown by the outliers present.

During wet weather monitoring, total phosphorus remained similar to dry weather monitoring, as ranges still largely overlapped, however, outliers occurred at R1 (Figure 140).

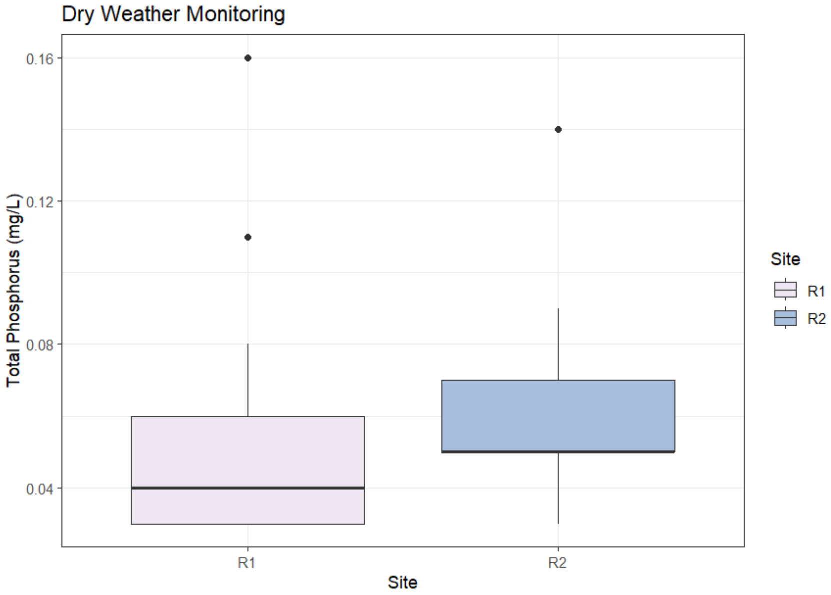

Figure 139: Summary of total phosphorus (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

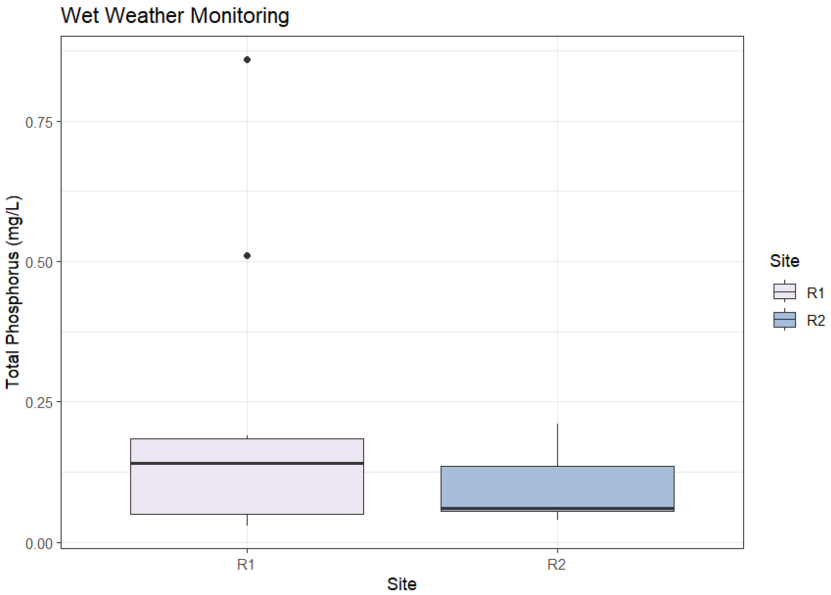

Figure 140: Summary of total phosphorus (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total phosphorus concentrations at Robins Creek sites were non-compliant with the ANZECC (2000) guideline of 0.05 mg/L on 17 occasions (Figure 141). This included on six occasions at R1 (in August 2022 and 2023, December 2022 and 2023, April 2023, and February 2024), and on 11 occasions at R2 (in December 2021, 2022, and 2023, January 2022, February 2022, 2023, and 2024, April 2023, June 2023, August 2023, and October 2023). The median total phosphorus for Robins Creek sites (0.05 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

During wet weather monitoring, non-compliance with the ANZECC (2000) guideline for total phosphorus occurred at Robins Creek sites on 17 occasions across both sites (Figure 142). R1 exceeded the guideline on eight occasions (excluding in February 2022, June 2023, and August 2023). R2 also exceeded the total phosphorus guideline on nine occasions (excluding in February 2022 and November 2023). The median total phosphorus for Robins Creek sites (0.05 mg/L) during wet weather monitoring was in line with the ANZECC (2000) guidelines.

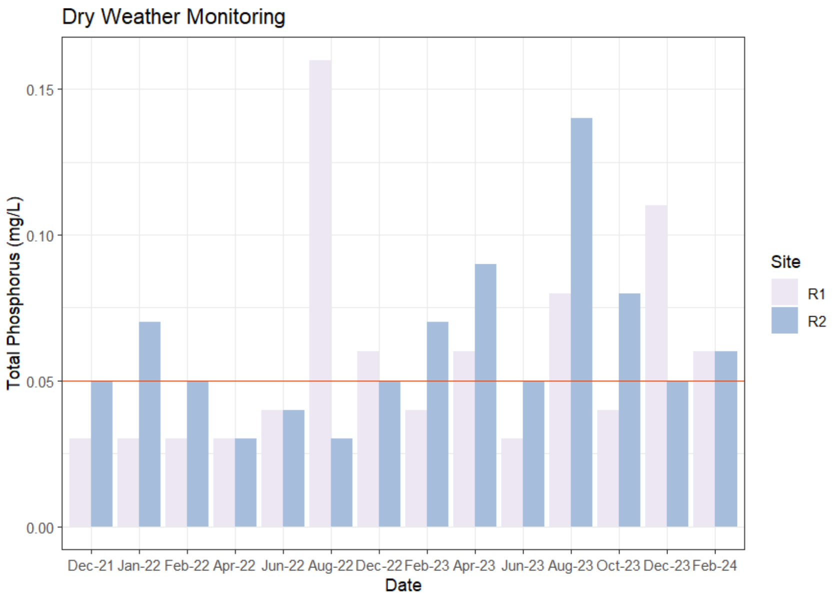

Figure 141: Total phosphorus (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

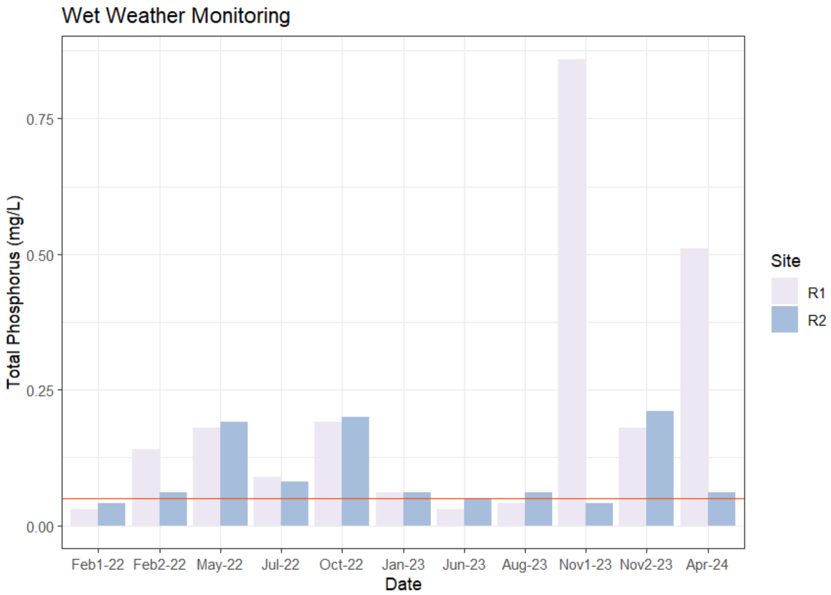

Figure 142: Total phosphorus (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Phosphate

Phosphate concentrations remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 143). However, both sites were within a narrow range, with outliers present at R1.

During wet weather monitoring, phosphate remained similar to dry weather monitoring, as ranges still largely overlapped, however, outliers occurred at both sites (Figure 144).

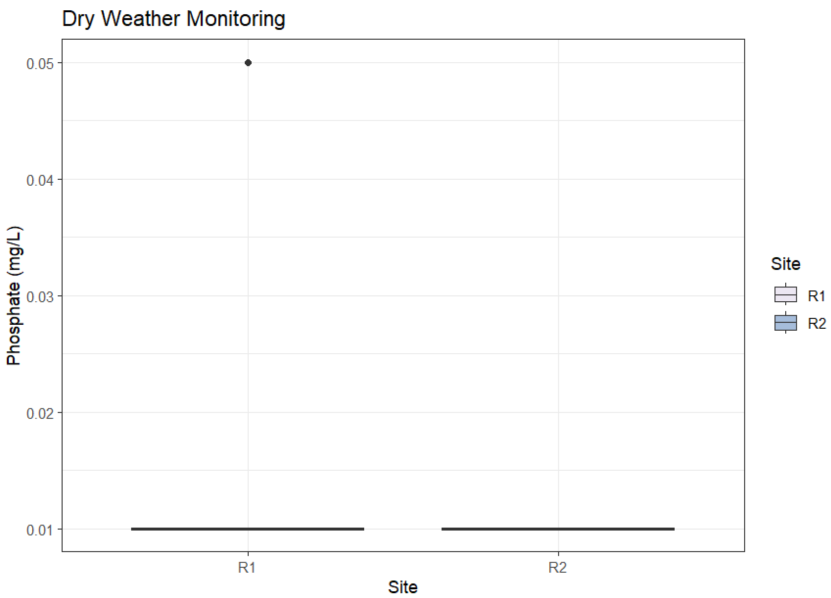

Figure 143: Summary of phosphate (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

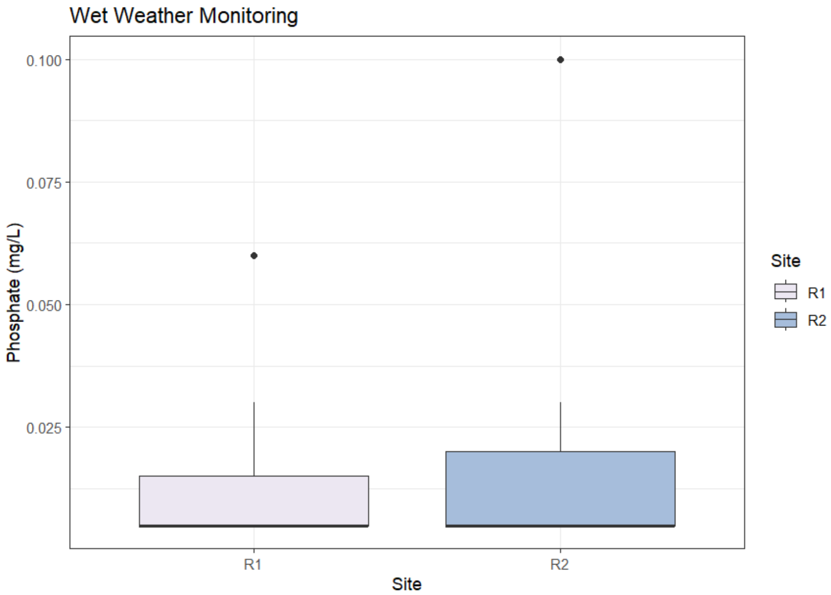

Figure 144: Summary of phosphate (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, phosphate concentrations at Robins Creek sites were low (<0.01 mg/L) for all sampling events (Figure 145). However, phosphate levels did exceed the ANZECC (2000) guideline (0.02 mg/L) at R1 in August 2023 (0.05 mg/L). The median phosphate for Robins Creek sites (0.01 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, phosphate concentrations at Robins Creek sites exceeded the ANZECC (2000) guideline (0.02 mg/L) on seven occasions, at R1 on three occasions (in May 2022, October 2022, and November 2023), and at R2 on four occasions (in May 2022, October 2022, January 2023, and November 2023) (Figure 146). The median phosphate for Robins Creek sites (0.005 mg/L) during wet weather monitoring was below the ANZECC (2000) guidelines.

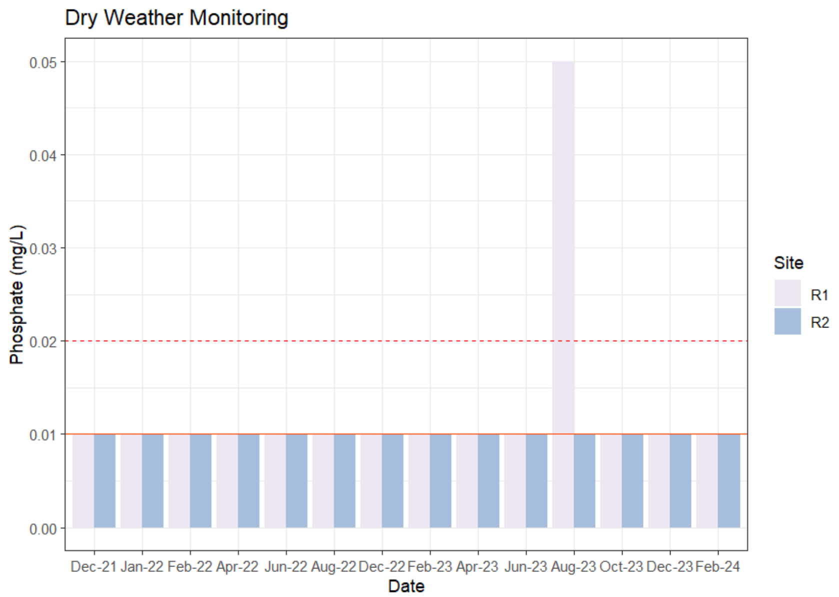

Figure 145: Phosphate (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

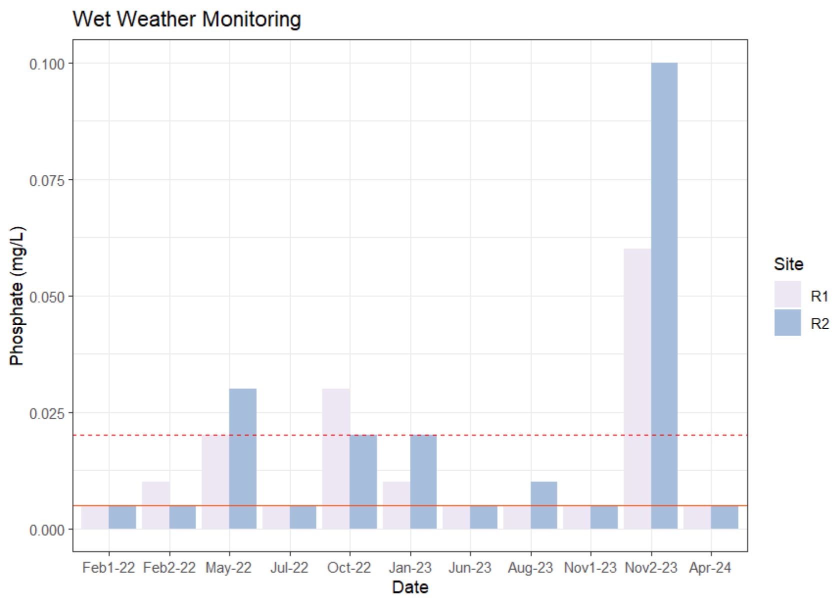

Figure 146: Phosphate (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Suspended Solids

Total Suspended Solids were within a narrow range across both Robins Creek sites during dry weather monitoring for the 2021-24 period. However, outliers were present at R2 (Figure 147).

During wet weather monitoring, trends for both Robins Creek sites were similar to dry weather monitoring. However, ranges still largely overlapped for all sites, and the highest range was recorded at R1 (Figure 148).

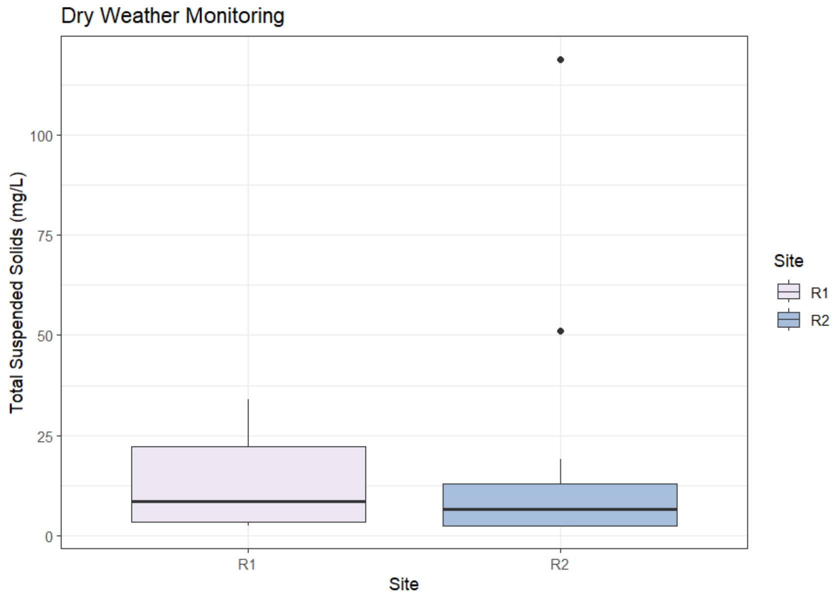

Figure 147: Summary of Total Suspended Solids (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

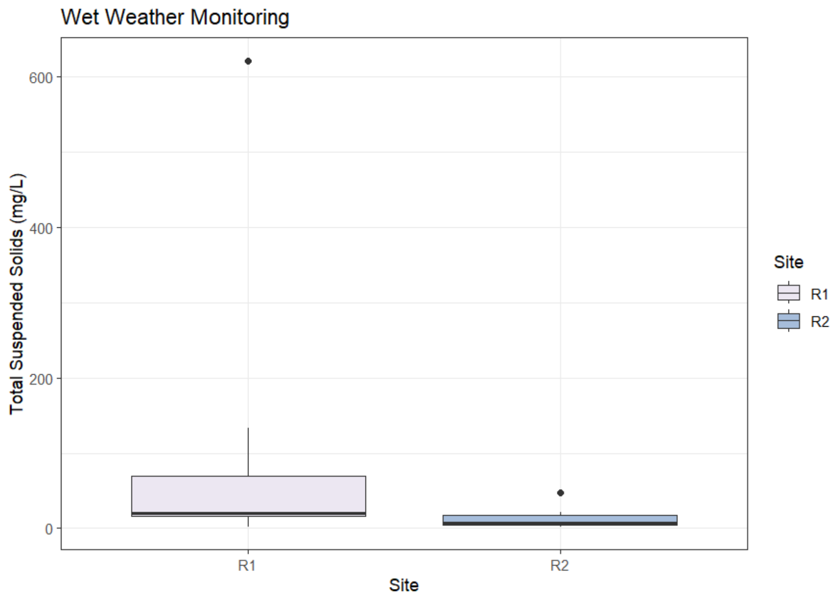

Figure 148: Summary of Total Suspended Solids (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total suspended solids remained overall low at all Robins Creek sites (Figure 149), however, the maximum value was recorded at R2 (119 mg/L) October 2023. The median total suspended solids for Robins Creek sites was 8.00 mg/L during dry weather monitoring. Levels were particularly elevated across both sites in August and October 2023, however, low rainfall was recorded in the week prior to sampling (as shown in Table 3). There are currently no ANZECC (2000) guidelines for total suspended solids.

During wet weather monitoring, total suspended solids showed an increase compared to dry weather monitoring events (Figure 150). The highest value was recorded at R1 in April 2024 (622 mg/L). Levels were particularly elevated at R1 in April 2024, and this is associated with a high rainfall event (as shown in Table 3). The median total suspended solids for Robins Creek sites was 11.00 mg/L during wet weather monitoring.

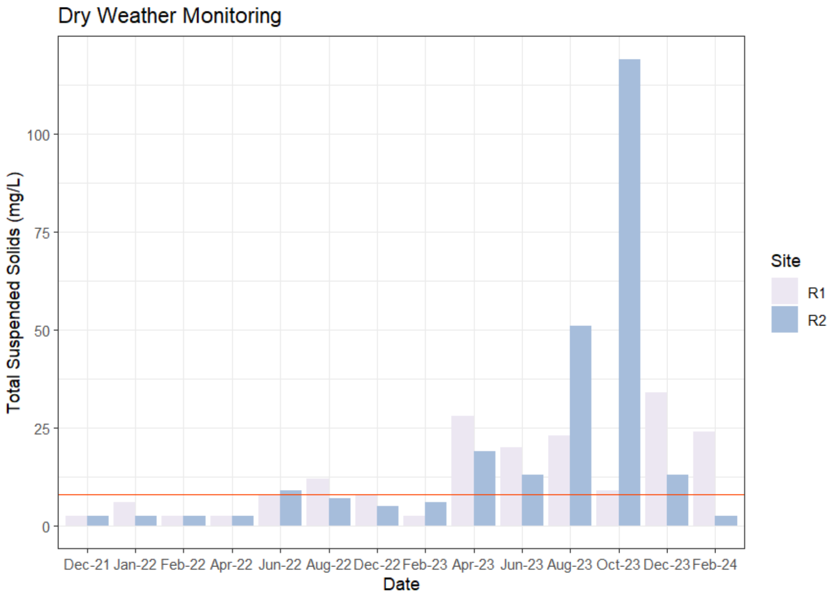

Figure 149: Total Suspended Solids (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

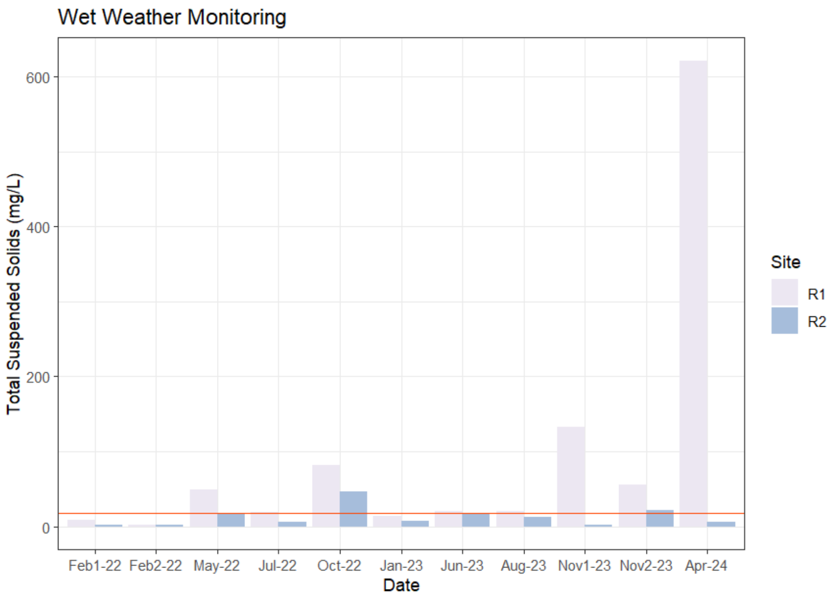

Figure 150: Total Suspended Solids (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Chlorophyll-a

Chlorophyll-*a* concentrations remained similar between Robins Creek sites during dry weather monitoring for the 2021-24 period (Figure 151). However, both sites were within a narrow range, with significantly elevated outliers (maximum of 1050 mg/L) present at R1.

During wet weather monitoring, chlorophyll-*a* remained similar to dry weather monitoring, as ranges were narrow and overlapped, however, outliers occurred at both sites (Figure 152).

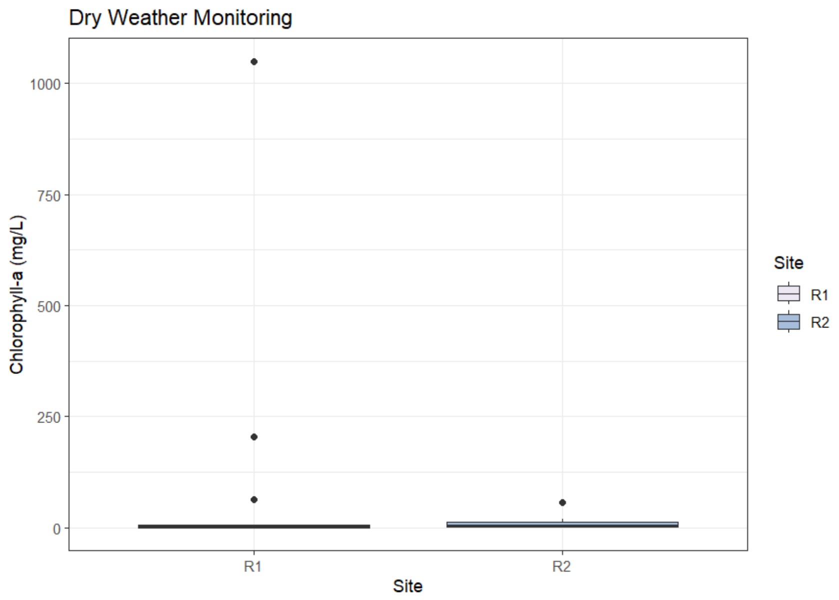

Figure 151: Summary of chlorophyll-*a* (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

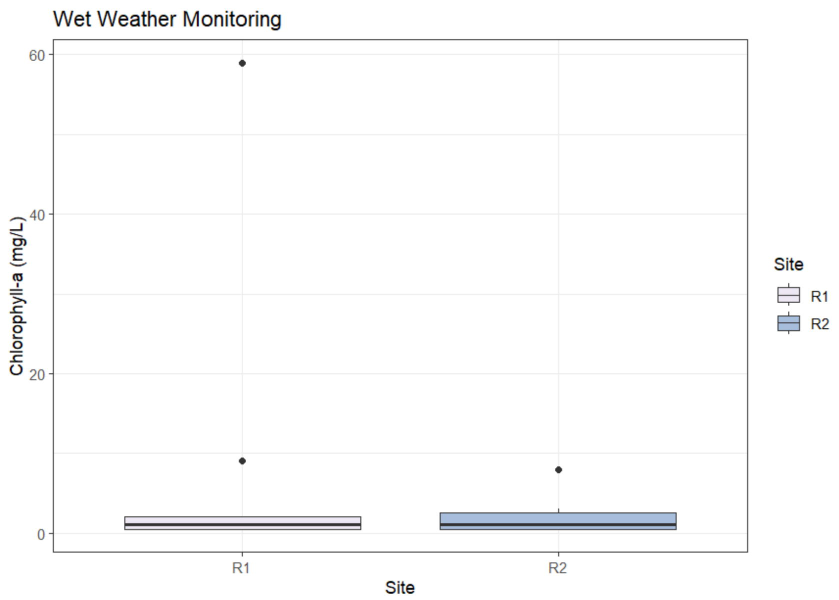

Figure 152: Summary of chlorophyll-*a* (mg/L) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, chlorophyll-*a* levels at all Robins Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 153). Chlorophyll-*a* levels were highest at R1 in October 2023 (1050 mg/L), followed by R1 in August 2023 (204 mg/L). The median chlorophyll-*a* for Robins Creek sites (4.00 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines. High nutrient availability and environmental conditions (including warmer temperatures, low rainfall to reduce flushing of the system, and high light penetration to promote photosynthesis) contribute to elevated levels of chlorophyll-*a* in waterways.

During wet weather monitoring, chlorophyll-*a* levels at all Robins Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 154). Values were highest at R1 during June 2023, with a maximum value of 59.0 mg/L. The median chlorophyll-*a* for Robins Creek sites (4.00 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

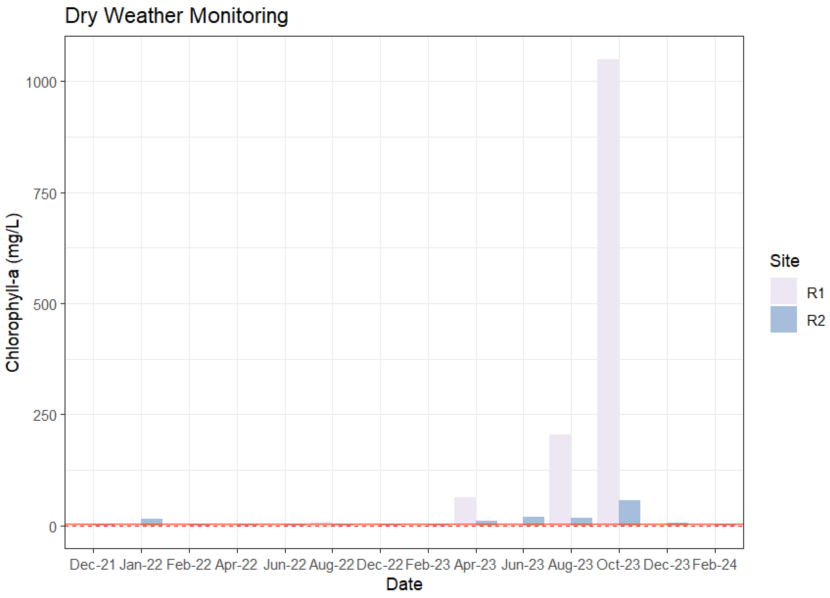

Figure 153: Chlorophyll-*a* (mg/L) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

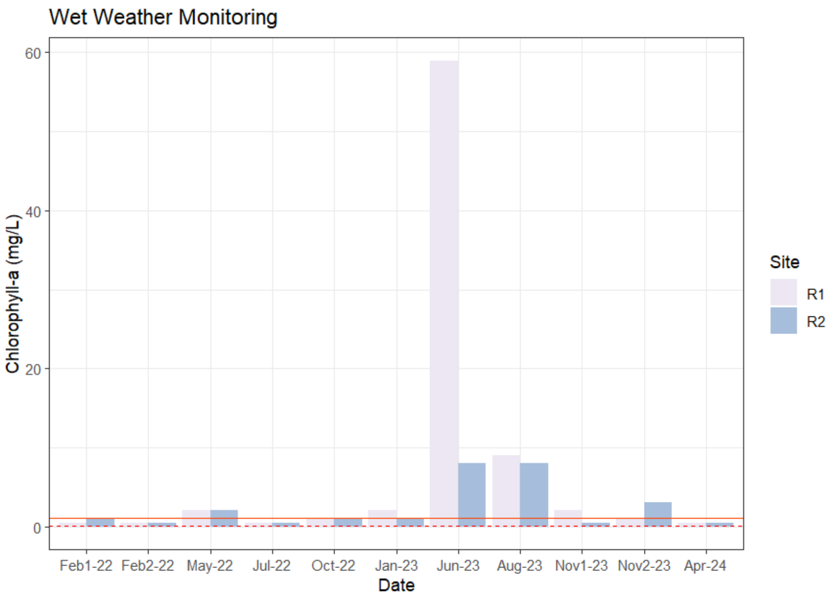

Figure 154: Chlorophyll-*a* (mg/L) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Enterococci

Enterococci concentrations were similar between Robins Creek sites during dry weather monitoring for the 2021-24 period. However, R2 experienced events where *Enterococci* was elevated, as shown by the outliers present (Figure 155).

During wet weather monitoring there was more variability within each site, however, ranges still largely overlapped for both sites (Figure 156).

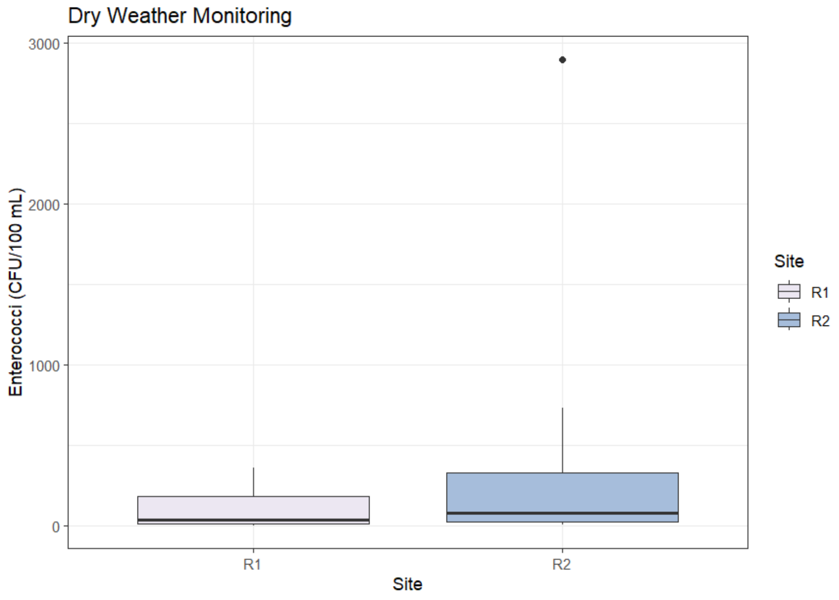

Figure 155: Summary of *Enterococci* (CFU/100 mL) at Robins Creek sites during dry weather monitoring events from December 2021 to April 2024.

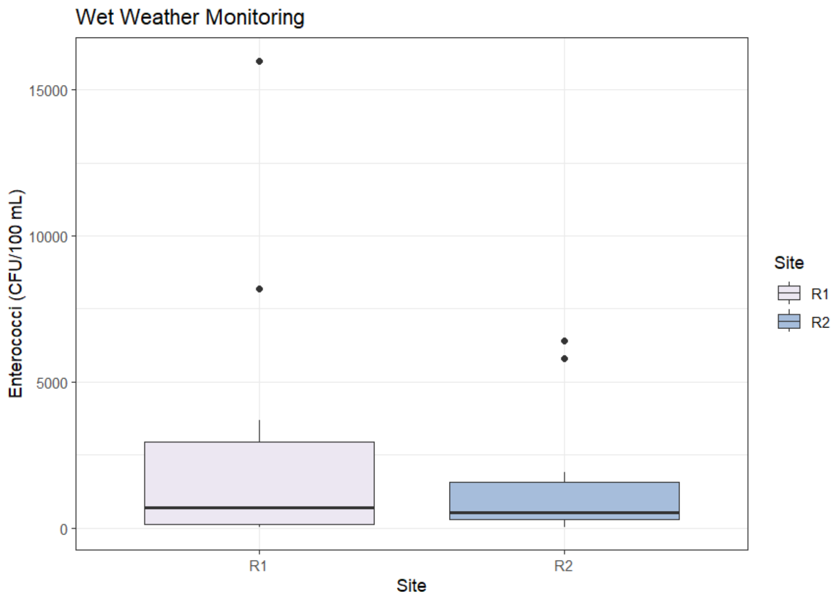

Figure 156: Summary of *Enterococci* (CFU/100 mL) at Robins Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, *Enterococci* at Robins Creek sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on ten occasions (Figure 157). This included on six occasions at R1 (in December 2021 and 2023, January 2022, April 2022, August 2022, and February 2024). At R2, the primary guideline was exceeded on four occasions (in December 2021 and 2022, April 2022, and February 2023).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline on six occasions during dry weather monitoring. This included at R1 on two occasions (in February and June 2023), and at R2 on four occasions (in August 2023, October 2023, December 2023, and February 2024).

The median *Enterococci* for Robin Creek sites (40.50 CFU/100 mL) during dry weather monitoring was above the primary contact ANZECC (2000) guidelines, but did not exceed the secondary contact guidelines.

During wet weather monitoring, *Enterococci* levels at Robins Creek sites showed an increase in non-compliance with the ANZECC (2000) guidelines (Figure 158). Levels were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on seven occasions. This included at R1 on four occasions (during both February 2022 events, July 2022, and June 2023), and at R2 on three occasions (during both February 2022 events and July 2022).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 15 occasions. This included at R1 on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024), with a high maximum value of 16,000 CFU/100mL in November 2022. At R2, the secondary guideline was exceeded on eight occasions (in May 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024).

The median *Enterococci* for Robins Creek (360 CFU/100 mL) during wet weather monitoring was above the ANZECC (2000) primary and secondary contact guidelines. Levels were particularly elevated at R2 in October 2023, however, low rainfall was recorded in the week prior to sampling (as shown in Table 3).

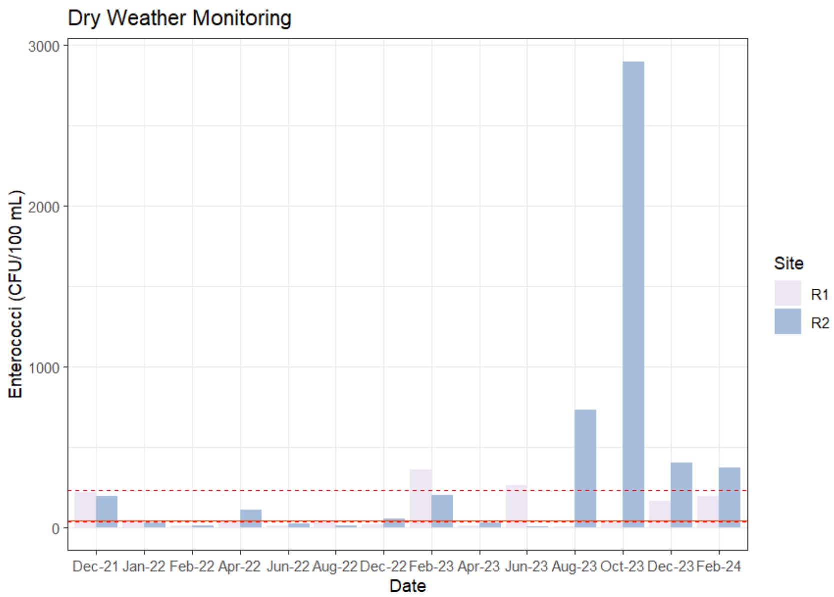

Figure 157: *Enterococci* (CFU/100 mL) at Robins Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

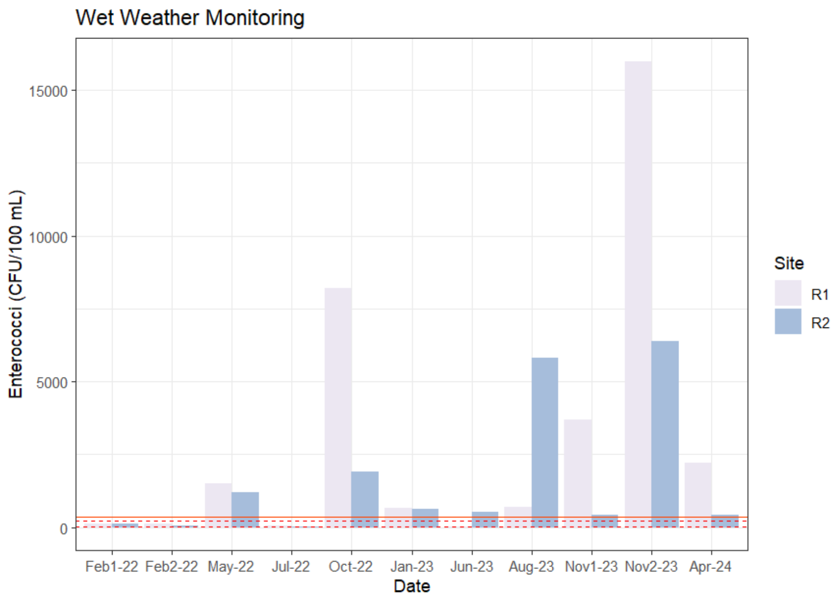

Figure 158: *Enterococci* (CFU/100 mL) at Robins Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

Reid Creek

Two sites (RE1 and R3) were sampled within the Reid Creek catchment on 25 occasions between December 2021 and April 2024, with 14 dry weather monitoring events and 11 wet weather monitoring events. A summary of findings for each water quality parameter is outlined below.

pH

Overall, pH remained similar across the Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 159), as recorded values within the upper and lower quartiles of data largely overlapped between sites, however, the median was higher at R3.

During wet weather monitoring, ranges still largely overlapped in line with dry weather monitoring (Figure 160).

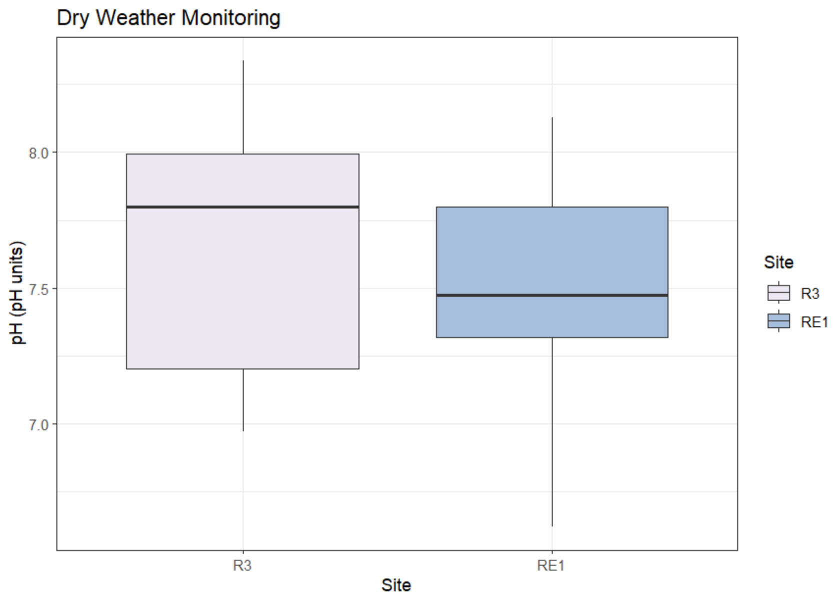

Figure 159: Summary of pH (pH units) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

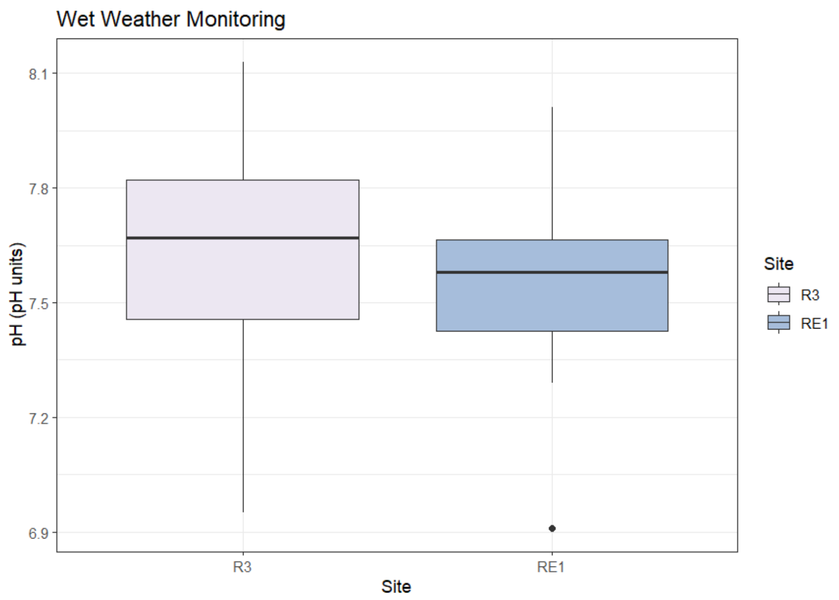

Figure 160: Summary of pH (pH units) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, pH at Reid Creek sites did not comply with the ANZECC (2000) guidelines of 6.5 – 8.0 pH units on six occasions (Figure 161). This included at RE1 in February and June 2023, and at R3 on four occasions (in April 2022, February 2023, April 2023, and June 2023). The median pH for Reid Creek sites (7.71 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

During wet weather monitoring, pH at Reid Creek sites remained within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units for all sites, excluding at both sites in June 2023 (8.01 pH units and 8.13 pH units respectively). Recorded pH was similar between dry weather and wet weather monitoring. The median pH for Reid Creek sites (7.56 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines (Figure 162).

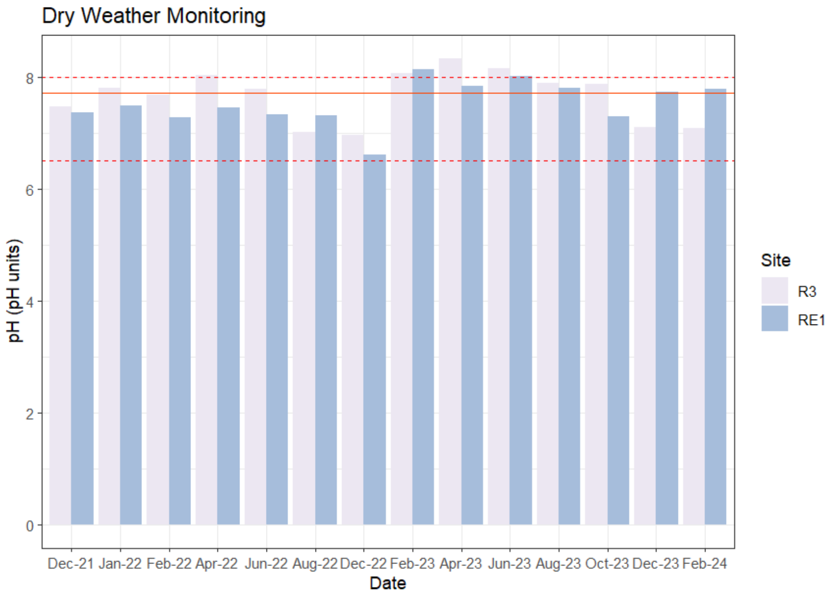

Figure 161: pH (pH units) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

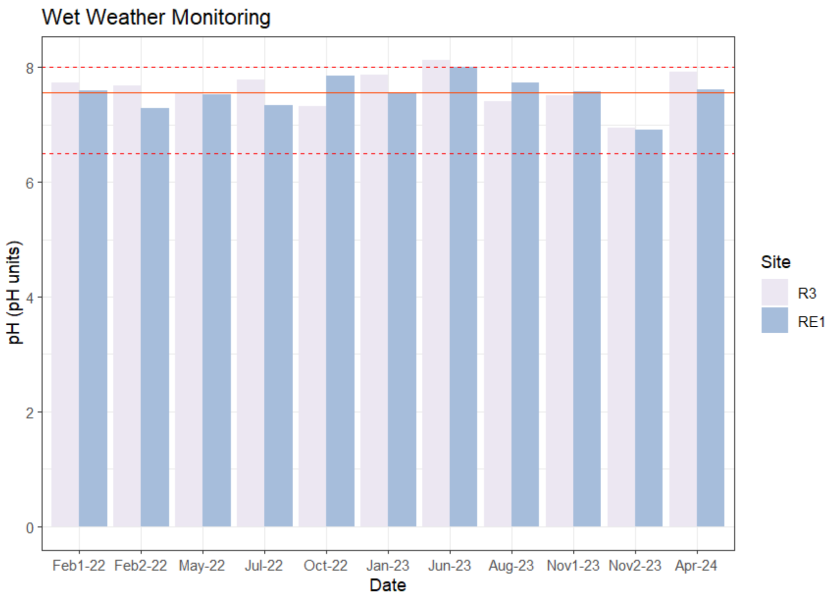

Figure 162: pH (pH units) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Electrical conductivity

Electrical conductivity experienced a wide range at RE1, with a higher median compared to R3 during dry weather monitoring for the 2021-24 period (Figure 163).

During wet weather monitoring, this trend was maintained, with a wide range of variability in electrical conductivity at RE1 (Figure 164).

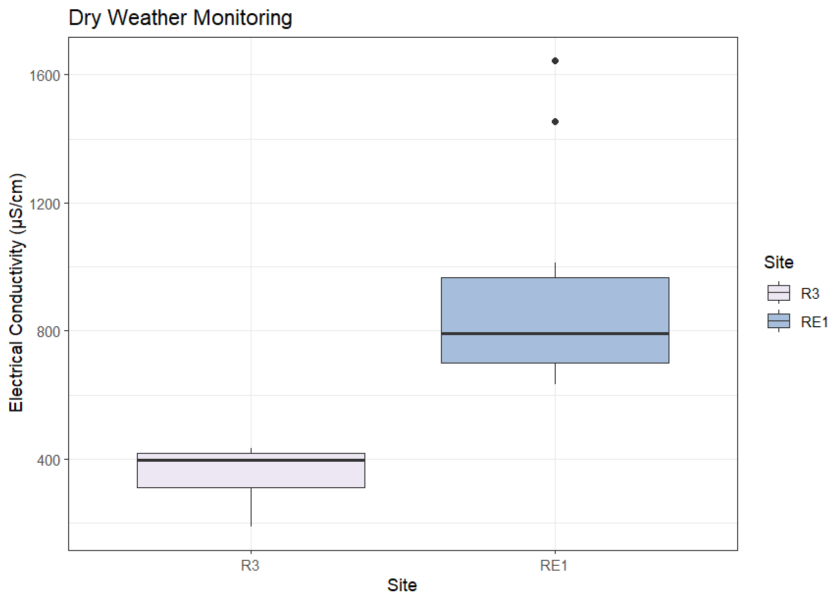

Figure 163: Summary of electrical conductivity (µS/cm) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

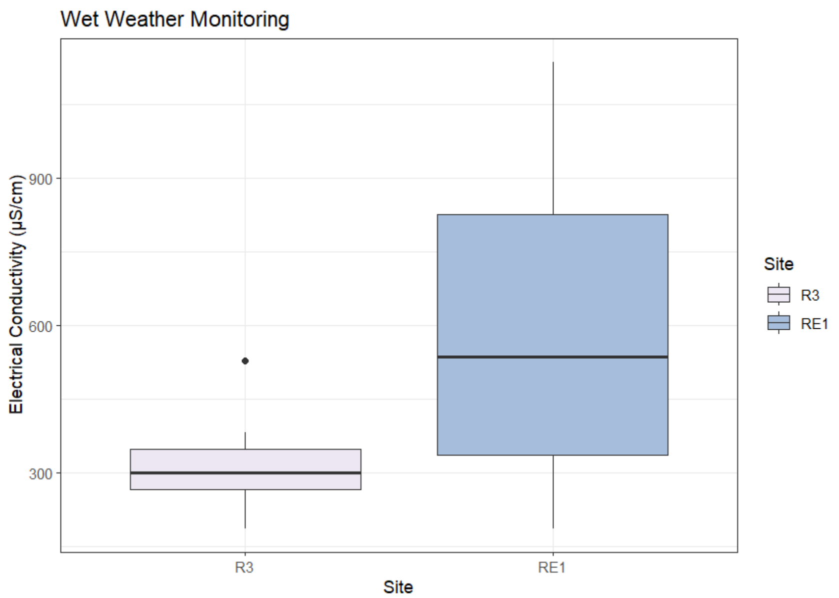

Figure 164: Summary of electrical conductivity (µS/cm) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, electrical conductivity at Reid Creek sites frequently exceeded the upper ANZECC (2000) guideline of 300 µS/cm for both sites, on a total of 25 occasions (Figure 165). Electrical conductivity was compliant with the guideline at R3 on three occasions (in January, April, and August 2022). The highest recorded value was at RE1 in October 2023 (1645 µS/cm). The median electrical conductivity for Reid Creek sites (532.00 µS/cm) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, electrical conductivity at Reid Creek was slightly lower compared to dry weather monitoring. However, the upper ANZECC (2000) guideline was still exceeded at RE1 on nine occasions (excluding in May and October 2022) (Figure 166). Electrical conductivity was also above the ANZECC (2000) guidelines at R3 on five occasions (in January 2023, June 2023, August 2023, and both

November 2023 events). The median electrical conductivity for Reid Creek sites (342.50 µS/cm) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

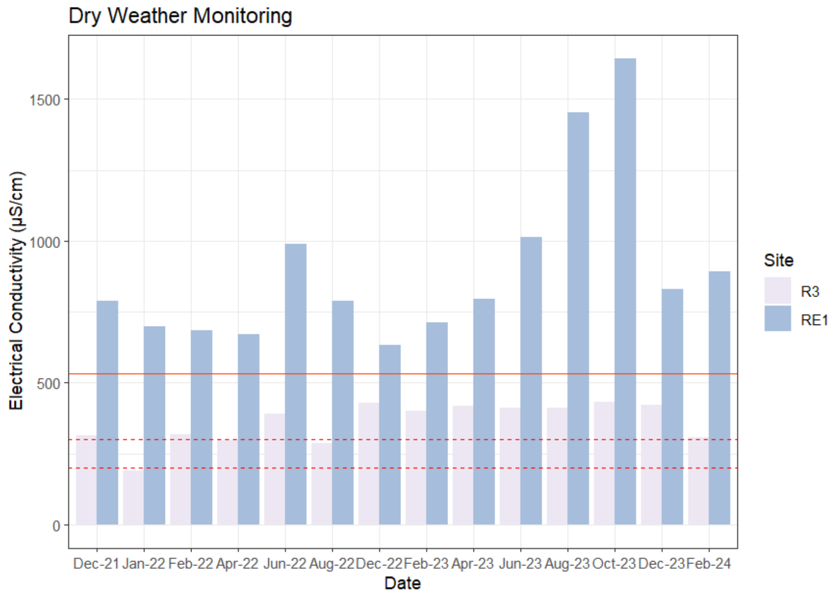

Figure 165: Electrical conductivity (µS/cm) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

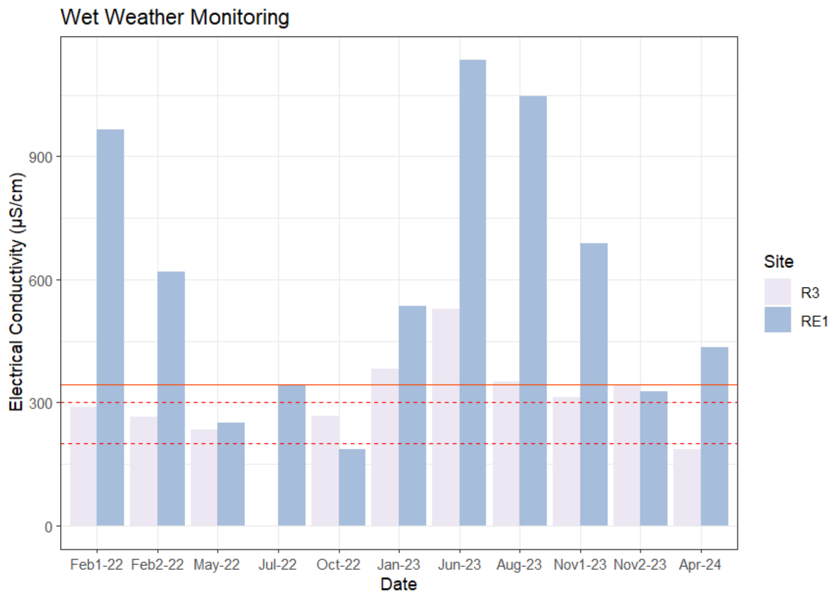

Figure 166: Electrical conductivity (µS/cm) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Temperature

Temperature remained consistent between the Reid Creek sites throughout the 2021-2024 dry weather monitoring period (Figure 167), with the range of both sites overlapping.

During wet weather monitoring, temperature at all sites also remained consistent across both sites (Figure 168).

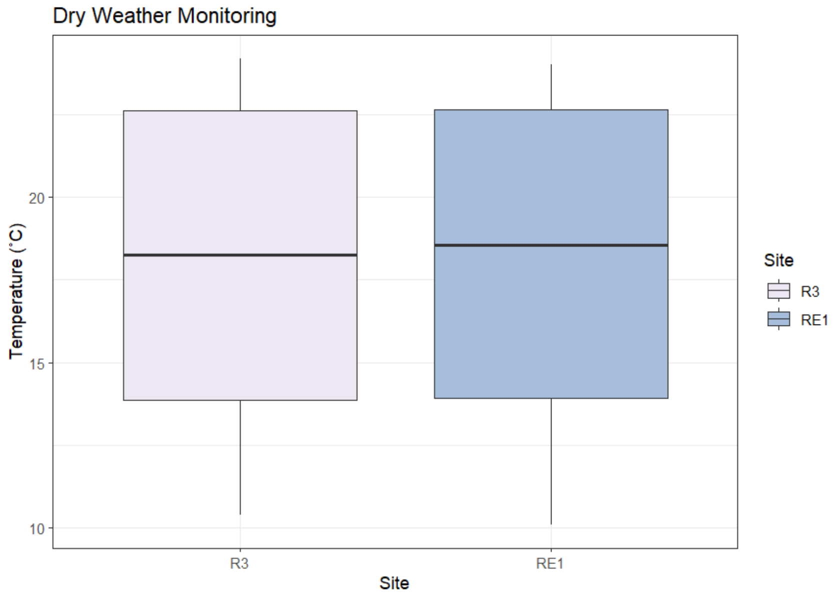

Figure 167: Summary of temperature (˚C) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

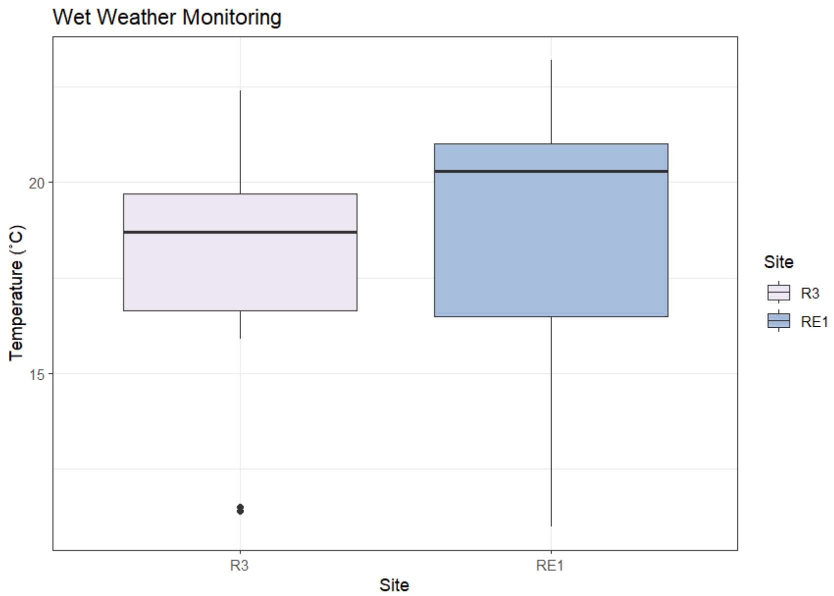

Figure 168: Summary of temperature (˚C) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, temperature ranged from a maximum of 24.2˚C at R3 in February 2024 and a minimum of 10.1˚C at RE1 in June 2022 (Figure 169). Reid Creek sites all showed similar temperature trends. The median temperature for Reid Creek sites was 18.5˚C during dry weather monitoring. There are currently no ANZECC (2000) guidelines for temperature for lowland rivers and temperature can also experience temporal and diurnal changes at sites.

During wet weather monitoring, temperature ranged from a maximum of 23.2˚C at RE1 in February 2022 and a minimum of 11.0˚C in August 2023 (Figure 170). Reid Creek sites all showed similar temperature trends, and temperature was not recorded in April and June 2023 due to equipment error. The median temperature for Reid Creek sites was 19.6˚C during wet weather monitoring.

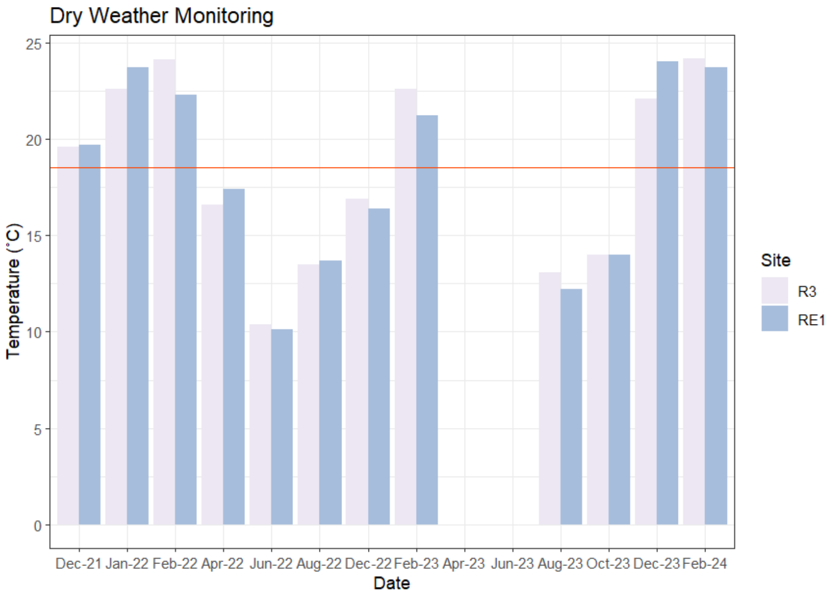

Figure 169: Temperature (˚C) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

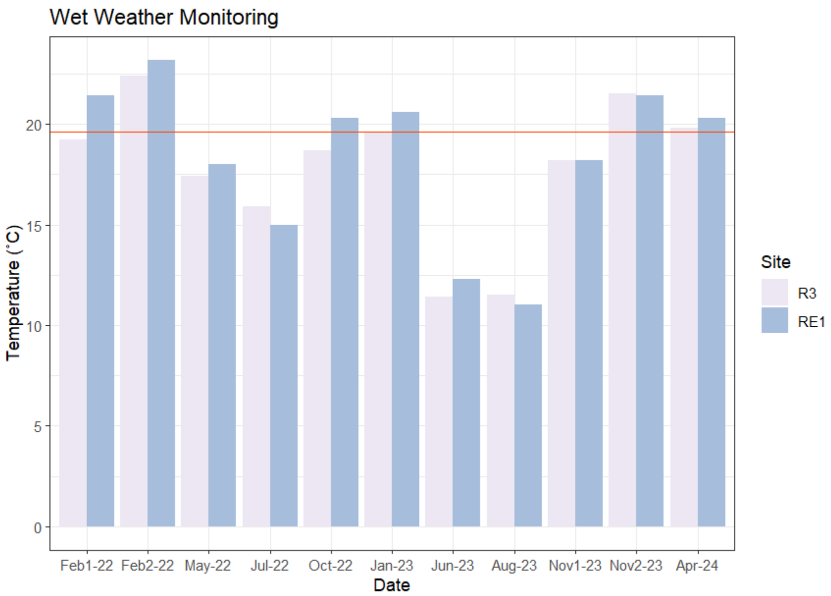

Figure 170: Temperature (˚C) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Dissolved oxygen

Dissolved oxygen, including the median and range of values, remained similar between Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 171).

During wet weather monitoring, dissolved oxygen remained similar to dry weather monitoring, as ranges still largely overlapped, however, the median for R3 was slightly higher (Figure 172).

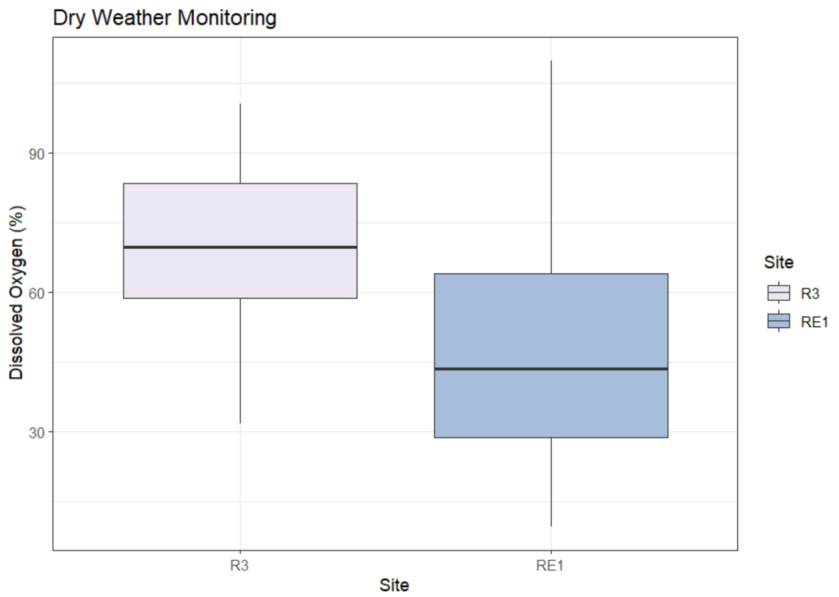

Figure 171: Summary of dissolved oxygen (%) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

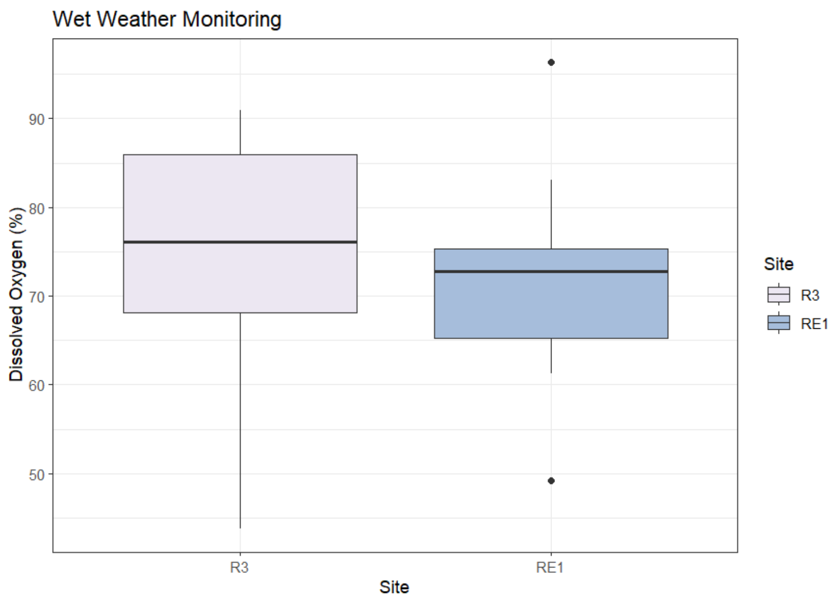

Figure 172: Summary of dissolved oxygen (%) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, dissolved oxygen levels at Reid Creek sites were below the lower ANZECC (2000) guideline of 85% at both sites for the majority of sampling events (Figure 173). Dissolved oxygen was compliant with the ANZECC (2000) guidelines on five occasions, including at RE1 in June 2023 and February 2024, and at R3 in August 2022 and 2023, and June 2023. The median dissolved oxygen for Reid Creek sites (60.25%) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, dissolved oxygen remained low. Dissolved oxygen was compliant with the ANZECC (2000) guidelines on four occasions (Figure 174). This included at RE1 in October 2022, and at R3 in May 2022, July 2022, and January 2023. The highest dissolved oxygen was recorded at RE1 in October 2022

(96.4%) and the lowest was at R3 in February 2022 (43.8%). The median dissolved oxygen for Reid Creek sites (67.30%) during wet weather monitoring was below the ANZECC (2000) guidelines.

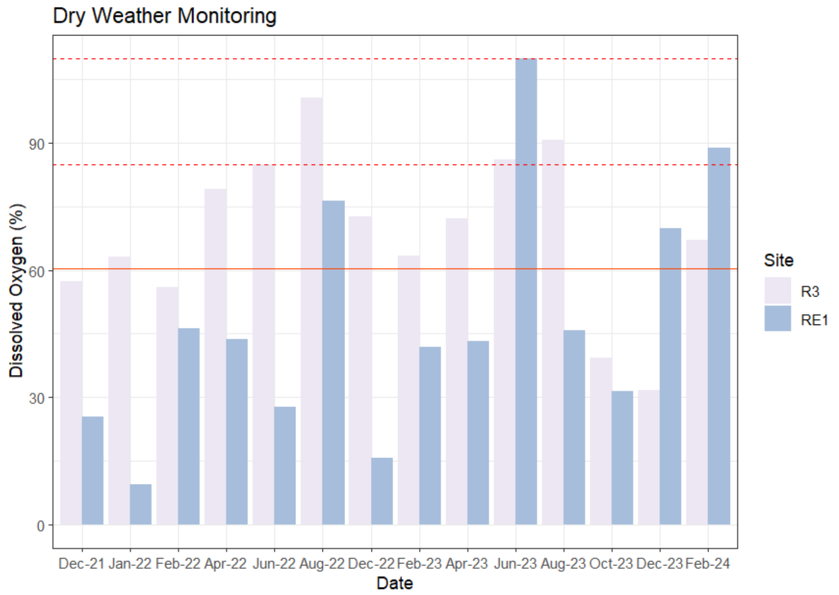

Figure 173: Dissolved oxygen (%) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

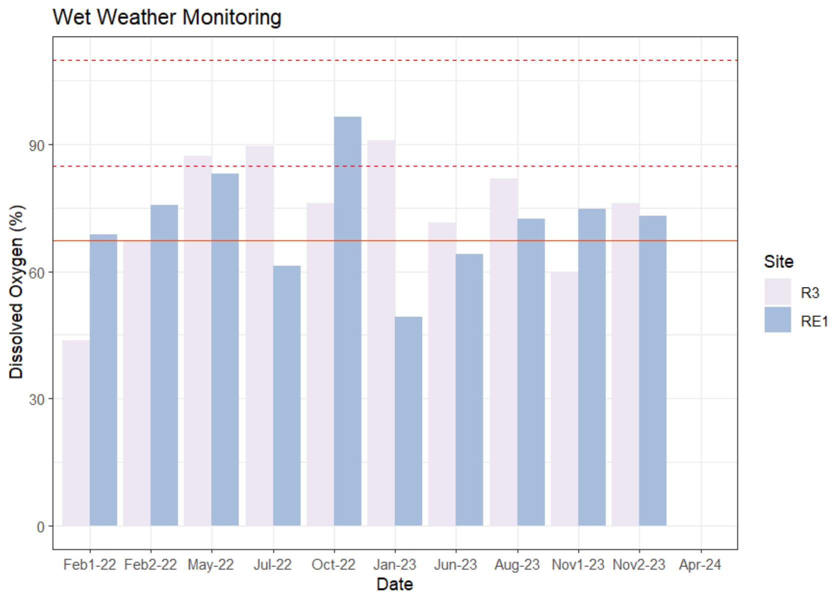

Figure 174: Dissolved oxygen (%) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Turbidity

Turbidity, including the median and range of values, remained similar between Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 175). However, outliers were observed at both sites and the median was higher at RE1.

During wet weather monitoring, turbidity remained similar to dry weather monitoring, as ranges still largely overlapped, however, turbidity was overall higher at RE1 (Figure 176).

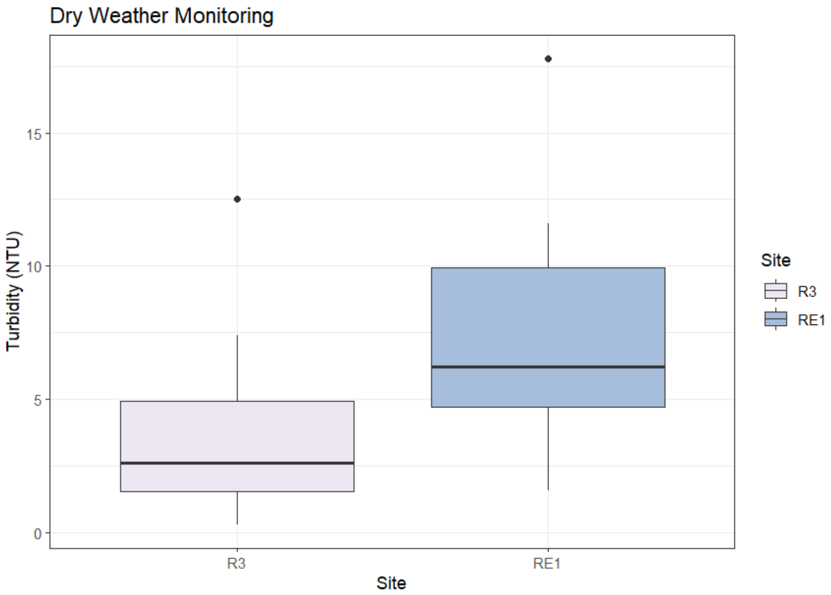

Figure 175: Summary of turbidity (NTU) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

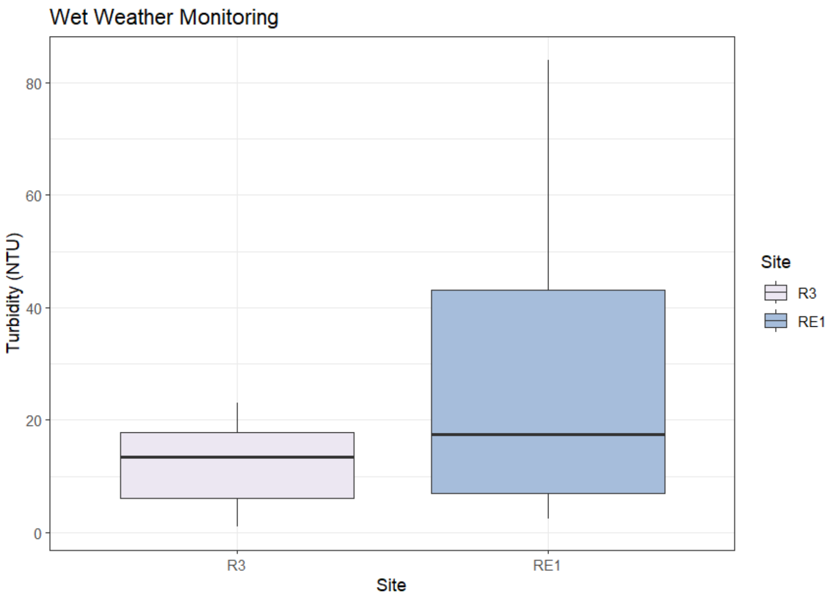

Figure 176: Summary of turbidity (NTU) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, turbidity at Reid Creek sites remained within or below the ANZECC guideline range of 6 – 50 NTU (Figure 177). Maximum turbidity was recorded at RE1 (17.8 NTU) in December 2021. The median turbidity for Reid Creek sites (4.73 NTU) during dry weather monitoring was within the ANZECC (2000) guidelines. Results below 6 NTU should not be considered as non-compliant, instead is representative of very low suspended sediments, which is a positive result.

During wet weather monitoring, turbidity at Reid Creek sites remained within the ANZECC guideline range of 6 – 50 NTU (Figure 178). This excluded on three occasions at RE1 (in October 2022, where the maximum turbidity was 84.1 NTU, November 2023, and February 2024). The median turbidity for Reid Creek sites (12.75 NTU) during wet weather monitoring was within the ANZECC (2000) guidelines.

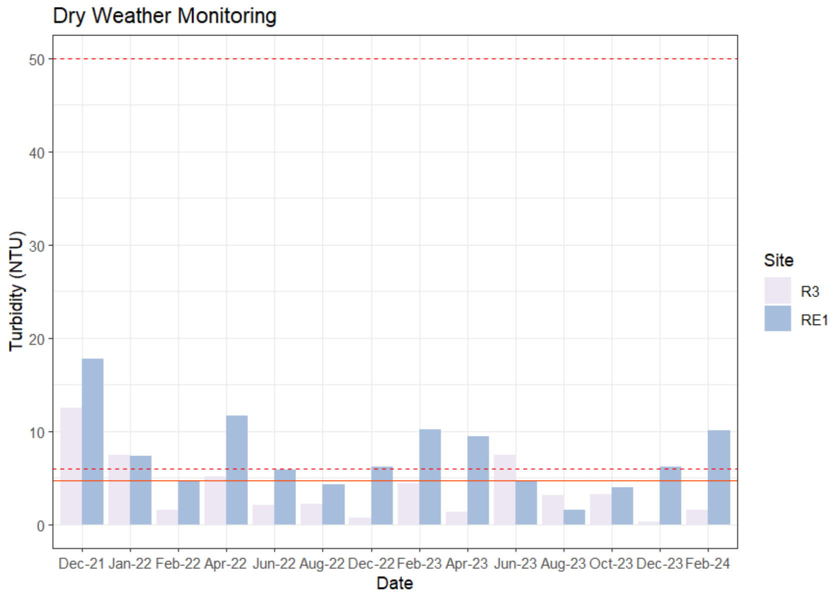

Figure 177: Turbidity (NTU) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

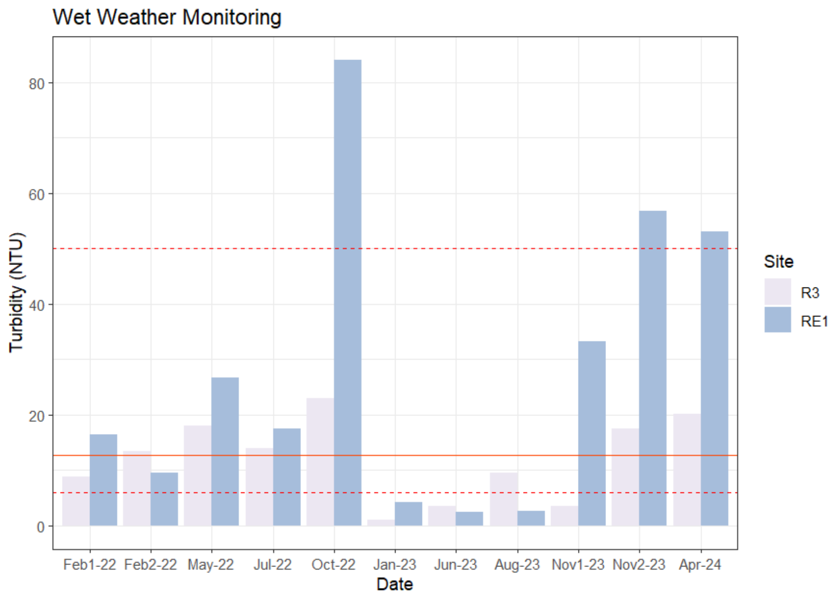

Figure 178: Turbidity (NTU) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Total nitrogen

Total nitrogen values were higher at RE1 compared to R3 during dry weather monitoring for the 2021-24 period (Figure 179).

During wet weather monitoring, total nitrogen remained similar between Reid Creek sites, as ranges still largely overlapped, however, the median was higher at RE1 (Figure 180).

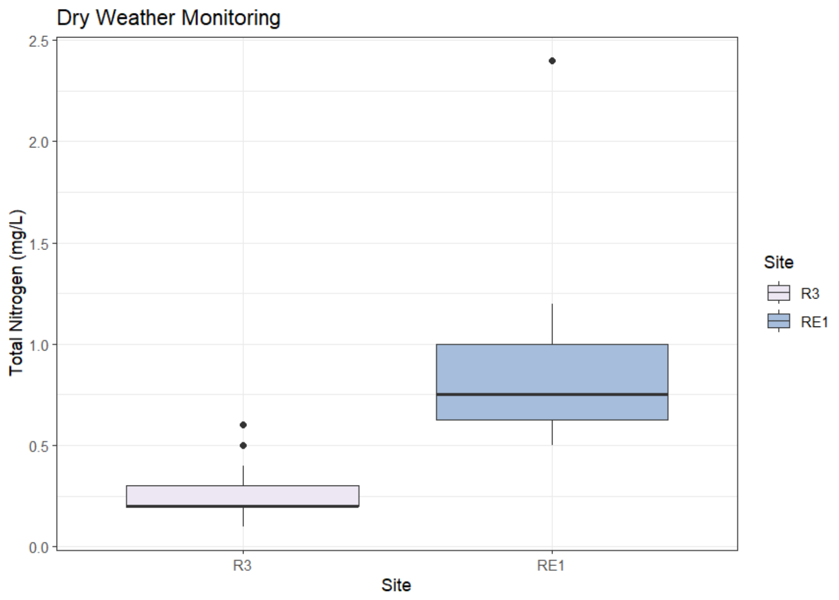

Figure 179: Summary of total nitrogen (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

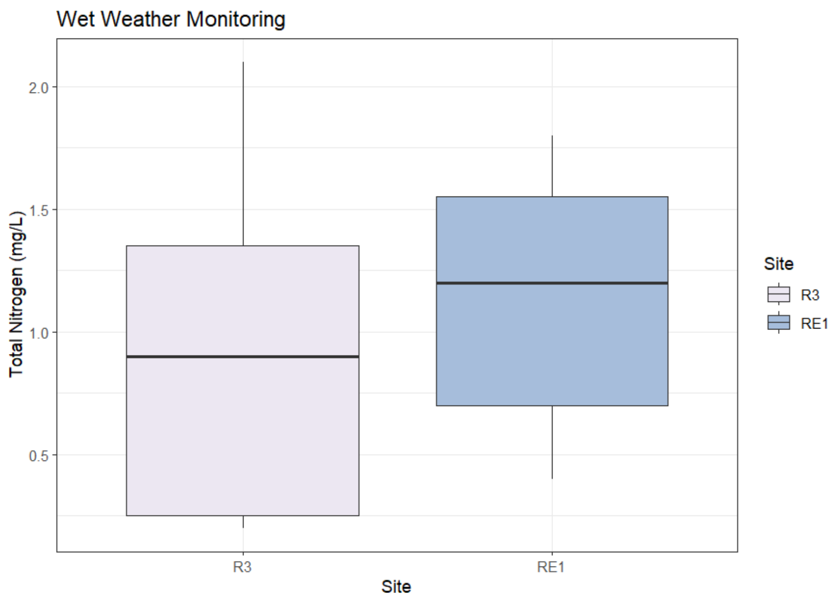

Figure 180: Summary of total nitrogen (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total nitrogen concentrations at Reid Creek sites exceeded the ANZECC (2000) guideline of 0.5 mg/L on 16 occasions (Figure 181). This included at RE1 during all sampling events, and at R3 in April 2023 and October 2023. The median total nitrogen for Reid Creek sites (0.50 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

During wet weather monitoring, non-compliance with the ANZECC (2000) guideline occurred on 16 occasions (Figure 182). This included on ten occasions at RE1 (excluding in June 2023), and on six occasions at R3 (in May 2022, July 2022, October 2022, both November 2023 events, and April 2024). The median total nitrogen for Reid Creek sites (1.45 mg/L) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

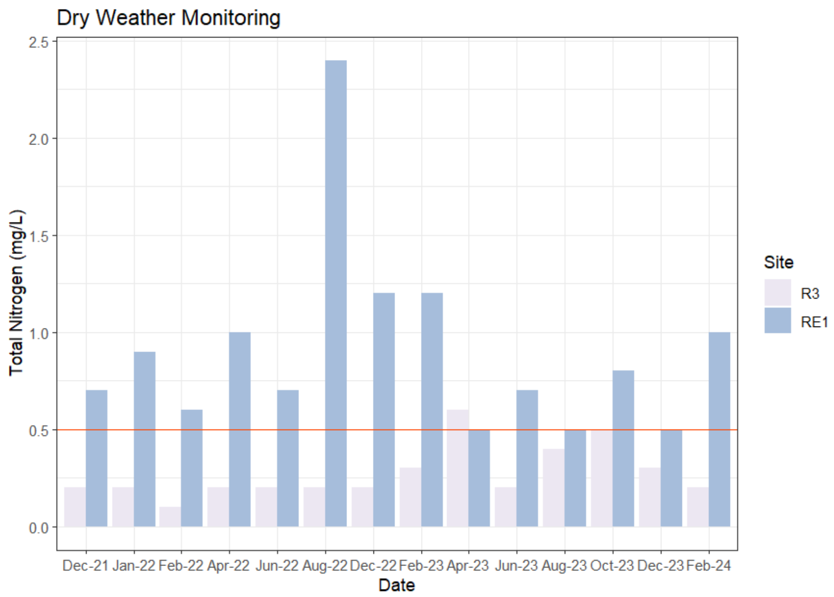

Figure 181: Total nitrogen (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

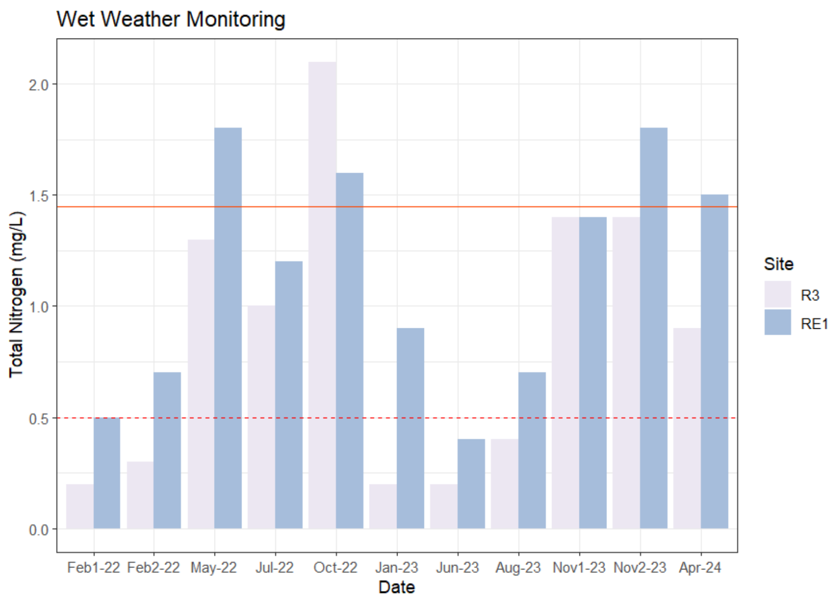

Figure 182:Total nitrogen (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Ammonia

Ammonia was elevated at RE1, with outliers present, compared to R3 during dry weather monitoring for the 2021-24 period (Figure 183).

During wet weather monitoring, ammonia remained similar between Reid Creek sites, as ranges still largely overlapped, however, outliers occurred at RE1 (Figure 184).

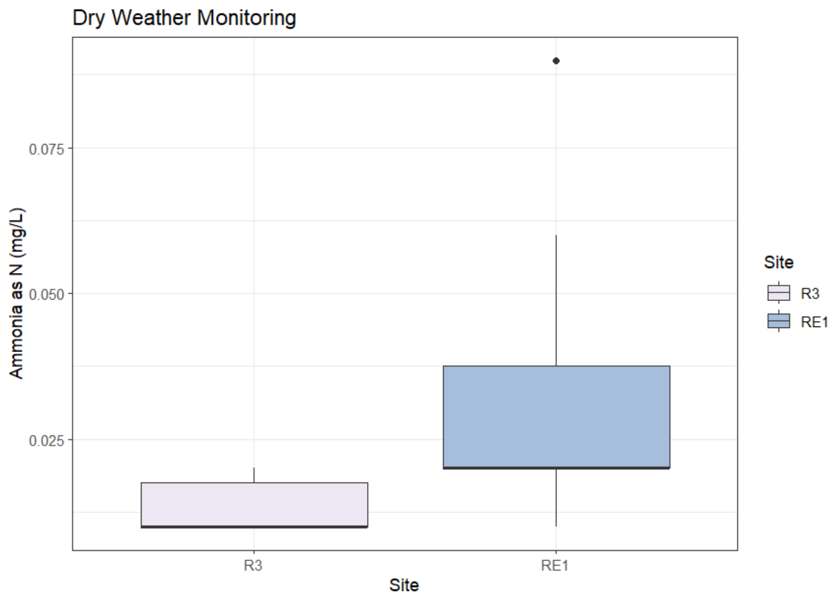

Figure 183: Summary of ammonia (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

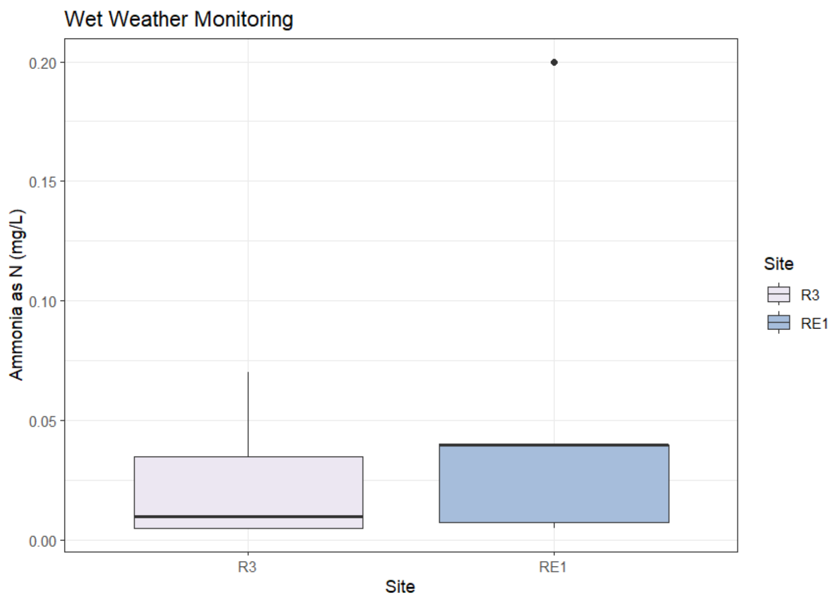

Figure 184: Summary of ammonia (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, ammonia concentrations at Reid Creek sites were low however did exceed the ANZECC (2000) guideline of 0.02 mg/L on 15 occasions (Figure 185). This included at RE1 on 11 occasions (excluding in April, August, and December 2023), and at R3 on four occasions (in June 2022, December 2022, April 2023, and December 2023). The median ammonia for Reid Creek sites (0.02 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

During wet weather monitoring, ammonia concentrations at Reid Creek sites did not comply with the ANZECC (2000) guideline of 0.02 mg/L on 12 occasions (Figure 186). This occurred at RE1 on seven occasions (in May 2022, July 2022, January 2023, August 2023, both November 2023 events, and April 2024), and R3 on five occasions (in October 2022, January 2023, June 2023, and both November 2023 events). The median ammonia for Reid Creek sites (0.06 mg/L) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

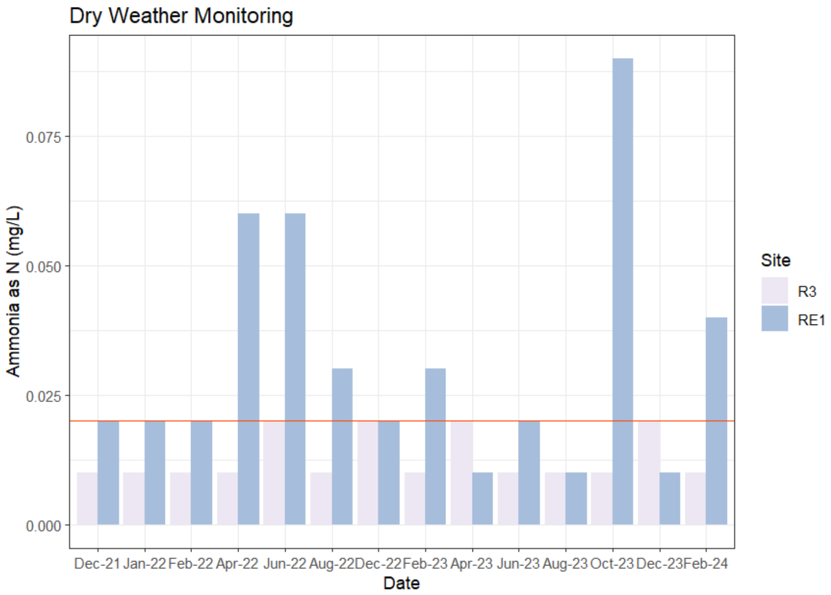

Figure 185: Ammonia (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

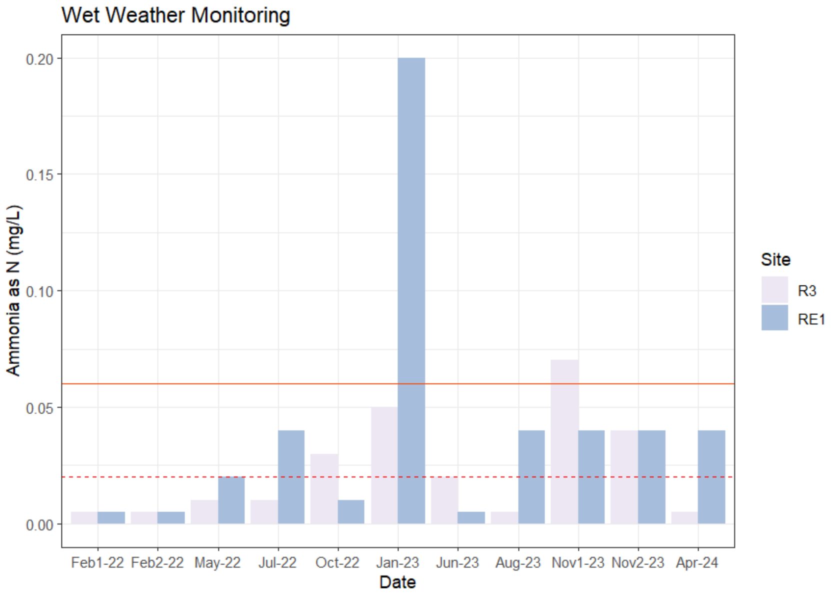

Figure 186: Ammonia (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

NOx

Nitrate and nitrite (NOx) concentrations remained similar between Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 187). Outliers were observed at both sites, and the median was higher at RE1.

During wet weather monitoring, NOx remained similar between sites, as ranges still largely overlapped, however, the median was higher at R3 (Figure 188).

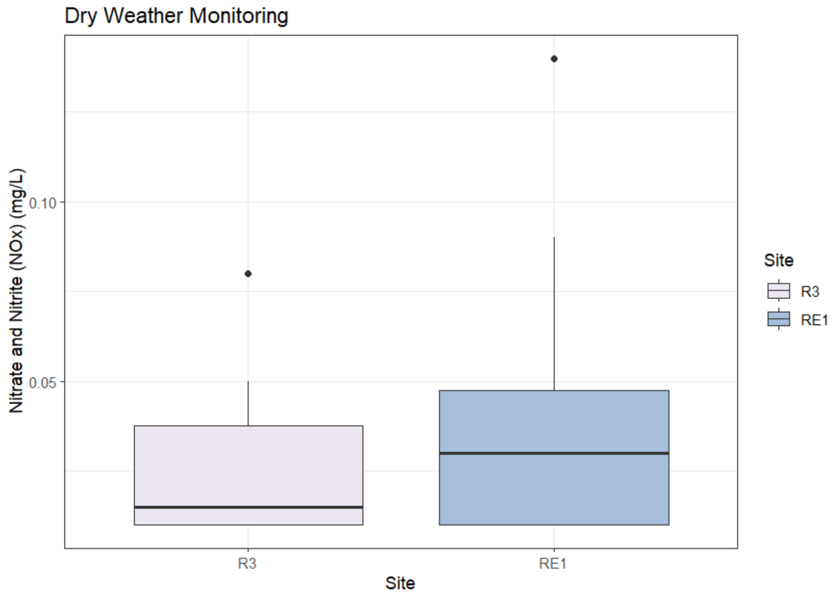

Figure 187: Summary of nitrate and nitrite (NOx) (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

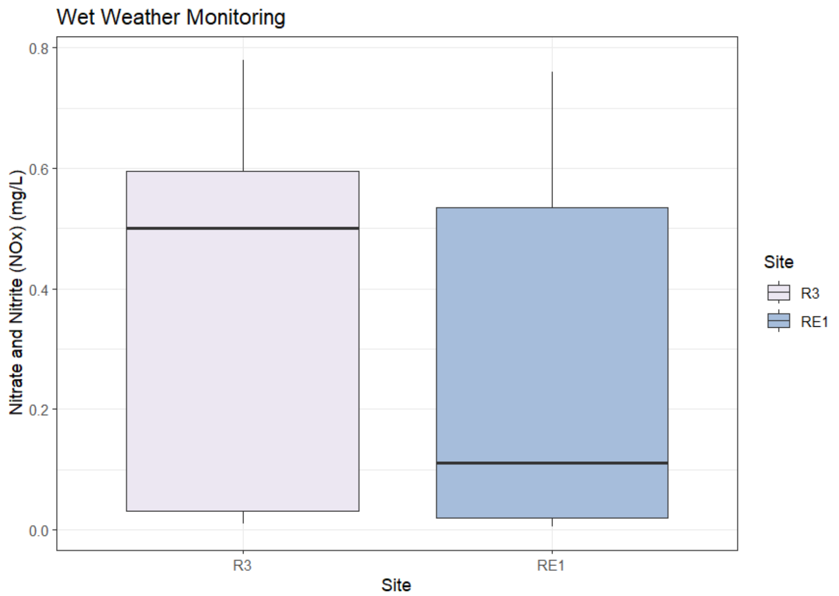

Figure 188: Summary of nitrate and nitrite (NOx) (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, NOx concentrations at Reid Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 11 occasions (Figure 189). This included at RE1 on seven occasions (in April 2022 and 2023, June 2022 and 2023, August 2022 and 2023, and February 2024). R3 was non-compliant the ANZECC (2000) guideline on four occasions (in April 2022, June 2022 and 2023, and August 2023). The median NOx for Reid Creek sites (0.02 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, NOx concentrations at Reid Creek sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 14 occasions (Figure 190). The ANZECC (2000) guideline was exceeded at RE1 on six occasions (in May 2022, July 2022, October 2022, both November 2023 events, and April 2024), and at R3 on eight occasions (in May 2022, July 2022, October 2022, June 2023, August 2023, both November 2023 events, and April 2024). The highest value was recorded at R3 in November 2023 (0.78 mg/L). The median NOx for Reid Creek sites (0.43 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

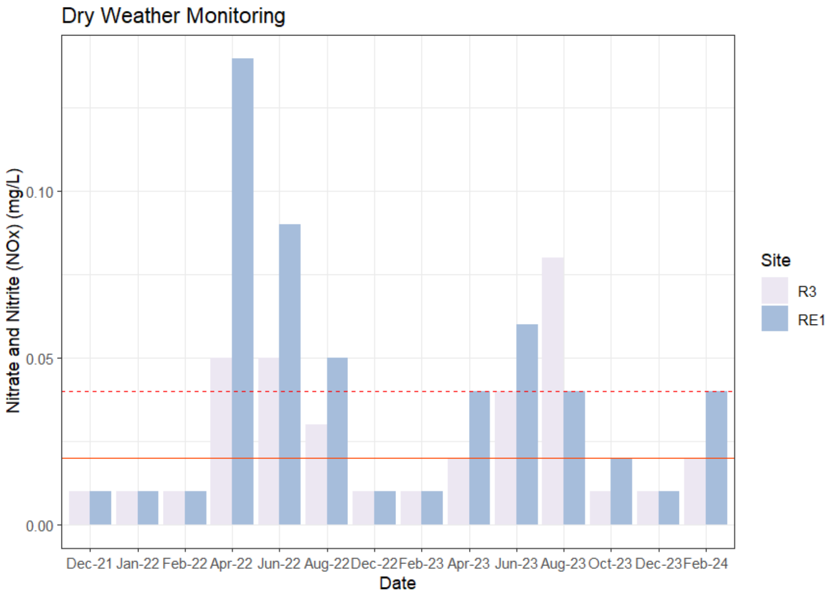

Figure 189: Nitrate and nitrite (NOx) (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

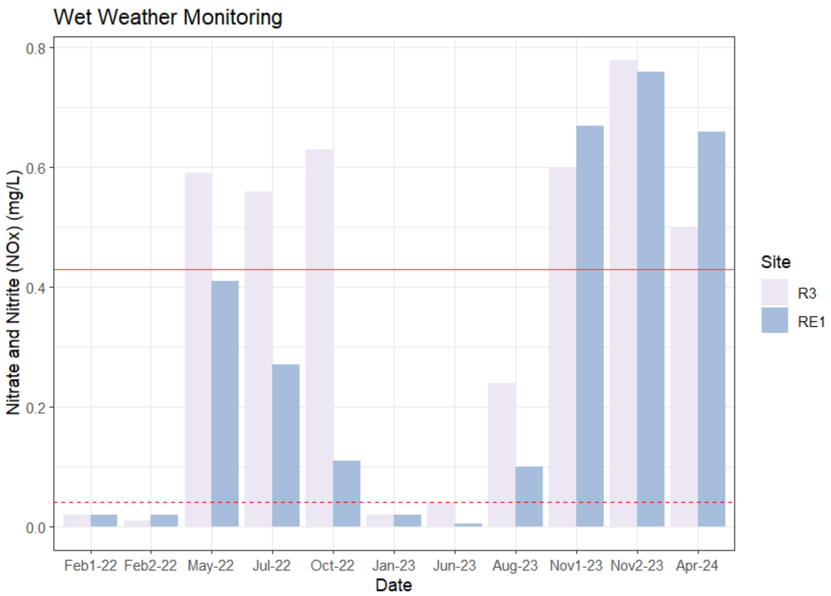

Figure 190: Nitrate and nitrite (NOx) (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Phosphorus

Total phosphorus concentrations were higher at RE1 compared to R3 during dry weather monitoring for the 2021-24 period (Figure 191). RE1 experienced events where total phosphorus was elevated, as shown by the outliers present.

During wet weather monitoring, total phosphorus remained similar to dry weather monitoring, as ranges still largely overlapped, however, levels were higher at RE1 (Figure 192).

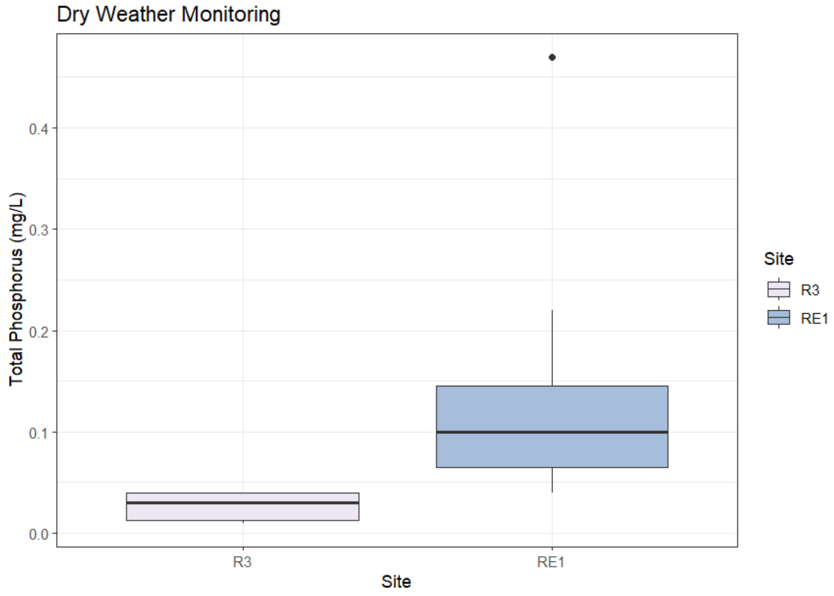

Figure 191: Summary of total phosphorus (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

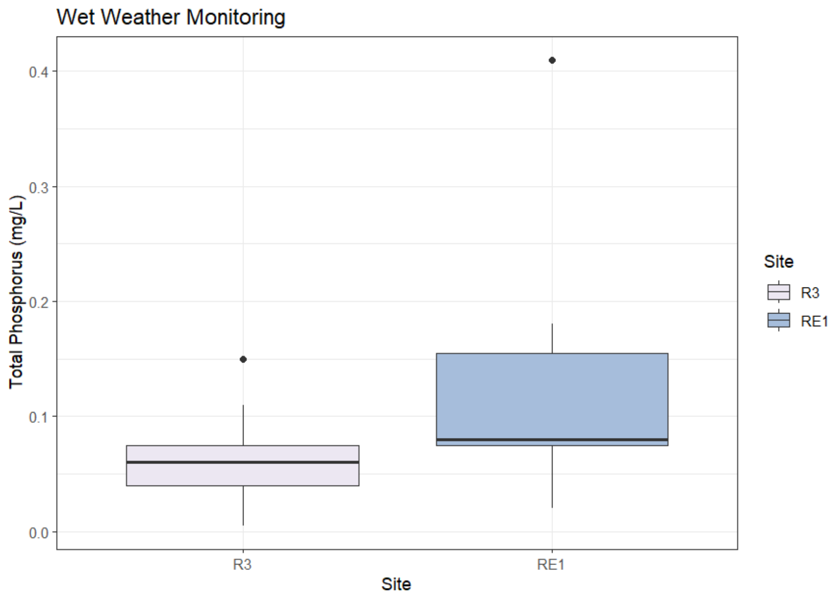

Figure 192: Summary of total phosphorus (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total phosphorus concentrations at Reid Creek sites exceeded the ANZECC (2000) guideline of 0.05 mg/L on 12 occasions (Figure 193). Total phosphorus concentrations at RE1 were above the guideline for 12 monitoring events (excluding in June and December 2023). However, R3 was compliant with the guidelines during the 2021-24 monitoring period. The maximum value recorded at RE1 in August 2022 was 0.47 mg/L. The median total phosphorus for Reid Creek sites (0.04 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, there was non-compliance with the ANZECC (2000) guideline for total phosphorus on 17 occasions (Figure 194). RE1 exceeded the guideline on nine occasions (excluding in June and August 2023). Total phosphorus at R3 also was above the guideline on eight occasions (excluding in February 2022, June and August 2023). The median total phosphorus for Reid Creek sites (0.11 mg/L) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

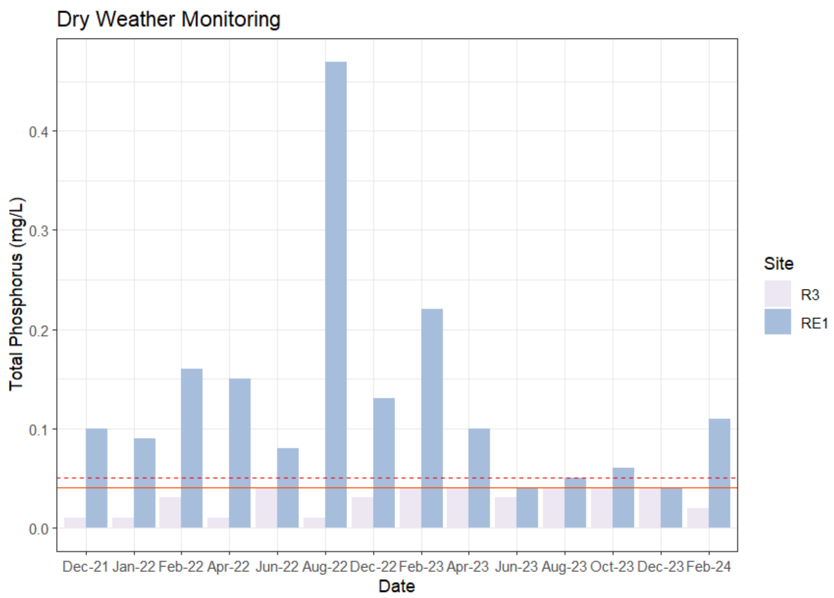

Figure 193: Total phosphorus (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

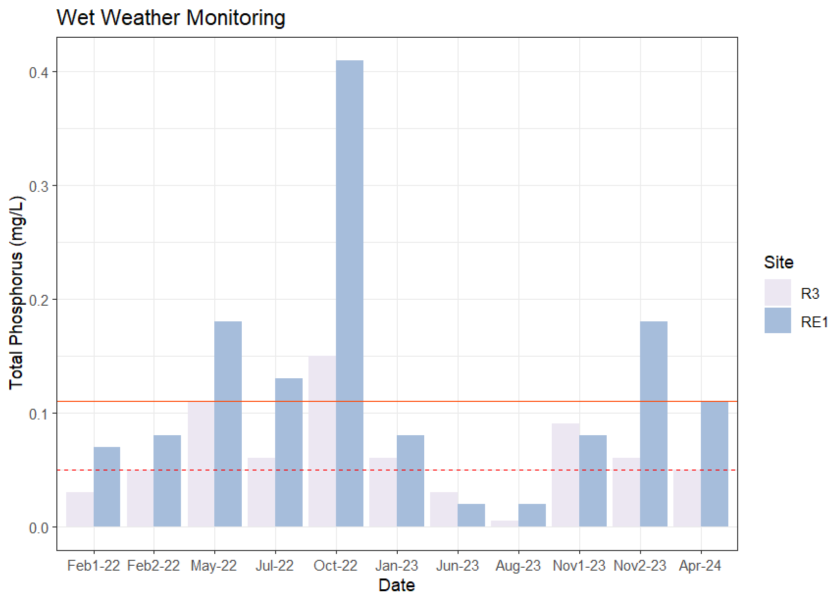

Figure 194: Total phosphorus (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Phosphate

Phosphate concentrations remained consistent throughout the monitoring period (at 0.01 mg/L) for both Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 195).

During wet weather monitoring, phosphate levels remained similar to dry weather monitoring, as ranges still largely overlapped, however, outliers occurred at both sites (Figure 196).

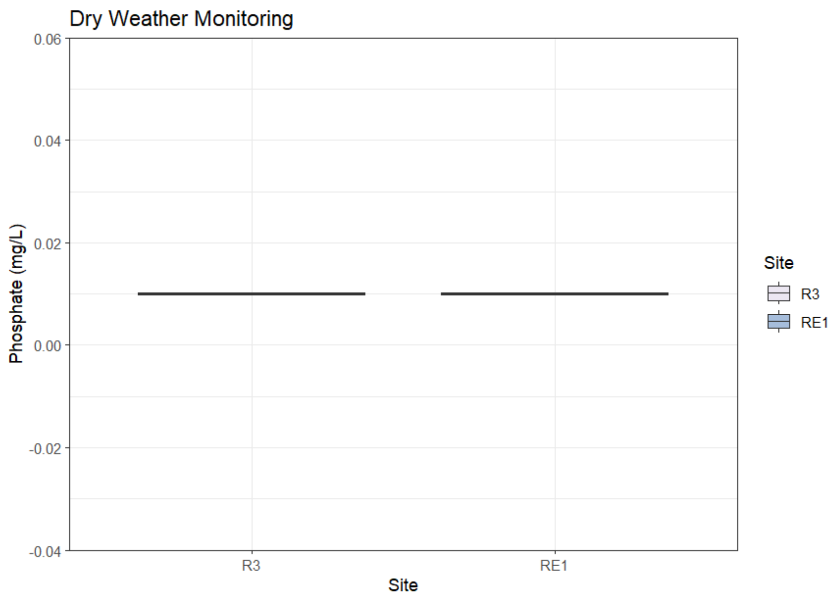

Figure 195: Summary of phosphate (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

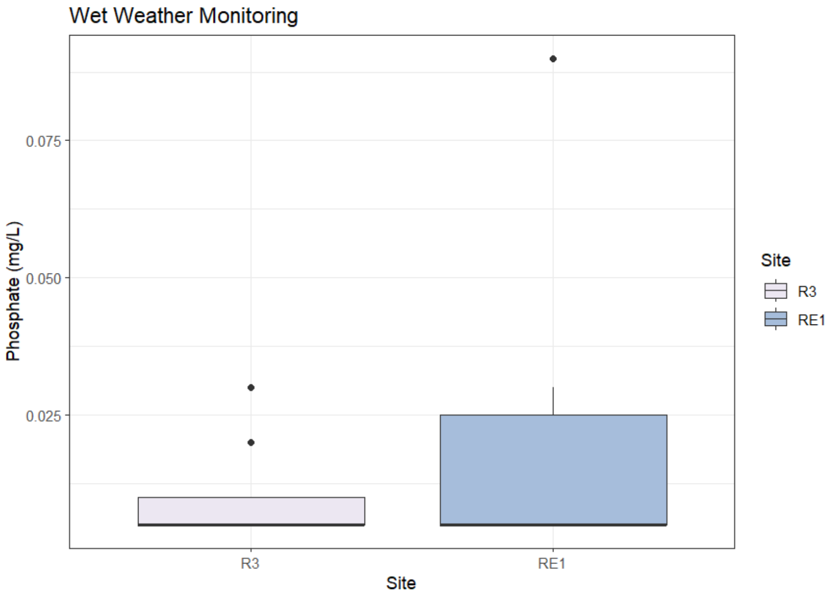

Figure 196: Summary of phosphate (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, phosphate concentrations at Reid Creek sites were low or below detection limits (<0.01 mg/L) for both sites during all sampling events (Figure 197). Phosphate levels did not exceed the ANZECC (2000) guideline (0.02 mg/L). The median phosphate for Reid Creek sites (0.01 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, phosphate concentrations at Reid Creek sites were predominantly below detection limits (<0.01 mg/L) for all sites and sampling events (Figure 198). However, phosphate levels exceeded the guidelines on four occasions at RE1 (in February 2022, October 2022, November 2023, and April 2024), and on two occasions at R3 (in October 2022 and November 2023). The maximum phosphate concentration was at RE1 in November 2023 (0.09 mg/L). The median phosphate for Reid Creek sites (0.02 mg/L) during wet weather monitoring was in line with the ANZECC (2000) guidelines.

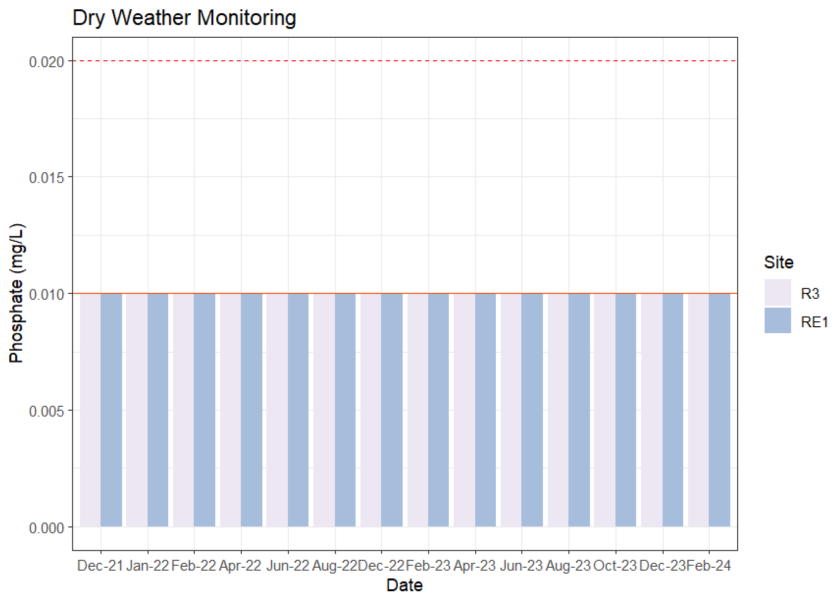

Figure 197: Phosphate (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

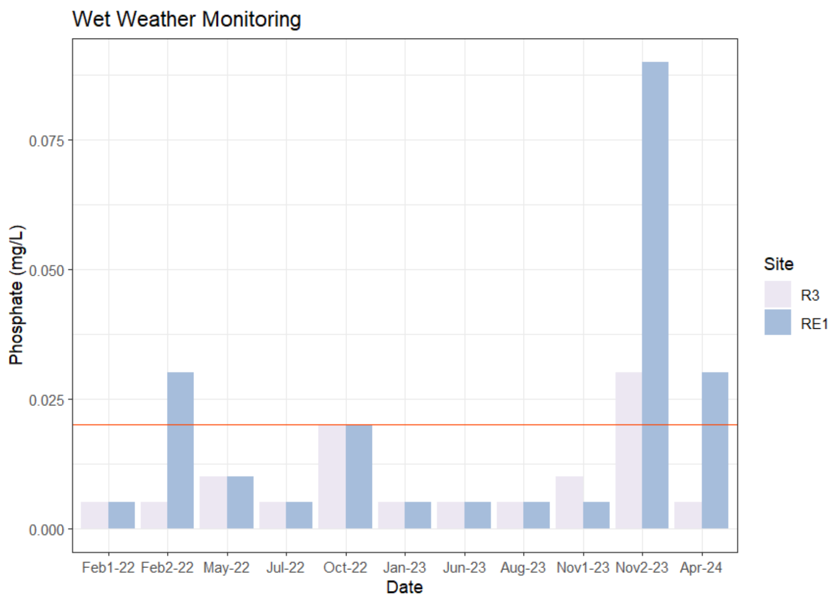

Figure 198: Phosphate (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Suspended Solids

Total Suspended Solids were within a narrow range across both Reid Creek sites during dry weather monitoring for the 2021-24 period. However, a significantly elevated outlier was present at RE1 (Figure 199).

During wet weather monitoring, trends for both Reid Creek sites remained similar. However, ranges still largely overlapped for both sites, and the highest range was recorded at RE1 with a high outlier value (Figure 200).

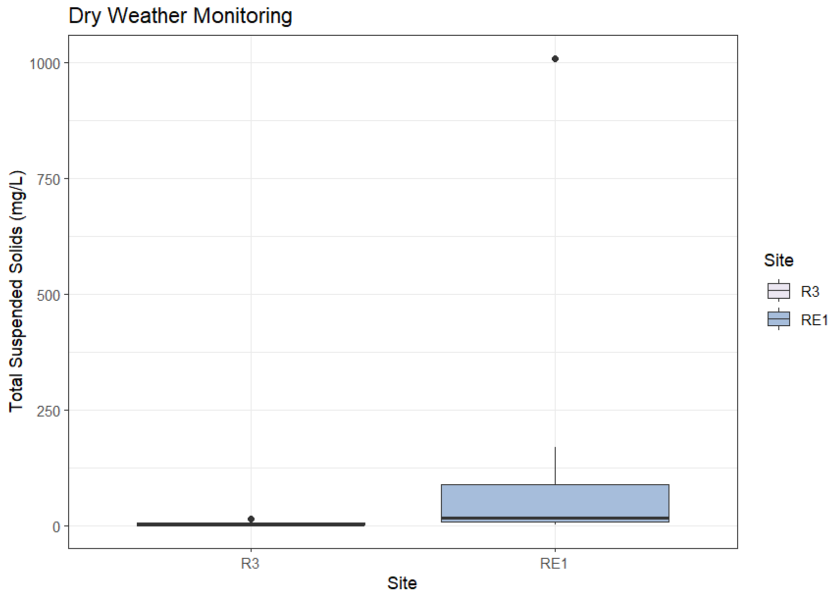

Figure 199: Summary of Total Suspended Solids (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

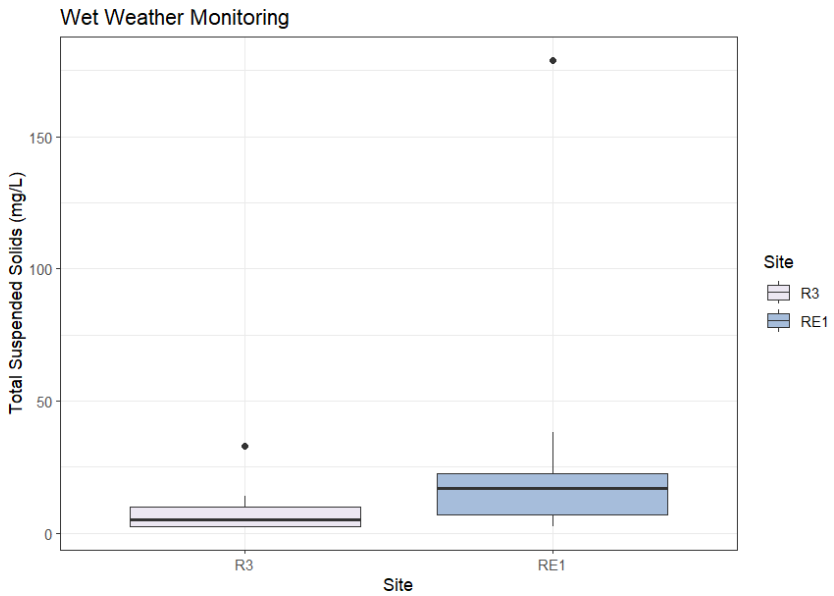

Figure 200: Summary of Total Suspended Solids (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total suspended solids varied across the Reid Creek sites (Figure 201). The maximum value was recorded at RE1 in August 2022 (1010 mg/L), however, whilst low rainfall was experienced in the week prior to sampling, this does not appear to be linked with high rainfall events (as shown in Table 3). The median total suspended solids for Reid Creek sites was 8.50 mg/L during dry weather monitoring. There are currently no ANZECC (2000) guidelines for total suspended solids.

During wet weather monitoring, total suspended solids showed a decline in maximum value compared to dry weather monitoring events (Figure 202). However, the maximum value for dry weather monitoring was impacted by one high outlier event, whereas the median values for both Reid Creek sites were similar. The highest values were recorded at RE1 in October 2022 (179.00 mg/L). The median total suspended solids for Reid Creek sites was 8.00 mg/L during dry weather monitoring.

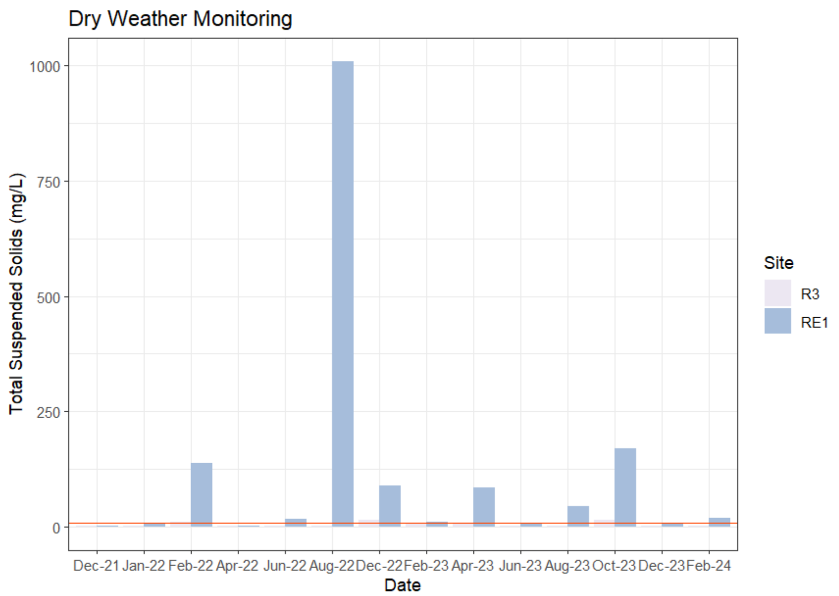

Figure 201: Total Suspended Solids (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

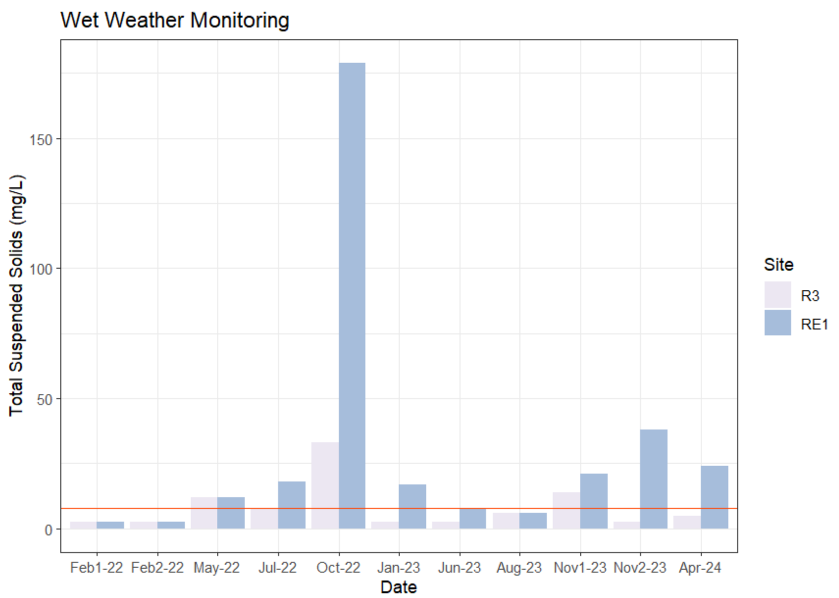

Figure 202: Total Suspended Solids (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Chlorophyll-a

Chlorophyll-*a* concentrations remained similar between Reid Creek sites during dry weather monitoring for the 2021-24 period (Figure 203). However, high outliers were present at RE1. High nutrient availability and environmental conditions (including warmer temperatures, low rainfall to reduce flushing of the system, and high light penetration to promote photosynthesis contribute to elevated levels of chlorophyll-*a* in waterways.

During wet weather monitoring, chlorophyll-*a* was lower compared to dry weather monitoring and ranges were narrow and overlapped, however, outliers occurred at RE1 (Figure 204).

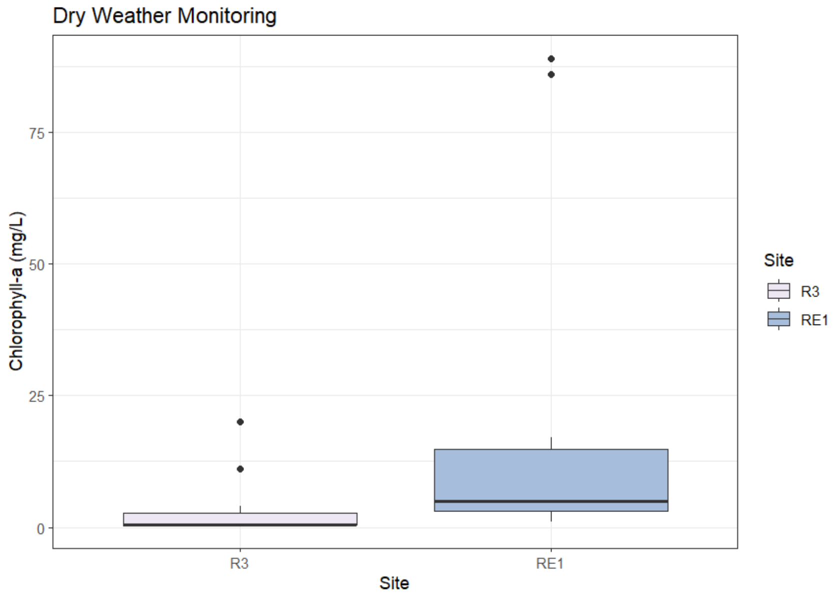

Figure 203: Summary of chlorophyll-*a* (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

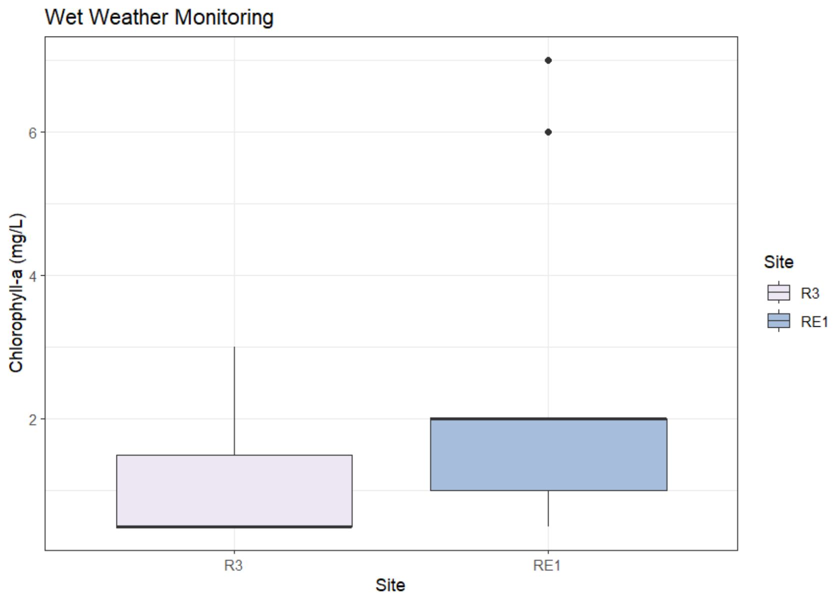

Figure 204: Summary of chlorophyll-*a* (mg/L) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, chlorophyll-*a* levels at all Reid Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 205). Values were consistently elevated at RE1 and R3 throughout the monitoring period. Chlorophyll-*a* levels were highest at RE1 in October 2023 (89.00 mg/L), followed by August 2022 (86.00 mg/L). The median chlorophyll-*a* for Reid Creek sites (3.00 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines. High nutrient availability and environmental conditions (including warmer temperatures, low rainfall to reduce flushing of the system, and high light penetration to promote photosynthesis) contribute to elevated levels of chlorophyll-*a* in waterways.

During wet weather monitoring, chlorophyll-*a* levels at all Reid Creek sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 206). Values were highest at RE1 during August 2023 (7.0 mg/L), however, overall were lower than recorded dry weather monitoring events. The median chlorophyll-*a* for Reid Creek sites (2.00 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

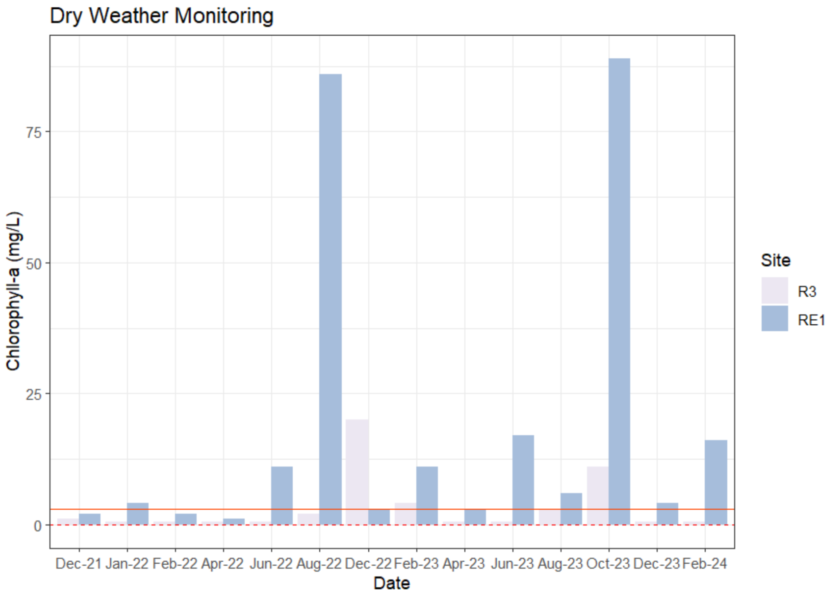

Figure 205: Chlorophyll-*a* (mg/L) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

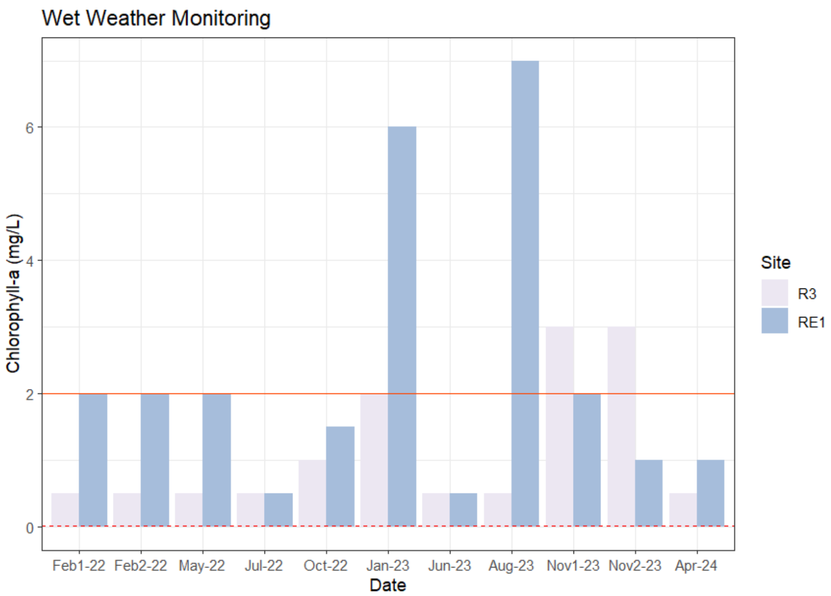

Figure 206: Chlorophyll-*a* (mg/L) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Enterococci

Enterococci concentrations were similar between Reid Creek sites during dry weather monitoring for the 2021-24 period. However, both sites experienced events where *Enterococci* was elevated, as shown by the outliers present (Figure 207).

During wet weather monitoring, there was more variability within each site and maximum values were higher compared to dry weather monitoring, however ranges still largely overlapped for both sites (Figure 208).

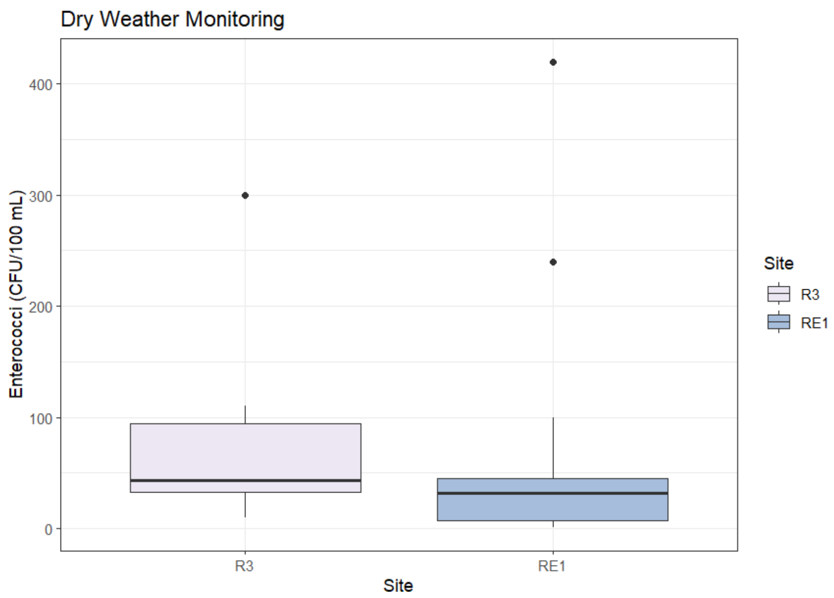

Figure 207: Summary of *Enterococci* (CFU/100 mL) at Reid Creek sites during dry weather monitoring events from December 2021 to April 2024.

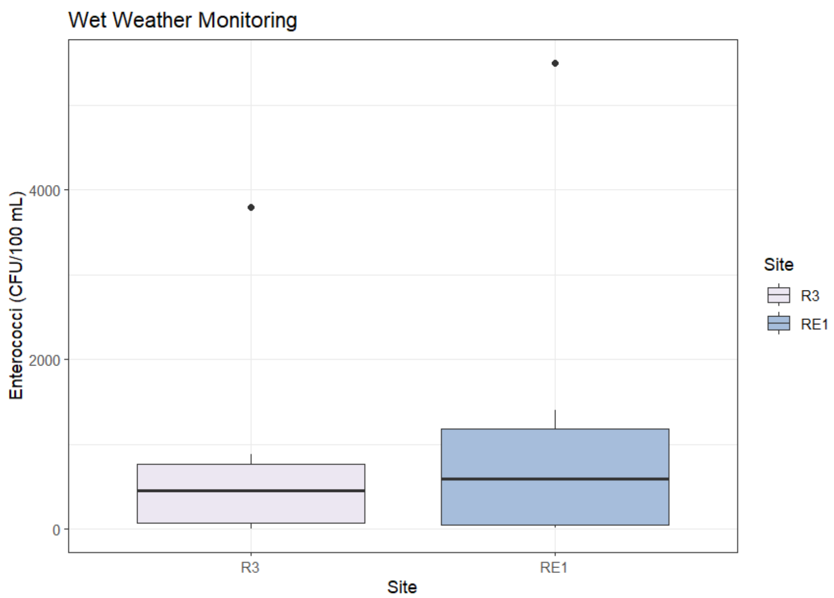

Figure 208: Summary of *Enterococci* (CFU/100 mL) at Reid Creek sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, *Enterococci* at Reid Creek sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 14 occasions (Figure 209). This included at RE1 on five occasions (in December 2021 and 2022, January 2022, April 2023, and October 2023). At R3, the primary guideline was exceeded on nine occasions (in December 2021 and 2022, January 2022, April 2022, February 2023, April 2023, June 2023, October 2023, and February 2024).

Enterococci levels exceeded the ANZECC secondary contact guideline (230 CFU/100 mL) on three occasions during the monitoring period. This included at RE1 in December 2023 and February 2024, and at R3 in December 2023.

The median *Enterococci* for Reid Creek sites (36.50 CFU/100 mL) during dry weather monitoring was above the primary contact ANZECC (2000) guidelines, but did not exceed the secondary contact guidelines.

During wet weather monitoring, *Enterococci* levels were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on three occasions (Figure 210). This included at RE1 in February 2022 and July 2022, and at R3 in February 2022.

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 14 occasions during wet weather monitoring. This occurred at RE1 on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024), and at R3 on seven occasions (in May 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024).

The median *Enterococci* for Reid Creek (1800.00 CFU/100 mL) during wet weather monitoring was above the ANZECC (2000) primary and secondary contact guidelines. Levels were higher during wet compared to dry weather monitoring, and this highlights the effects of rainfall and associated stormwater runoff on *Enterococci* levels in waterways.

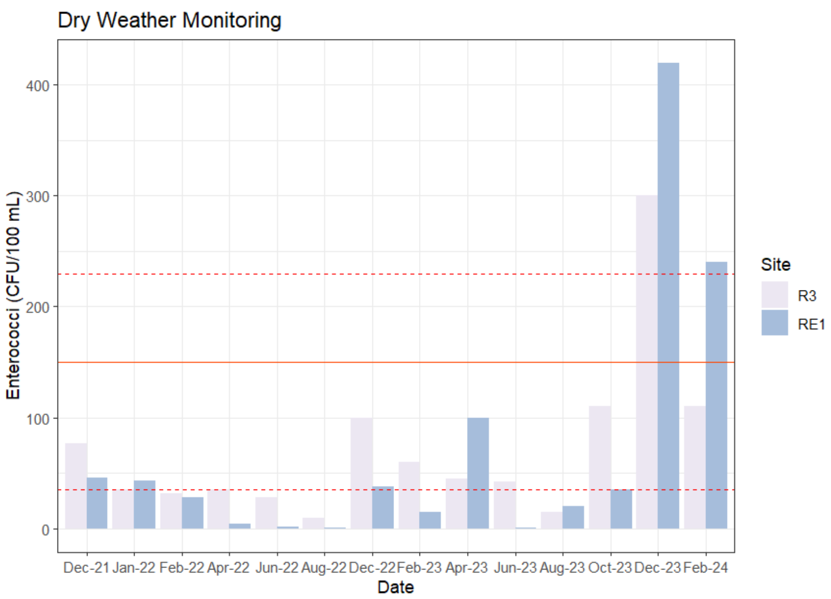

Figure 209: *Enterococci* (CFU/100 mL) at Reid Creek sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

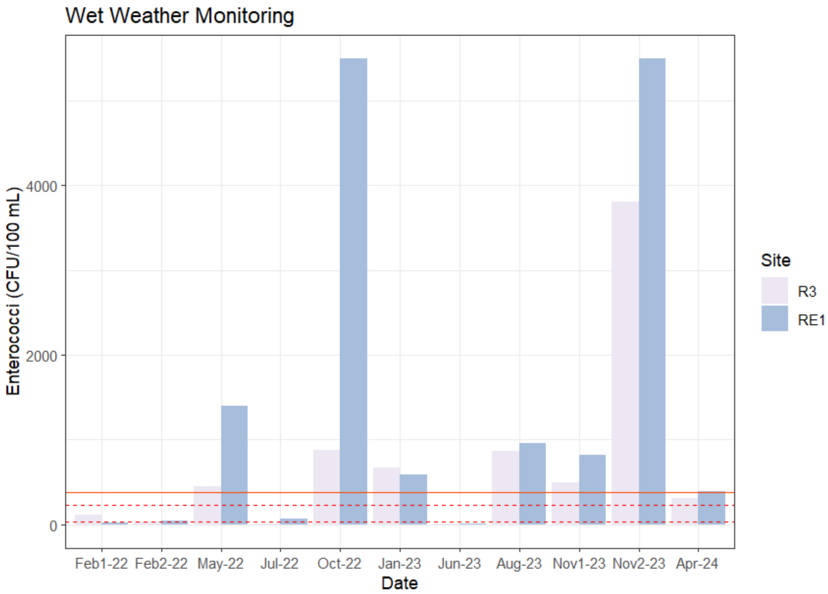

Figure 210: *Enterococci* (CFU/100 mL) at Reid Creek sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

Estuarine sites

Six estuarine sites were also monitored between December 2021 and April 2024 on 25 occasions, including Brooks Creek (B1), Duck Creek 1 (D1), Duck Creek 2 (D2), Hooka Creek (H1), Budjong Creek (BD1) and Minnegang Creek (MIN1), with 14 dry weather monitoring events and 11 wet weather monitoring events. A summary of findings for each water quality parameter is outlined below.

pH

Overall, pH remained similar across all Estuarine sites during dry weather monitoring for the 2021-24 period (Figure 211). Recorded values within the upper and lower quartiles of data largely overlapped between sites and outlier values were observed at D1, D2, H1, and MIN1.

During wet weather monitoring, ranges still largely overlapped and H1 and MIN1 had the highest pH ranges recorded (Figure 212).

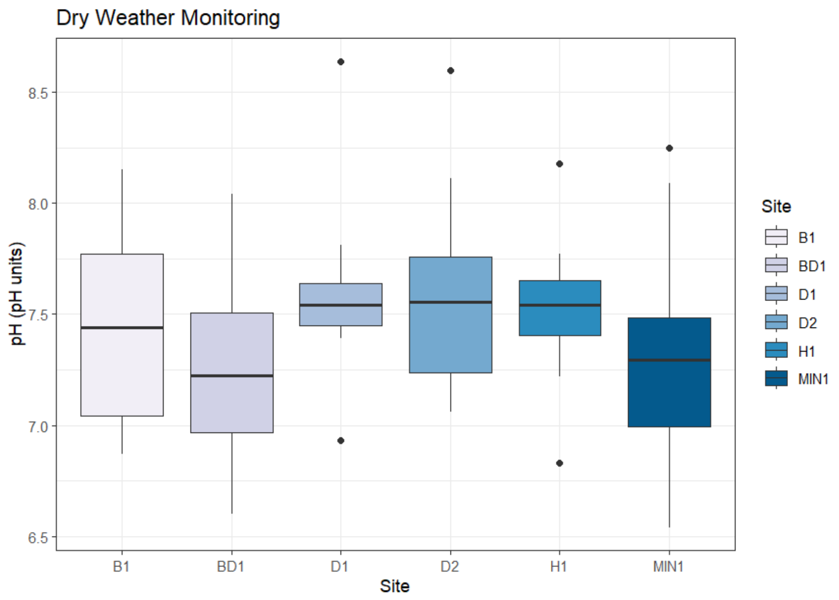

Figure 211: Summary of pH (pH units) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

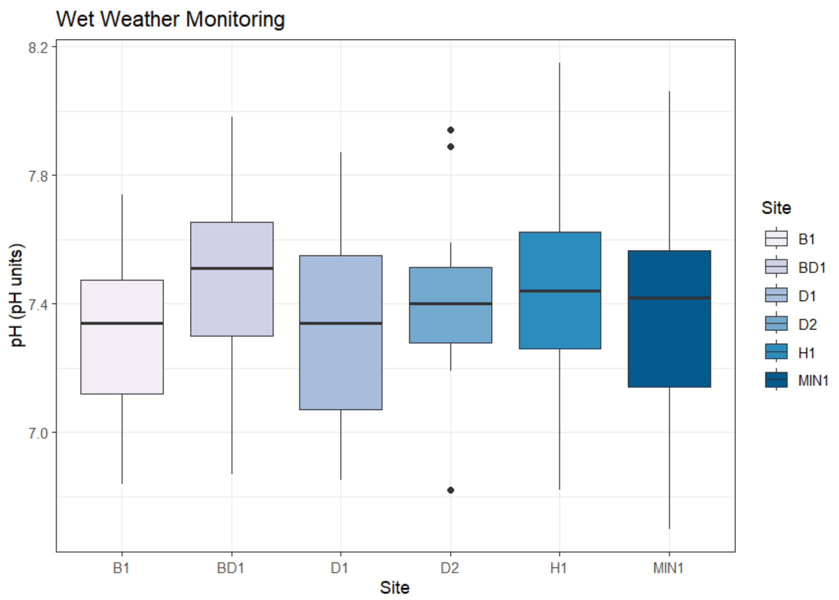

Figure 212: Summary of pH (pH units) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, pH at the Estuarine sites was predominantly within the ANZECC (2000) guidelines of 6.5 – 8.0 pH units (Figure 213). However, the upper guideline limit was exceeded on ten occasions. This included at B1 on three occasions (in June 2022, August 2023, and October 2023), BD1 in April 2023, D1 in June 2022, D2 on two occasions (in January 2022 and February 2023), H1 in June 2022, and MIN1 on two occasions (in January 2022 and April 2023). The highest pH was recorded at D1 in June 2022 (8.64 pH units). The median pH for Estuarine sites (7.49 pH units) during dry weather monitoring was within the ANZECC (2000) guidelines.

During wet weather monitoring, pH at the Estuarine sites was compliant with the ANZECC (2000) guidelines of 6.5 – 8.0 pH units at all sites across the monitoring period, excluding on two occasions (at H1 in February

2022 and MIN in July 2022). The maximum pH recorded was 8.15 pH units at H2 in February 2022 (Figure 214). The median pH for Estuarine sites (7.42 pH units) during wet weather monitoring was within the ANZECC (2000) guidelines.

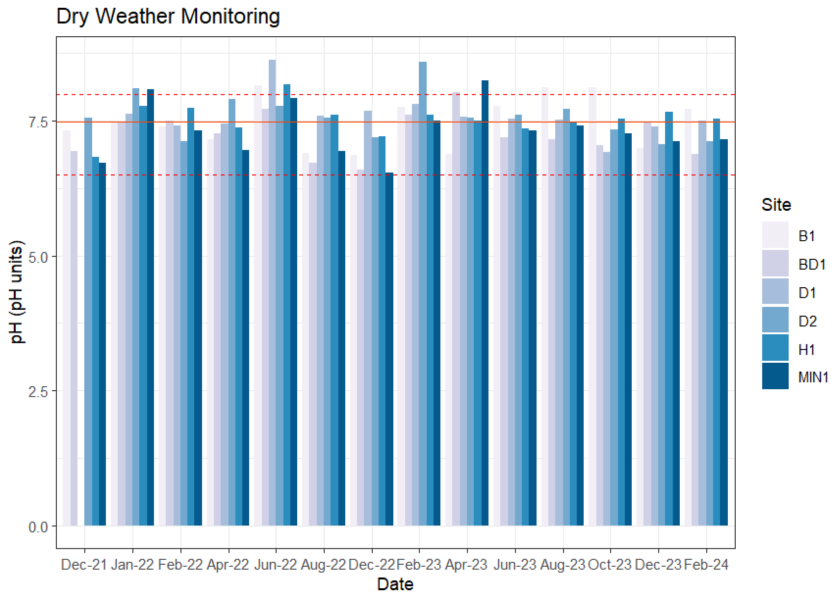

Figure 213: pH (pH units) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

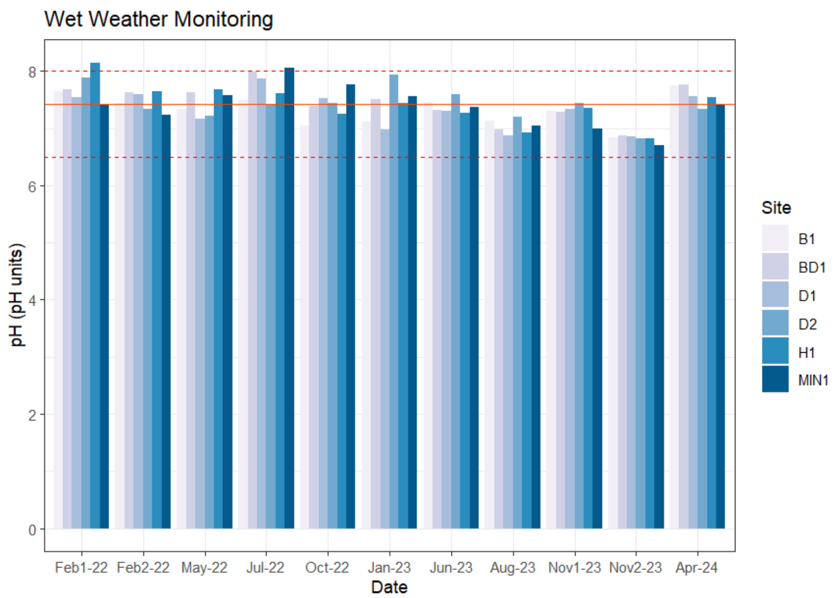

Figure 214: pH (pH units) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Electrical conductivity

Electrical conductivity experienced a wide range at D1 and H1 compared to the other Estuarine sites during dry weather monitoring for the 2021-24 period, with high outlier values for these two sites (Figure 215). All other sites had a narrow range of observed values that largely overlapped. Estuarine sites experienced high electrical conductivity, which is due to the influence of saline water within this catchment as the estuary is brackish.

During wet weather monitoring, this trend was maintained, with a wide range of variability in electrical conductivity at D1 and H1. Ranges still largely overlapped for all sites (Figure 216).

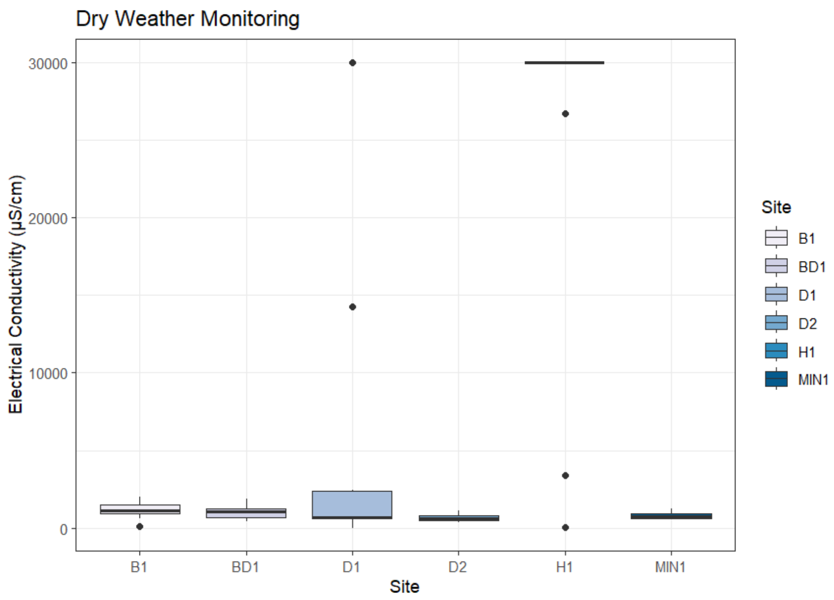

Figure 215: Summary of electrical conductivity (µS/cm) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

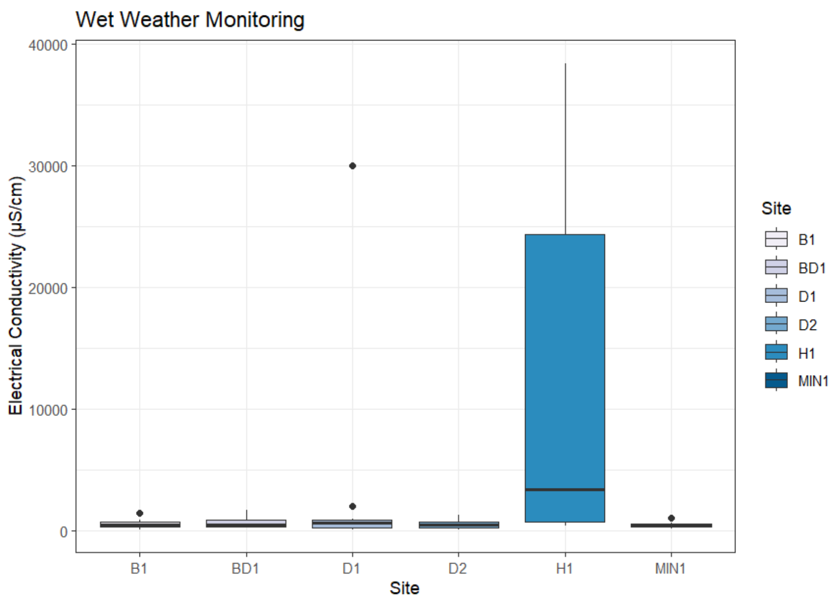

Figure 216: Summary of electrical conductivity (µS/cm) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, electrical conductivity at the Estuarine sites frequently exceeded the upper ANZECC (2000) guideline of 300 µS/cm for all sites across all monitoring events (Figure 217). The only compliant was B1 in February 2022. H1 had consistently high electrical conductivity relative to other Mullet

Creek sites, with concentrations above maximum detection limits (30,000 µS/cm) during 11 monitoring events, and BD1 also exceeded maximum detection levels in October 2023 (due to the contribution of saline water). The next highest electrical conductivity was recorded at D1 in June 2023 (14,260 µS/cm). The median electrical conductivity for Estuarine sites (976 µS/cm) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, electrical conductivity at the Estuarine sites was overall lower compared to dry weather monitoring. However, the upper ANZECC (2000) guideline was still exceeded at all sites on 51 occasions (Figure 218). B1 was compliant on three occasions (during both February 2022 and the October 2022 sampling event), and BD1 was compliant on two occasions (in October 2022 and November 2023). D1 and D2 were compliant on four occasions (in May 2022, July 2022, October 2022, and April 2024), and MIN1 was compliant on two occasions (in October 2022 and January 2023). In line with dry weather monitoring, H1 had high electrical conductivity relative to other Estuarine sites, exceeding the maximum level of detection in February 2022, June 2023 and November 2023 (due to the contribution of saline water). The median electrical conductivity for Estuarine sites (652 µS/cm) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

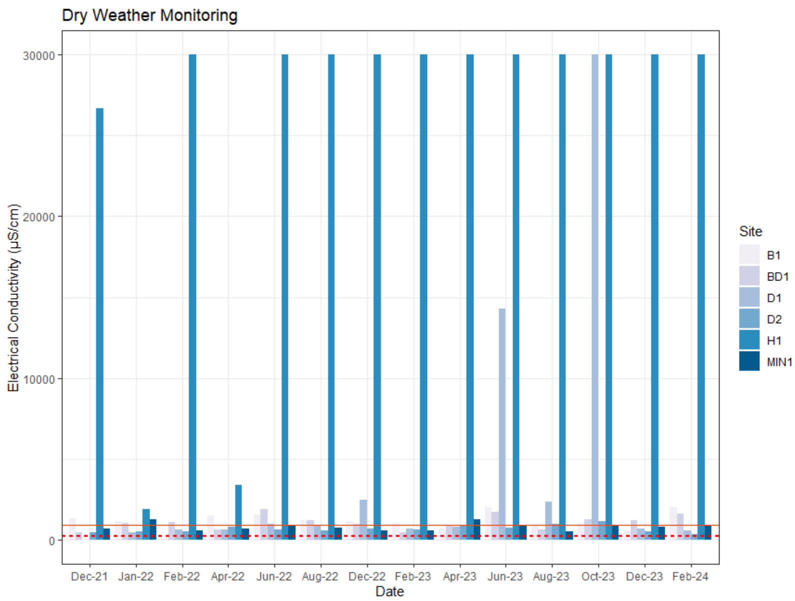

Figure 217: Electrical conductivity (µS/cm) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

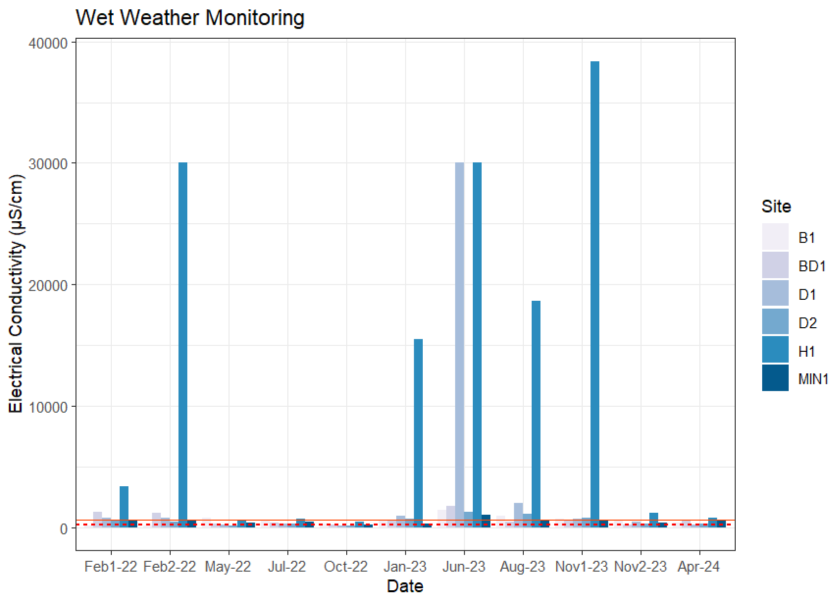

Figure 218: Electrical conductivity (µS/cm) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Temperature

Temperature remained consistent between the Estuarine sites throughout the 2021-2024 dry weather monitoring period (Figure 219), with the range of all sites overlapping.

During wet weather monitoring, temperature at all sites also remained consistent across all sites (Figure 220).

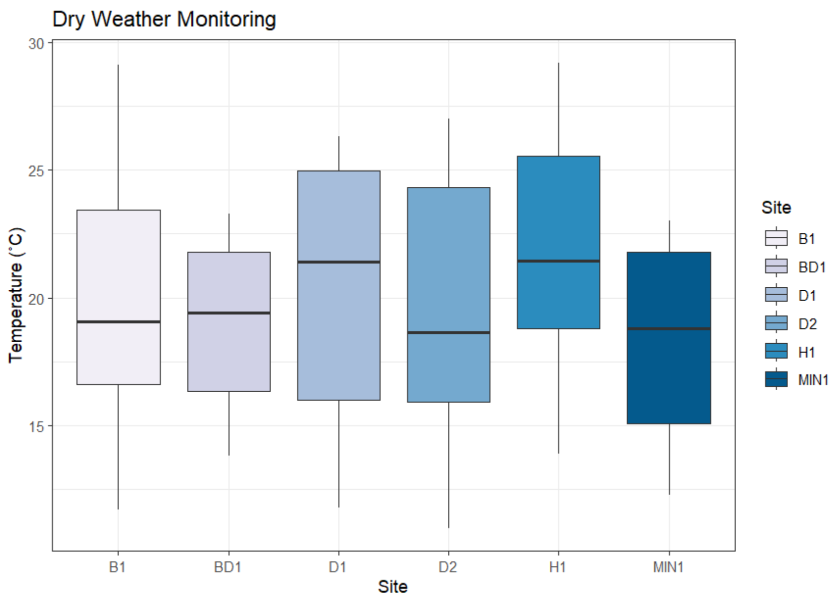

Figure 219: Summary of temperature (˚C) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

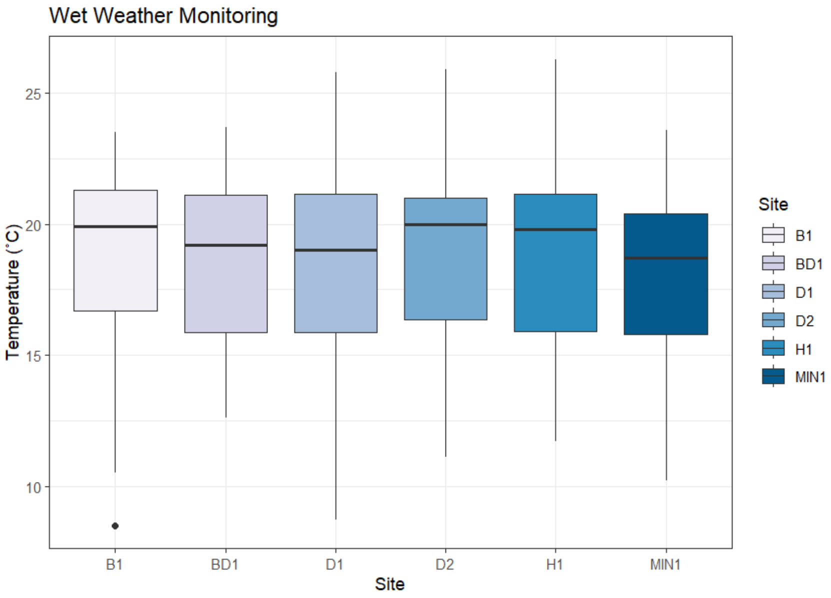

Figure 220: Summary of temperature (˚C) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, temperature ranged from a maximum of 29.2˚C at H1 in December 2023 and a minimum of 11.0˚C at D2 in June 2022 (Figure 221). Estuarine sites all showed similar temperature trends. The median temperature for Estuarine sites was 20.45˚C during dry weather monitoring. There are currently no ANZECC (2000) guidelines for temperature for lowland rivers and temperature can also experience temporal and diurnal changes at sites.

During wet weather monitoring, temperature ranged from a maximum of 26.3˚C at H1 in February 2022 and a minimum of 8.5˚C at B1 in August 2023 (Figure 222). Estuarine sites all showed similar temperature trends. The median temperature for Estuarine sites was 20.45˚C during wet weather monitoring.

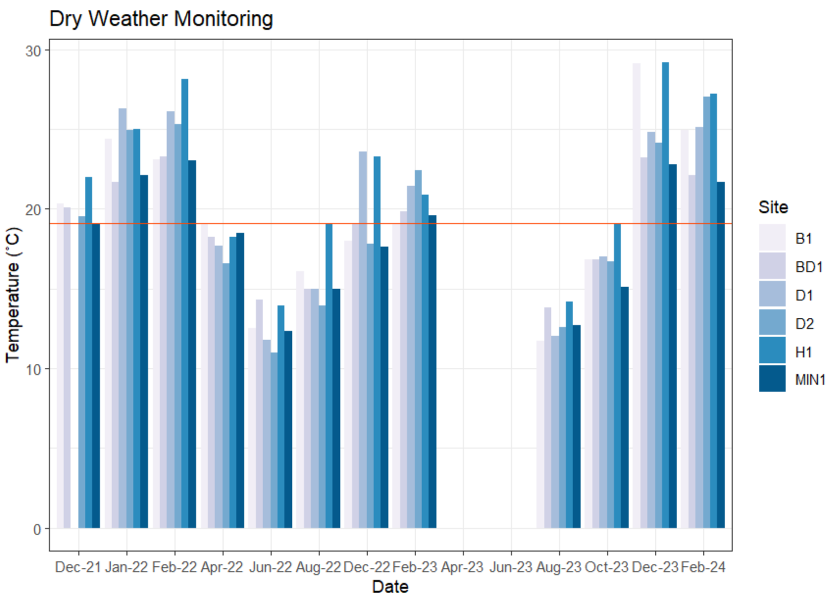

Figure 221: Temperature (˚C) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

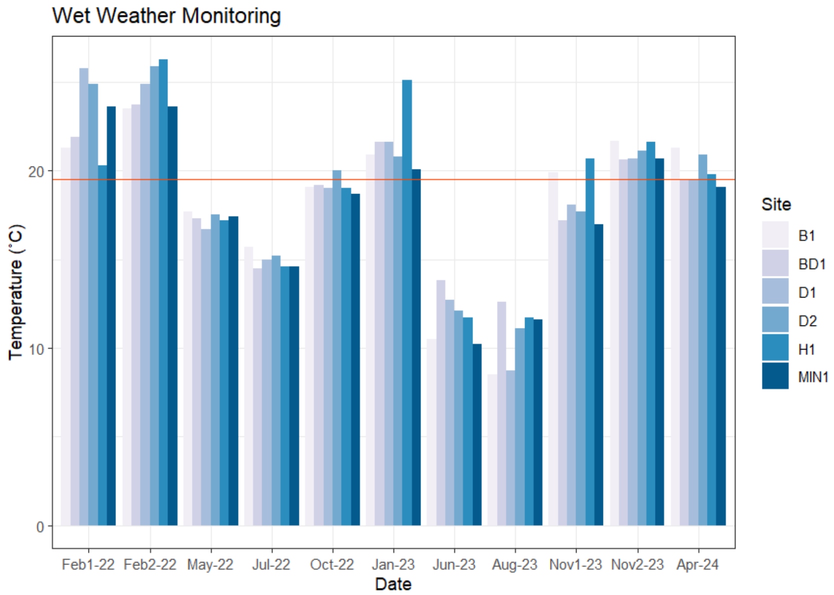

Figure 222:Temperature (˚C) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Dissolved oxygen

Dissolved oxygen was variable between Estuarine sites during dry weather monitoring for the 2021-24 period (Figure 223). Whilst there was some overlap between the ranges of each sites, D1 and H1 had the highest range of values. Conversely, dissolved oxygen at BD1 was notably low during the monitoring period.

During wet weather monitoring, dissolved oxygen was consistent across all Estuarine sites, as ranges largely overlapped (Figure 224).

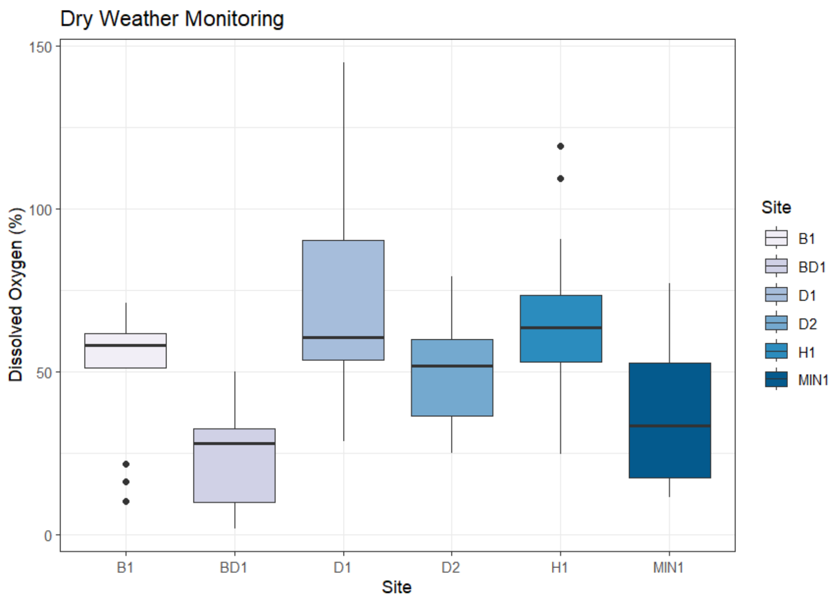

Figure 223: Summary of dissolved oxygen (%) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

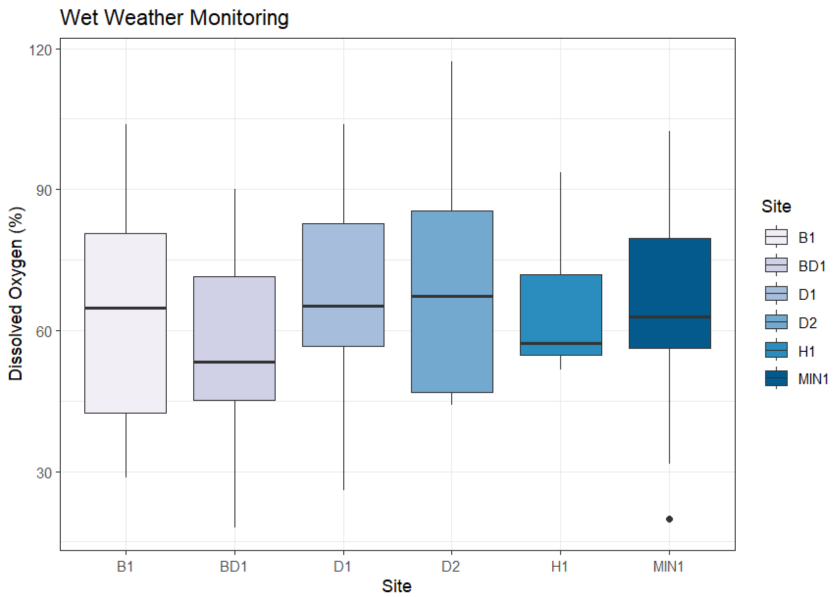

Figure 224: Summary of dissolved oxygen (%) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, dissolved oxygen levels at the Estuarine sites were consistently non-compliant with the ANZECC (2000) guidelines of 85-110% (Figure 225). Dissolved oxygen was consistently below the lower guideline limit at all sites (less than 85%). This suggests that high nutrient levels are contributing to eutrophic conditions, whereby excess plant and algal growth occurs, depleting available oxygen in waterways as they decompose. The sites that were compliant included at D1 on four occasions (in June 2022, August 2022, December 2022, and June 2023), and at H1 on three occasions (in June, August, and December 2022). The lowest dissolved oxygen was at BD1 (1.9%) in August 2022. The median dissolved oxygen for Estuarine sites (51.90%) during dry weather monitoring was well below the ANZECC (2000) guidelines.

During wet weather monitoring, dissolved oxygen was compliant with the ANZECC (2000) guidelines on 12 occasions (Figure 226). This included at B1 on two occasions (in May and October 2022), at BD1 in May 2022, at D1 on three occasions (in May 2022, July 2022, and August 2023), at D2 on three occasions (in May 2022, October 2022, and August 2023), at H1 in May 2022, and at MIN1 on two occasions (in May 2022 and August 2023). Dissolved oxygen was low across all sites, with a minimum of 18.08% at BD1 in February 2022. This low level of dissolved oxygen poses implications for aquatic species within these waterways. The median dissolved oxygen for Estuarine sites (66.40%) during wet weather monitoring was well below the ANZECC (2000) guidelines.

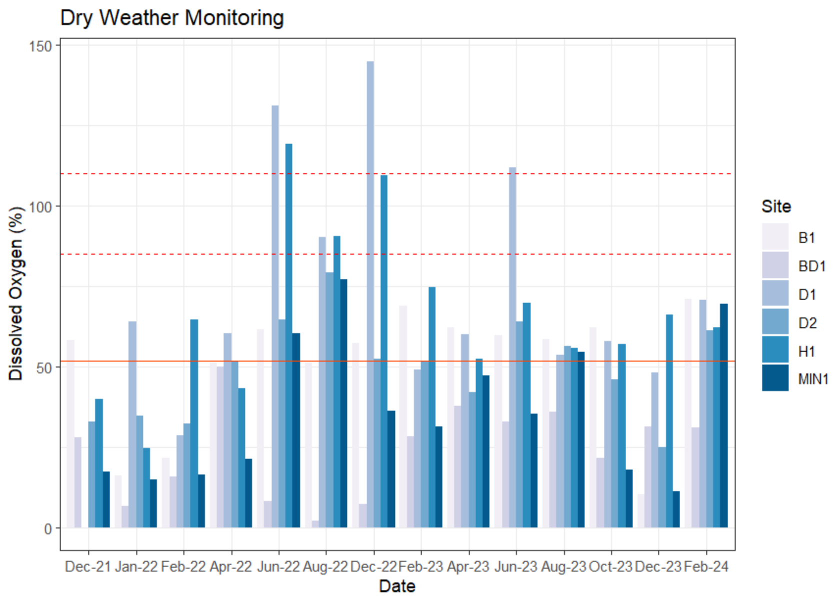

Figure 225: Dissolved oxygen (%) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

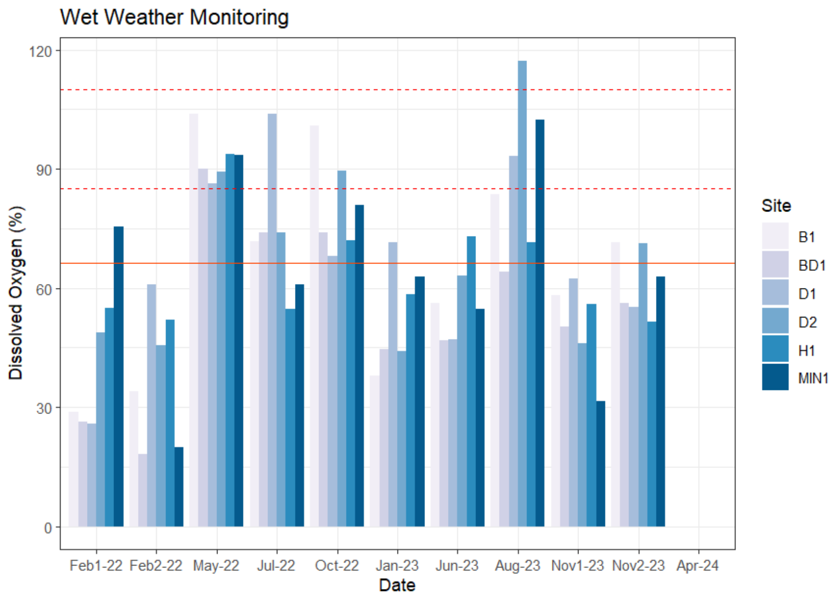

Figure 226: Dissolved oxygen (%) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Turbidity

Turbidity was similar between Estuarine sites during dry weather monitoring for the 2021-24 period (Figure 227). Whilst the ranges of each site largely overlapped and the medians were similar, outliers were present at B1, D1, and MIN1.

During wet weather monitoring, the range of turbidity values largely overlapped between all sites and outliers occurred BD1, D1, D2, and MIN1 (Figure 228).

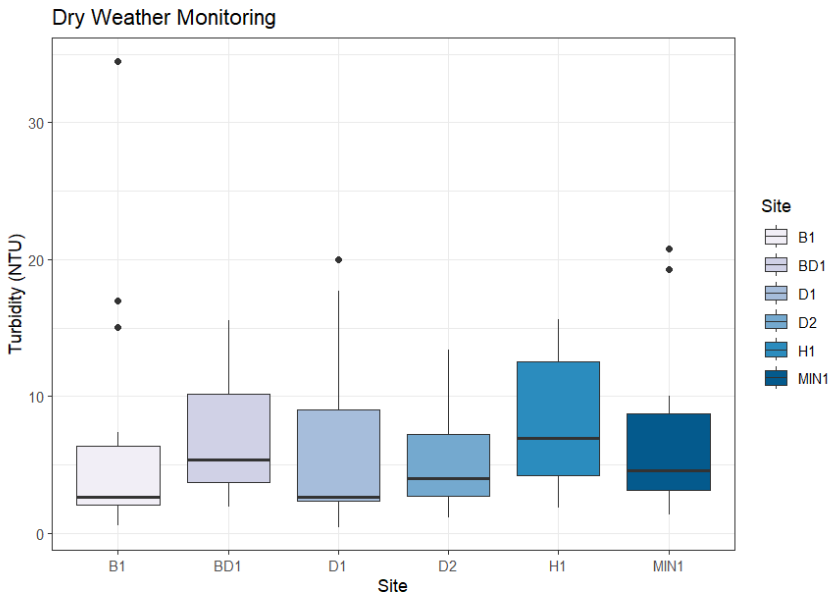

Figure 227: Summary of turbidity (NTU) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

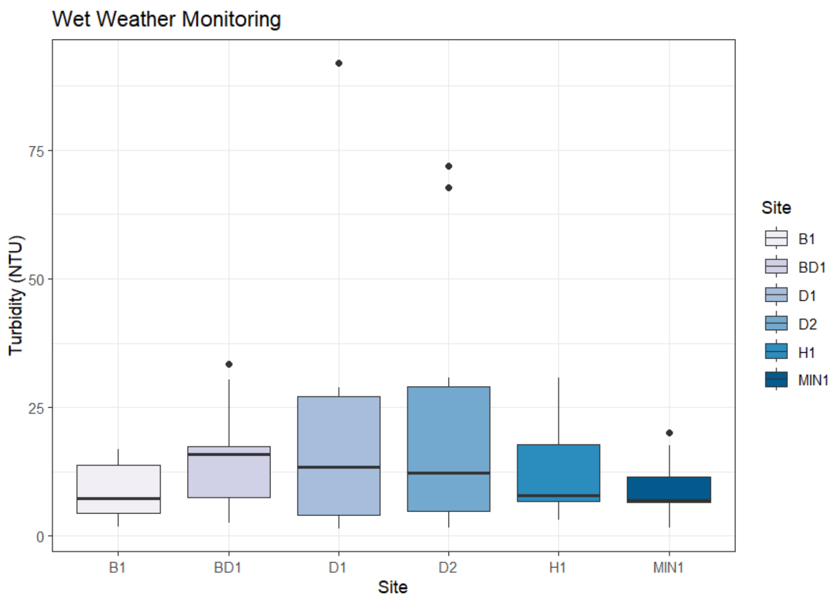

Figure 228: Summary of turbidity (NTU) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, turbidity at the Estuarine sites remained within the ANZECC guideline range of 6 – 50 NTU (Figure 229). Maximum turbidity was recorded at B1 (34.5 NTU) in February 2024. The median turbidity for Estuarine sites (4.37 NTU) during dry weather monitoring was below the ANZECC (2000) guidelines. Results below 6 NTU should not be considered as non-compliant, instead is representative of very low suspended sediments, which is a positive result.

During wet weather monitoring, turbidity at the Estuarine sites largely remained within the ANZECC guideline range of 6 – 50 NTU (Figure 230). This excluded at D1 in November 2023 (with a maximum of 92 NTU), and at D2 in October 2022 and November 2023. The median turbidity for Estuarine sites (11.11 NTU) during wet weather monitoring was within the ANZECC (2000) guidelines.

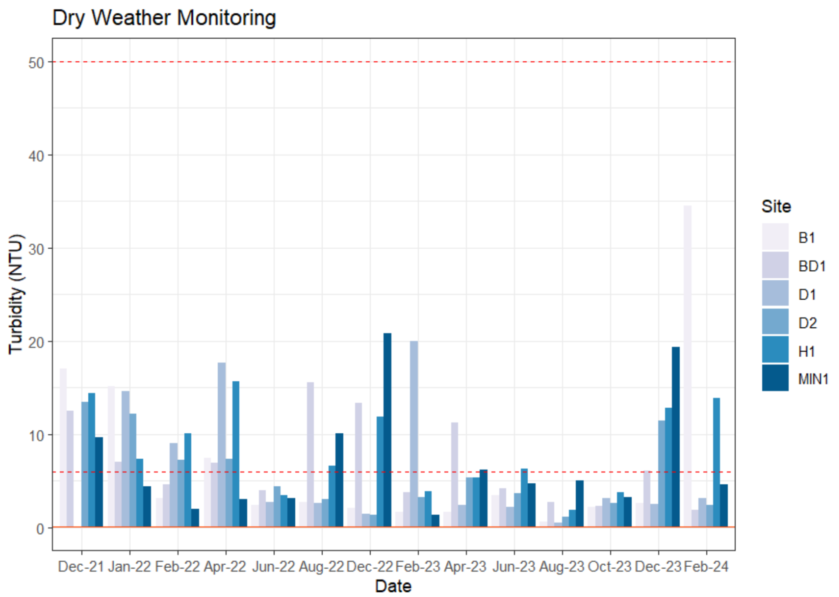

Figure 229: Turbidity (NTU) at Estuarine sites during dry weather monitoring events from December 2021 to February 2023. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

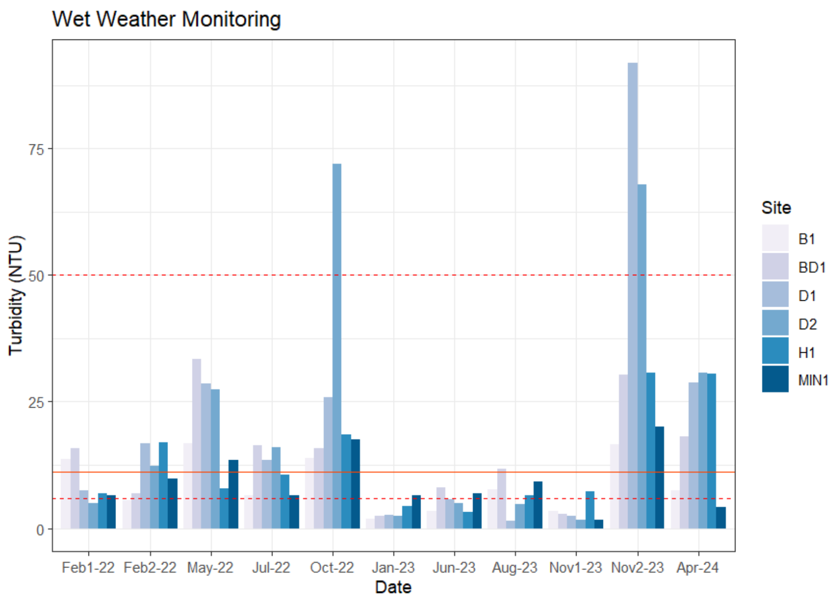

Figure 230: Turbidity (NTU) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guidelines (upper and lower limits) for lowland rivers are shown as the dashed red lines. The solid orange line represents the median for this catchment.

Total nitrogen

Total nitrogen remained consistent between Estuarine sites B1, D1, D2, H1, and MIN1 during dry weather monitoring for the 2021-24 period. However, the range of BD1 was wider compared to the other sites (Figure 231).

During wet weather monitoring, the ranges of all sites overlapped, however, outlier values were at B1, D1, D2, and H1 (Figure 232).

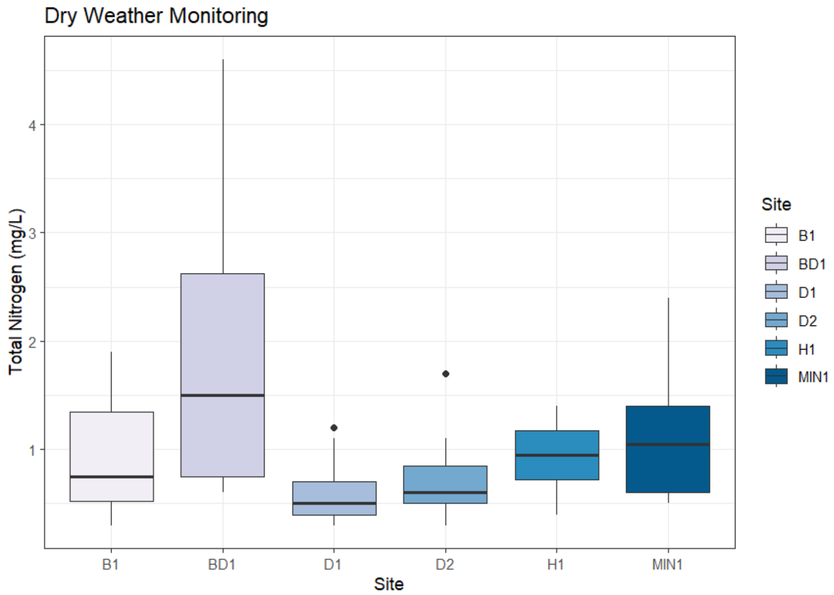

Figure 231: Summary of total nitrogen (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

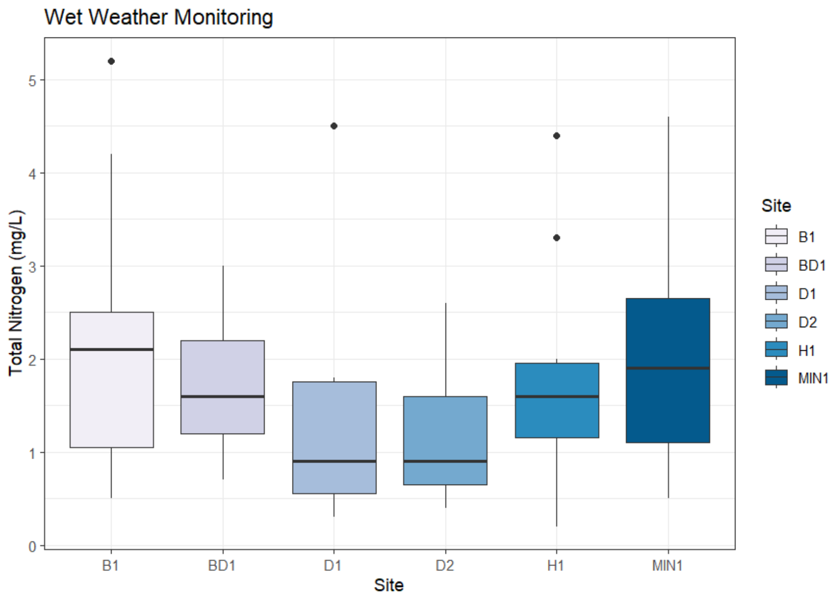

Figure 232: Summary of total nitrogen (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total nitrogen concentrations at the Estuarine sites frequently exceeded the ANZECC (2000) guideline of 0.5 mg/L (Figure 233). Sites were compliant on 13 occasions. This occurred at B1 on three occasions (in December 2021, February 2022 and 2023), at D1 on six occasions (in January 2022, February 2022, April 2022, June 2022 and 2023, and August 2023), at D2 on three occasions (in April 2022, August 2023, and June 2023), and H1 in February 2022. The median total nitrogen for Estuarine sites (0.80 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, non-compliance with the ANZECC (2000) guideline for total nitrogen was frequent and only three sites were compliant on one occasion (Figure 234). This included at D1, D2, and H1 in June 2023. The maximum value was recorded at B1 (5.2 mg/L) in November 2023. The median total nitrogen for Estuarine sites (1.45 mg/L) during wet weather monitoring exceeded the ANZECC (2000) guidelines.

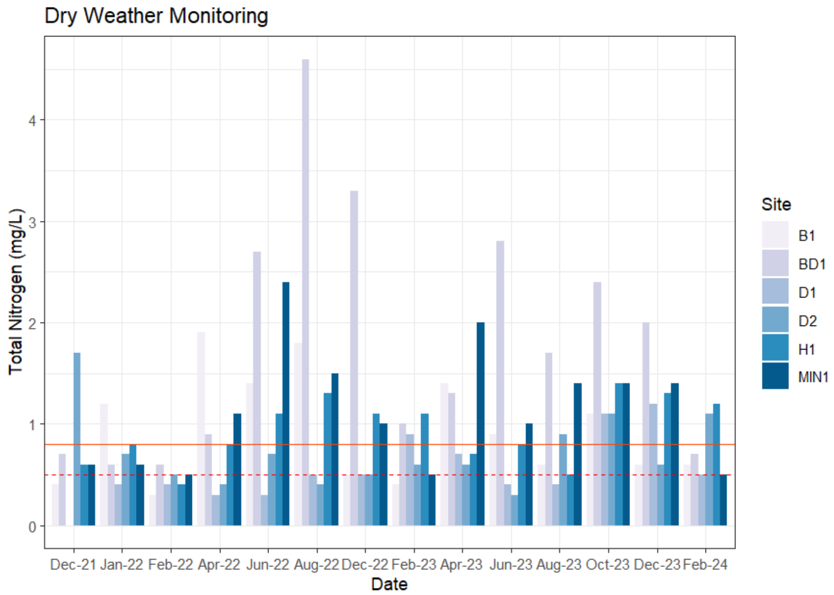

Figure 233: Total nitrogen (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

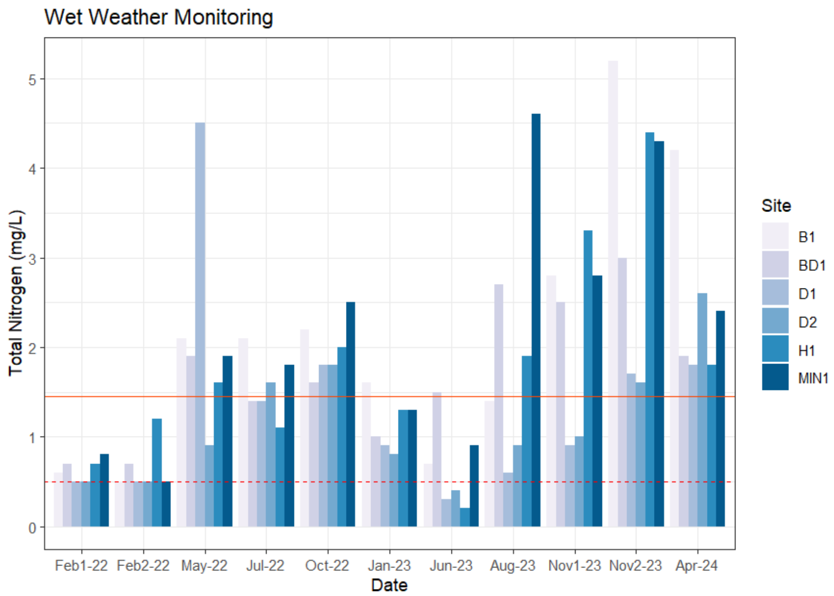

Figure 234: Total nitrogen (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Ammonia

Ammonia was predominantly within a narrow range across all Estuarine sites during dry weather monitoring for the 2021-24 period. However, ammonia ranges were highest for BD1, as shown by the outliers present (Figure 235).

During wet weather monitoring, the ranges for ammonia concentrations largely overlapped for all sites, however, the range of recorded values were wider, particularly at H1 (Figure 236).

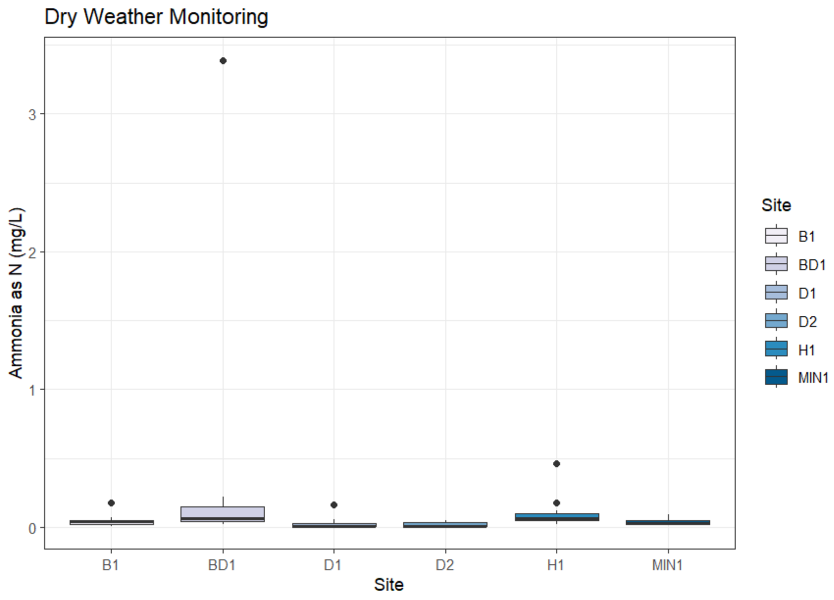

Figure 235: Summary of ammonia (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

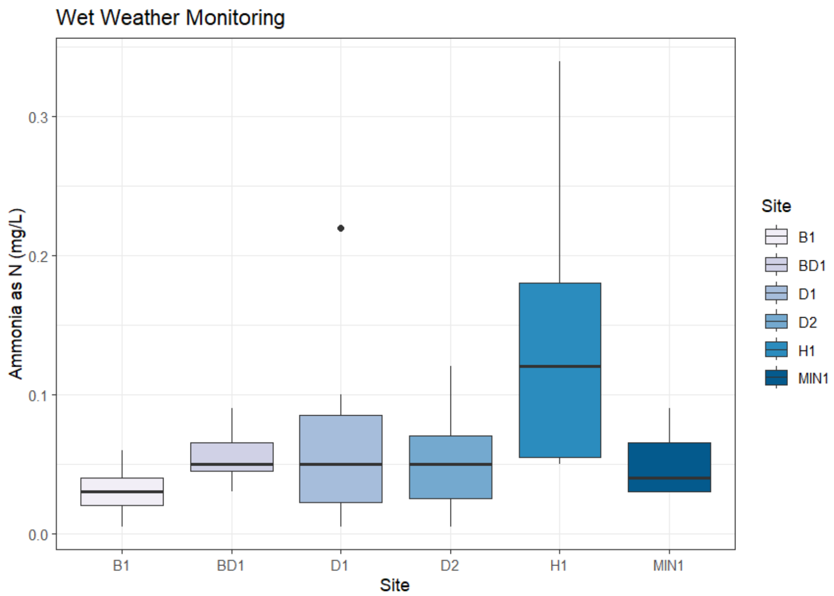

Figure 236: Summary of ammonia (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, ammonia concentrations at the Estuarine sites were low however did exceed the ANZECC (2000) guideline of 0.02 mg/L (Figure 237). Sites were compliant on 18 occasions, and this included B1 in April 2023, on nine occasions at D1 (excluding in June 2022, October 2023, and February 2023 and 2024), and on eight occasions at D2 (excluding in December 2021, January 2022, April 2022, June 2022, and February 2024). The highest ammonia value of 3.39 mg/L was recorded at BD1 in August 2022, which was significantly elevated relative to the other sampling events and the ANZECC (2000) guidelines (nearly 170 times the guideline value).Whilst low rainfall was recorded in the week prior to this sampling event, previous significant rainfall events occurred in this catchment in preceding month (July 2022 with 409 mm) which may have contributed higher nutrient loads to this system. The median ammonia for Estuarine sites (0.04 mg/L) during dry weather monitoring exceeded the ANZECC (2000) guidelines.

During wet weather monitoring, ammonia concentrations at the Estuarine sites also did not comply with the ANZECC (2000) guideline of 0.02 mg/L, excluding on eight occasions (Figure 238). Sites that were compliant included B1 on two occasions (in August and November 2023), and D1 on three occasions (during both February 2023 and the November 2023 sampling events), and at D2 on three occasions (in February 2022, June 2023, and August 2023). The maximum recorded ammonia value for wet weather monitoring of 0.34 mg/L was recorded at H1 in November 2023, however, this maximum was lower compared to dry weather monitoring. The median ammonia for Estuarine sites (0.05 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

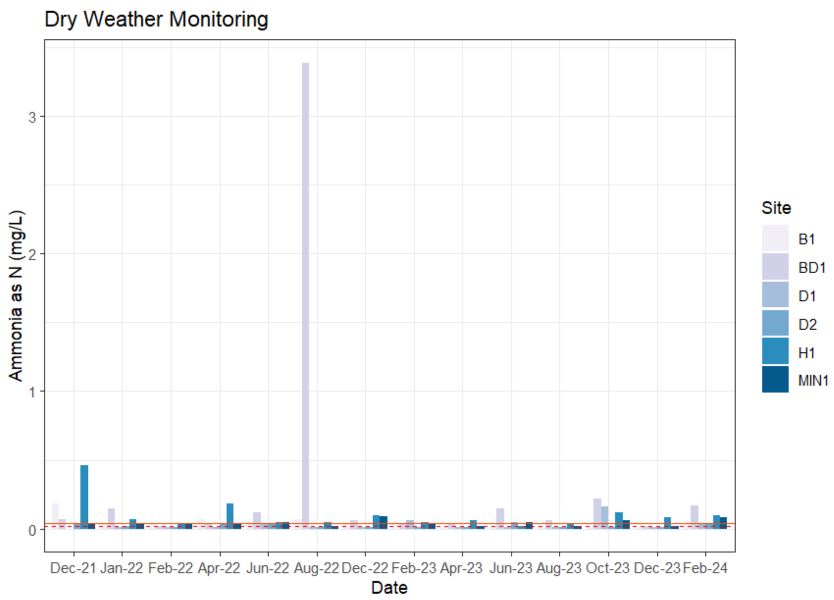

Figure 237: Ammonia (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

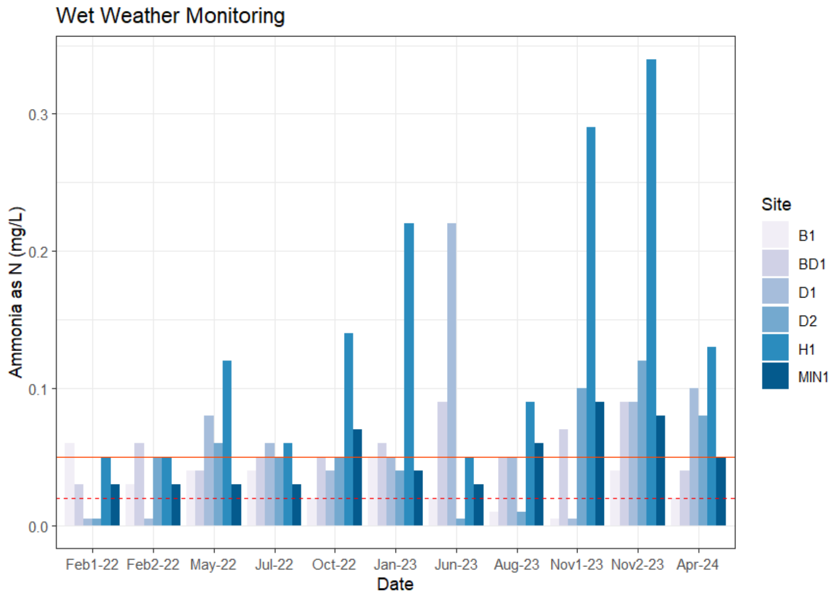

Figure 238: Ammonia (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

NOx

Nitrate and nitrite (NOx) concentrations showed high variability across all Estuarine sites during dry weather monitoring for the 2021-24 period. Sites with the lowest range of recorded values were D1, D2, and H1, however, B1, BD1, and MIN1 had wide ranges (Figure 239).

During wet weather monitoring, the range of NOx values was greater across all sites, however, ranges still largely overlapped for all sites (Figure 240).

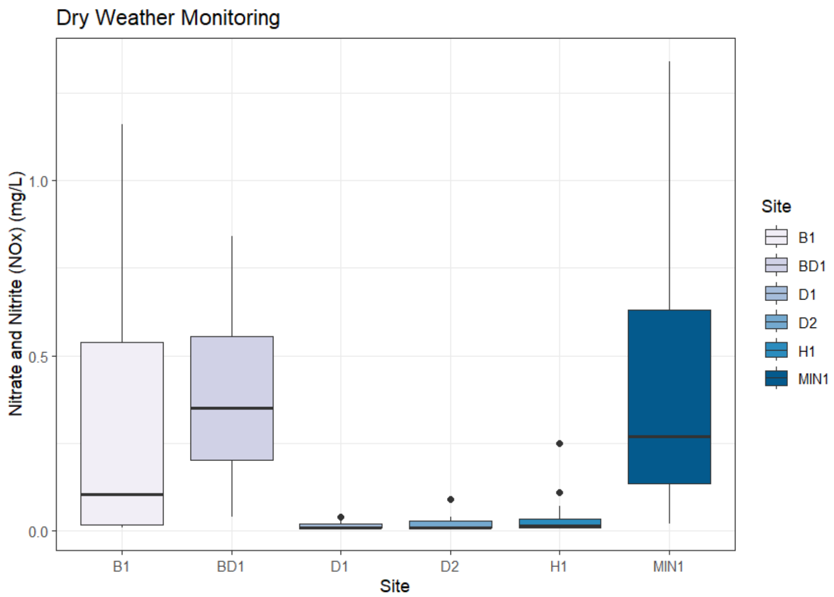

Figure 239: Summary of nitrate and nitrite (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

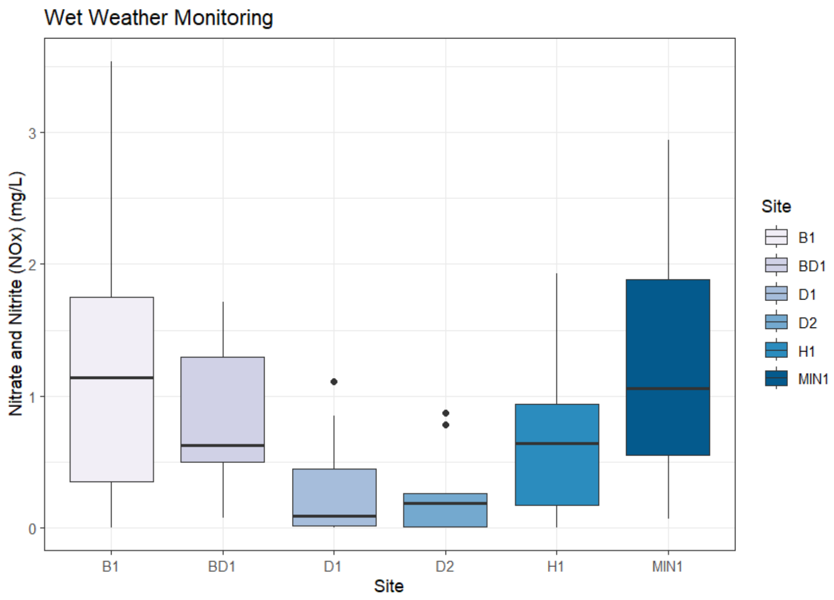

Figure 240: Summary of nitrate and nitrite (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, NOx concentrations at the Estuarine sites exceeded the ANZECC (2000) guideline of 0.04 mg/L on 46 occasions (Figure 241). The sites that were compliant were B1 on four occasions (in December 2023, and February 2022, 2023, and 2024), D1 on 11 occasions (excluding in April and August 2022), D2 on 11 occasions (excluding April 2022, and August 2022 and 2023), H1 on ten occasions (excluding in December 2021, April 2022, and August 2022 and 2023), and at MIN1 in February 2024. The median NOx for Estuarine sites (0.04 mg/L) during dry weather monitoring was in line with the ANZECC (2000) guidelines.

During wet weather monitoring, NOx concentrations at the Estuarine sites frequently exceeded the ANZECC (2000) guideline of 0.04 mg/L, excluding on 11 occasions (Figure 242). Sites that were compliant with the ANZECC (2000) guideline included at B1 in February 2022, at D1 on four occasions (during both February 2022 events, June 2023, and August 2023), at D2 on four occasions (during both February 2022 events, January 2023, and June 2023), and at H1 in February and June 2023. The highest value was recorded at B1 in April 2024 (3.54 mg/L), and this value is 88 times higher than the ANZECC (2000) guideline. The median NOx for Estuarine sites (0.38 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

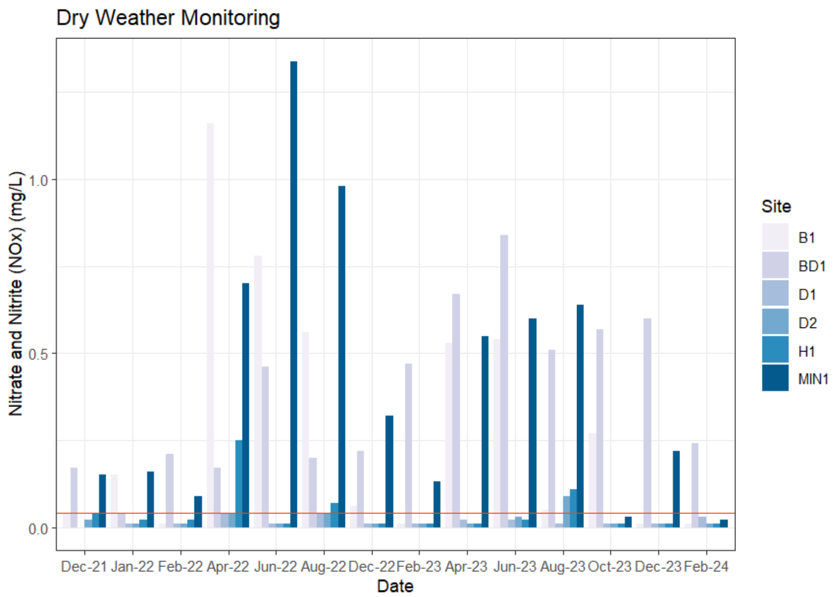

Figure 241: Nitrate and nitrite (NOx) (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

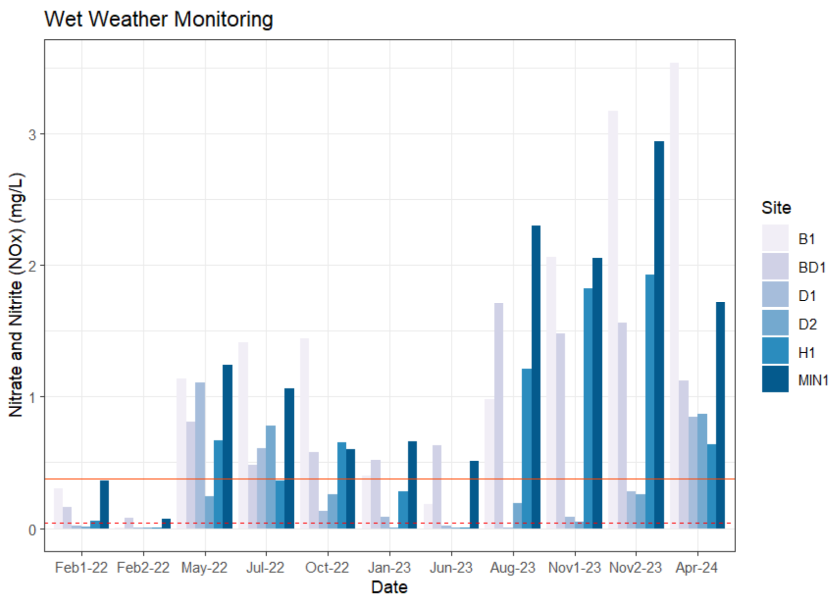

Figure 242: Nitrate and nitrite (NOx) (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Phosphorus

Total phosphorus concentrations were variable across all Estuarine sites during dry weather monitoring for the 2021-24 period. However, each site experienced events where total phosphorus was elevated, as shown by the outliers present, and this was highest at MIN1 (Figure 243).

During wet weather monitoring, there was slightly more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at MIN1, H1, and BD1 (Figure 244).

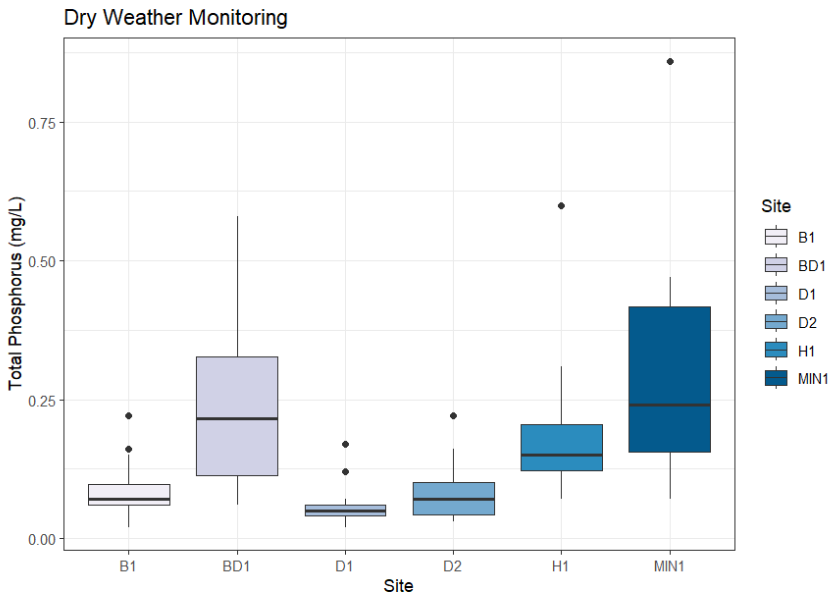

Figure 243: Summary of total phosphorus (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

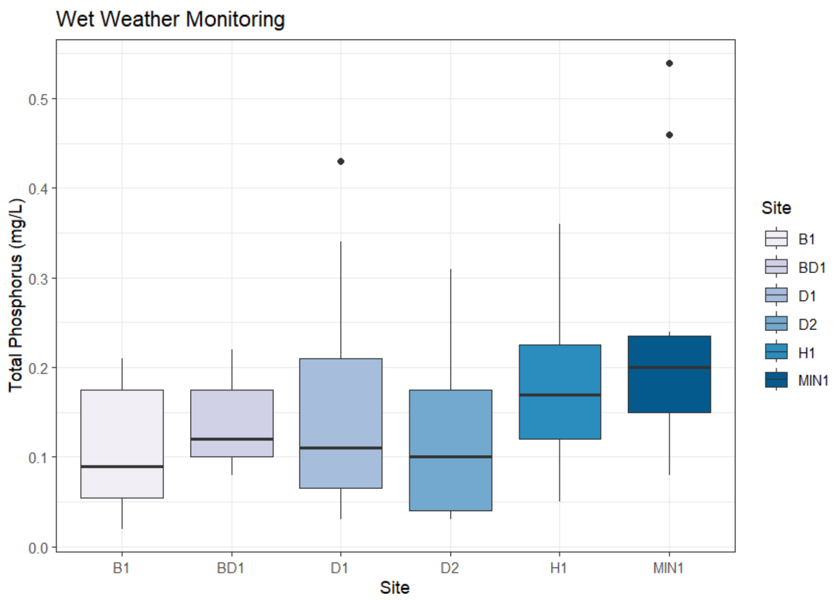

Figure 244: Summary of total phosphorus (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total phosphorus concentrations at the Estuarine sites frequently exceeded the ANZECC (2000) guideline of 0.05 mg/L, excluding on 11 occasions (Figure 245). The sites that were compliant were B1 in June 2023, D1 on six occasions (in January 2022, February 2022, April 2022, June 2022, December 2022, and June 2023), and four occasions at D2 (in February 2022, August 2022, December 2022, and June 2023). The highest total phosphorus value was recorded at MIN1 in April 2023 (0.86 mg/L). The median total phosphorus for Estuarine sites (0.12 mg/L) during dry weather monitoring was above the ANZECC (2000) guidelines.

During wet weather monitoring, there was high non-compliance with the ANZECC (2000) guideline for total phosphorus at the Estuarine sites similar to dry weather monitoring. Sites were compliant with the guideline on eight occasions (Figure 246). This included at B1 on two occasions (in June and August 2023), at D1 on two occasions (in February 2022 and August 2023), and at D2 on four occasions (during both February 2022 events, June 2023, and August 2023). The highest total phosphorus value was recorded at MIN1 in August 2023 (0.54 mg/L). The median total phosphorus for Estuarine sites (0.12 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

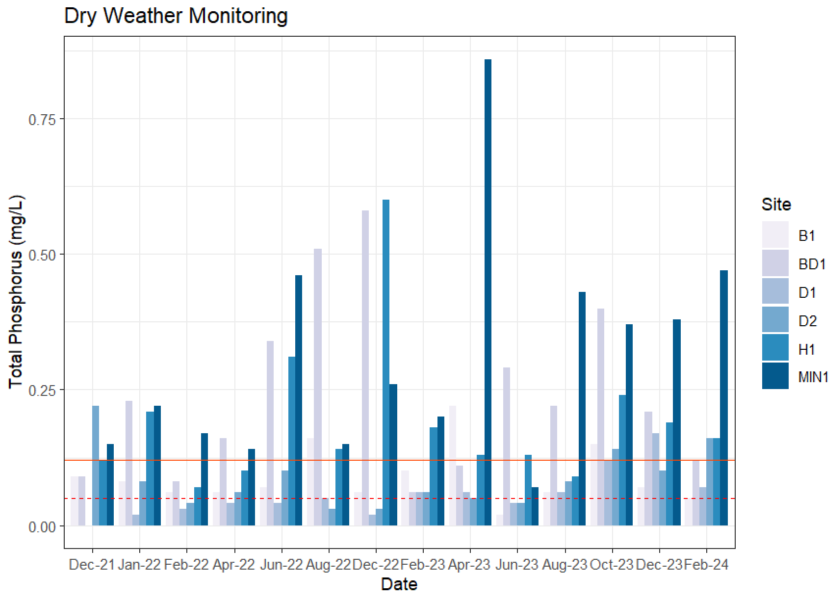

Figure 245: Total phosphorus (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

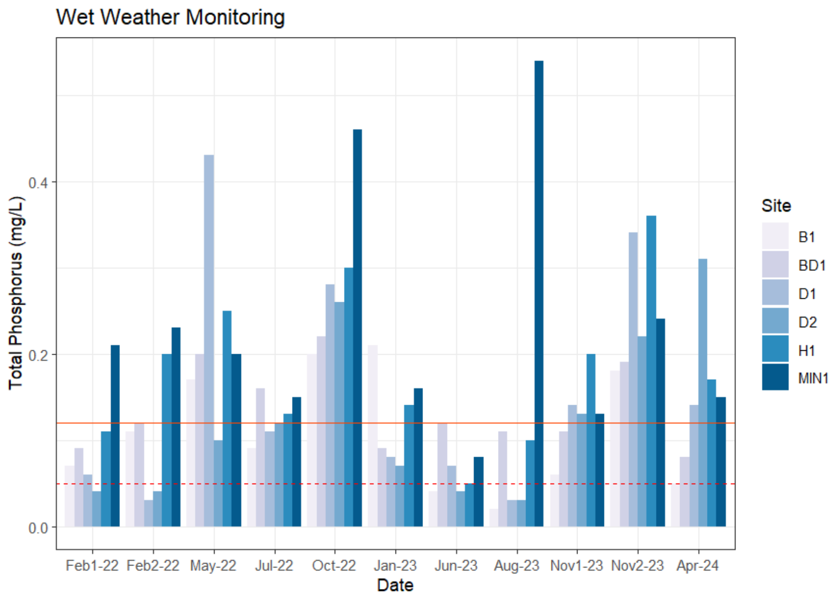

Figure 246: Total phosphorus (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Phosphate

Phosphate concentrations were variable across all Estuarine sites during dry weather monitoring for the 2021-24 period. MIN1, BD1, and B1 had the widest range of values (Figure 247).

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at H1 and MIN1 (Figure 248).

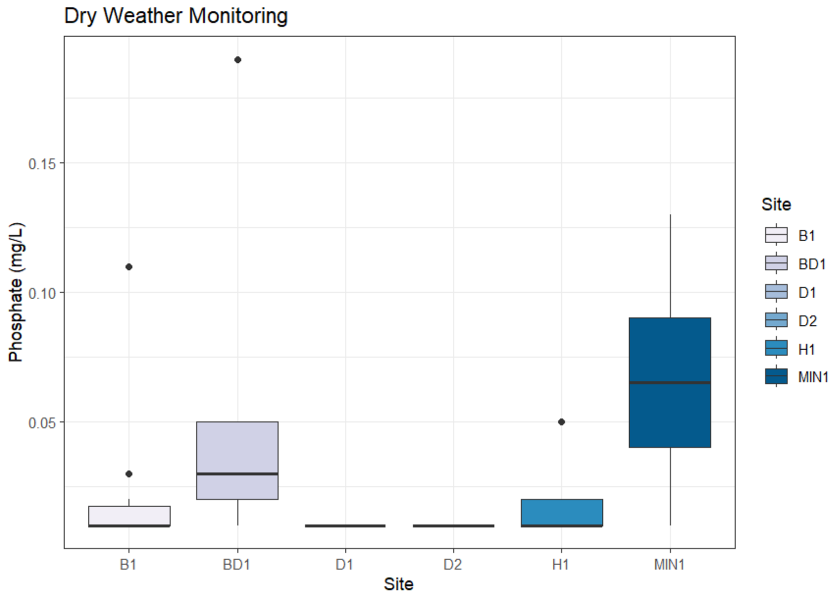

Figure 247: Summary of phosphate (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

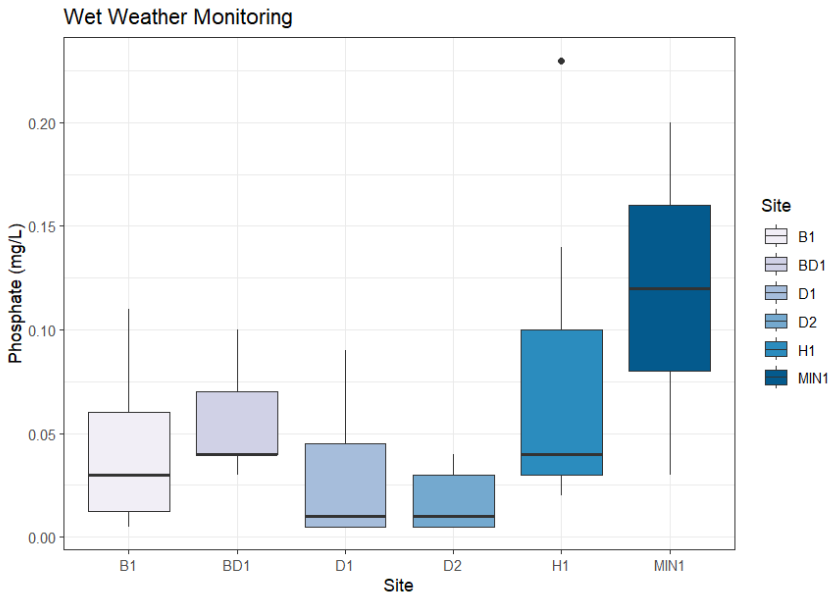

Figure 248: Summary of phosphate (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, phosphate concentrations at the Estuarine sites exceeded the ANZECC (2000) guideline (0.02 mg/L) on 33 occasions (Figure 249). This included at B1 on four occasions (in January 2022, February 2023, April 2023, and October 2023), and BD1 on 13 occasions (excluding June 2022). Levels at H1 were also above the guideline for five monitoring events (in February 2022, April 2022, December 2022 and 2023, and October 2023), and at MIN1 on 11 occasions (excluding in April 2022 and 2023, and October 2023). The highest phosphate concentration was recorded at BD1 in August 2022 (0.19 mg/L). The median phosphate for Estuarine sites (0.01 mg/L) during dry weather monitoring was below the ANZECC (2000) guidelines.

During wet weather monitoring, phosphate levels were compliant with the ANZECC (2000) guideline on 15 occasions (Figure 250). Compliance occurred at B1 on three occasions (during both February 2022 and the June 2023 events), at D1 and D2 on six occasions (in during both February 2022 events, July 2022, January 2023, June 2023, and August 2023). The highest phosphate concentration was recorded at H1 in November 2023 (0.23 mg/L). The median phosphate for Estuarine sites (0.03 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

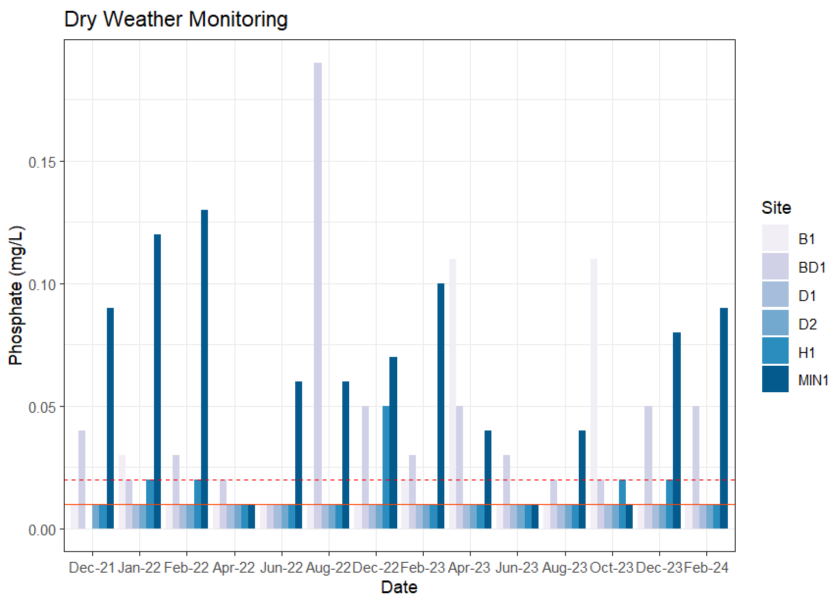

Figure 249: Phosphate (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

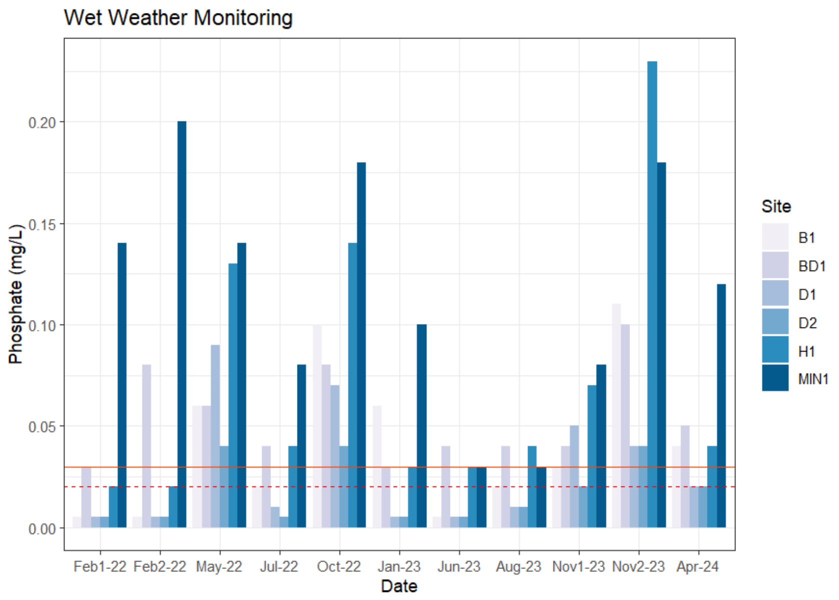

Figure 250: Phosphate (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Total Suspended Solids

Total Suspended Solids were within a narrow range across all Estuarine sites during dry weather monitoring for the 2021-24 period. However, all sites experienced events where levels were elevated, as shown by the outliers present, and this was highest at MIN1 (Figure 251).

During wet weather monitoring, the ranges of total suspended solids still largely overlapped for all sites, but were wider at all sites (Figure 252).

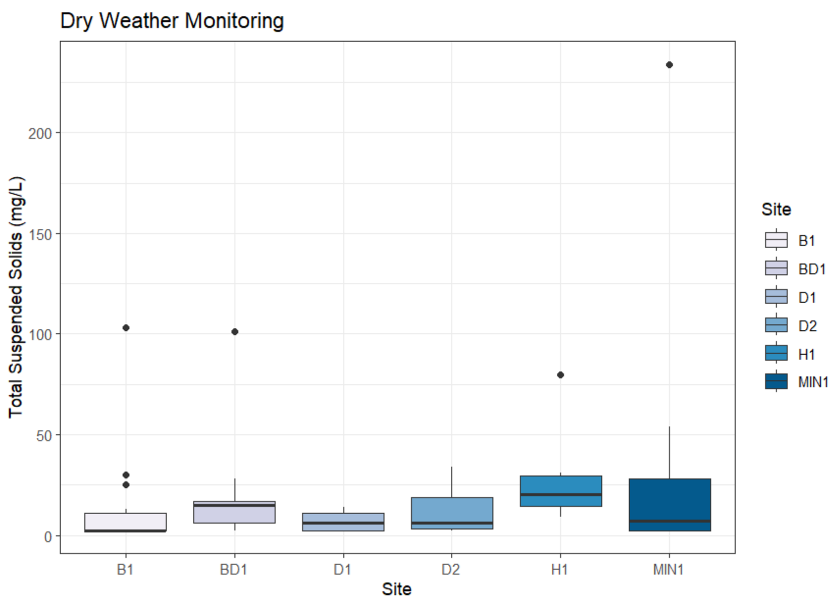

Figure 251: Summary of total suspended solids (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

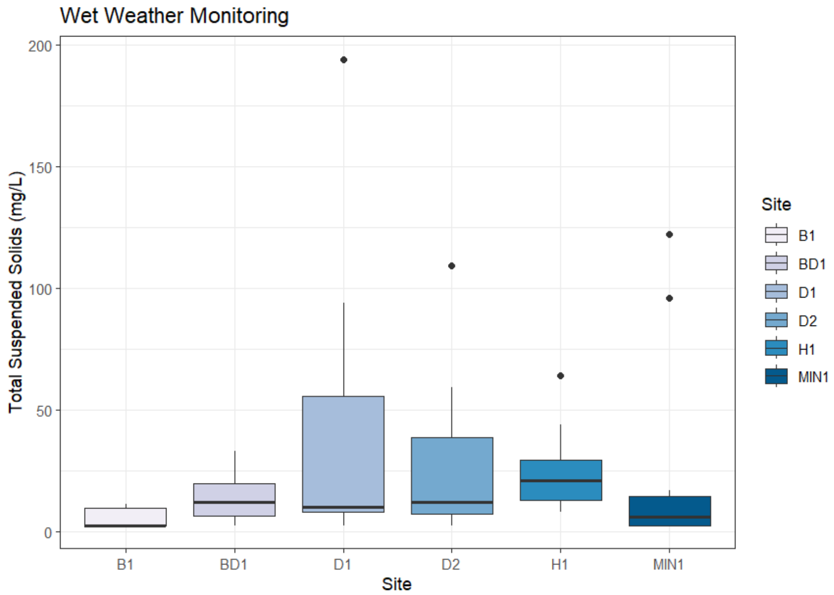

Figure 252: Summary of total suspended solids (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, total suspended solids remained relatively low at the majority of Estuarine sites (Figure 253). The highest value was recorded at MIN1 in April 2023 (234 mg/L), followed by B1 in February 2024 (103 mg/L), however, these events were not linked with high rainfall (as shown in Table 3). The median total suspended solids for Estuarine sites was 9.00 mg/L during dry weather monitoring. There are currently no ANZECC (2000) guidelines for total suspended solids.

During wet weather monitoring, total suspended solids showed a slight decrease compared to dry weather monitoring events (Figure 254). The highest values were recorded at D1 in November 2023 (194 mg/L), which was more in line with the maximum values recorded in dry weather monitoring. The median total suspended solids for Estuarine sites was 10.00 mg/L during wet weather monitoring.

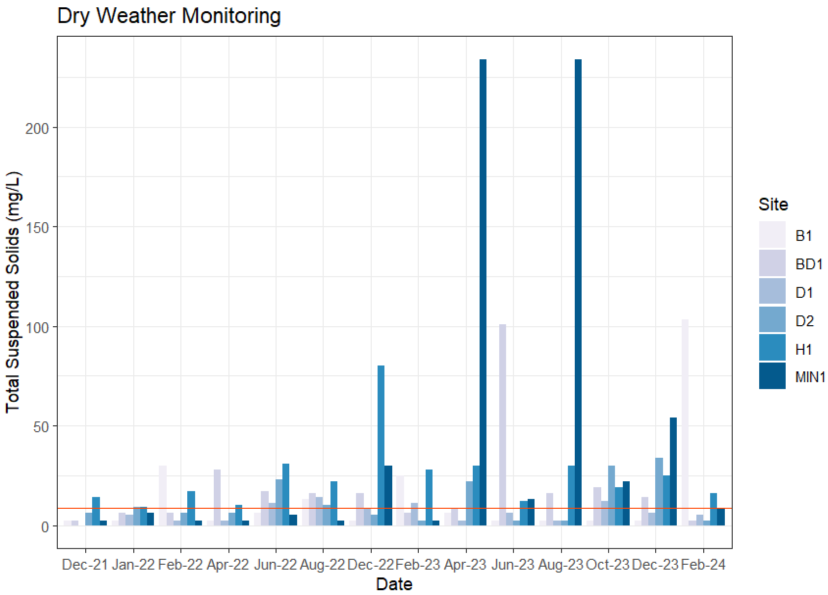

Figure 253: Total Suspended Solids (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The solid orange line represents the median for this catchment.

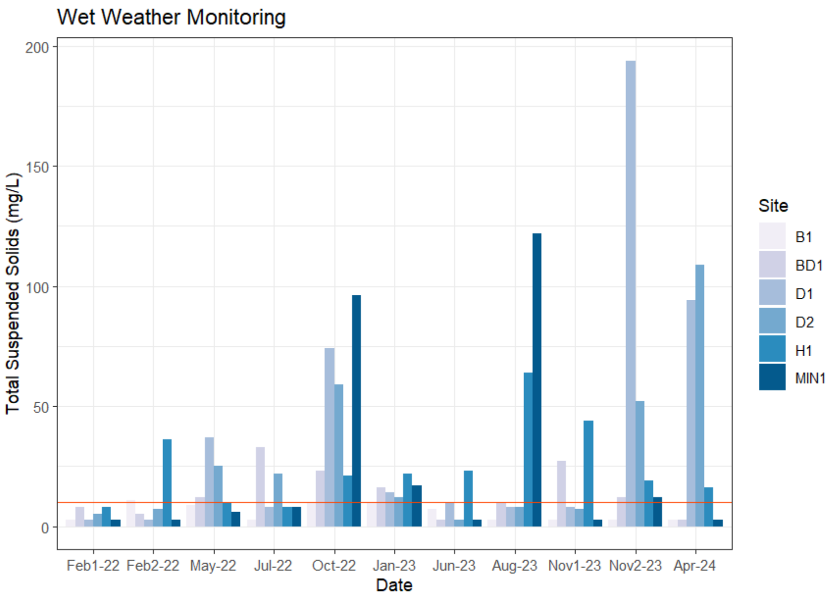

Figure 254: Total Suspended Solids (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The solid orange line represents the median for this catchment.

Chlorophyll-a

Chlorophyll-*a* concentrations were variable across all Estuarine sites during dry weather monitoring for the 2021-24 period. However, sites experienced events where chlorophyll-*a* was elevated, as shown by the outliers present, and this was highest at B1 and H1 (Figure 255). High nutrient availability and environmental conditions (including warmer temperatures, low rainfall to reduce flushing of the system, and high light penetration to promote photosynthesis) contribute to elevated levels of chlorophyll-*a* in waterways.

During wet weather monitoring, there was more variability within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at MIN1 (Figure 256).

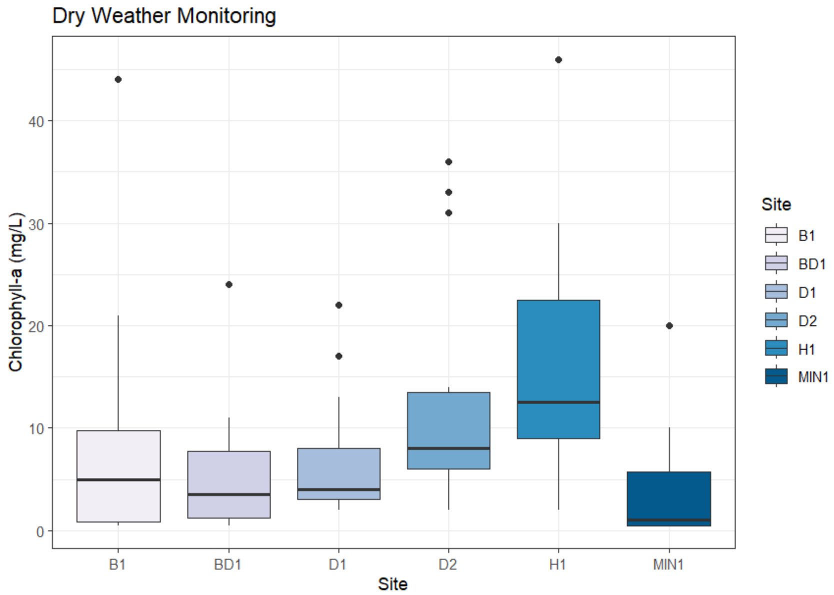

Figure 255: Summary of chlorophyll-*a* (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

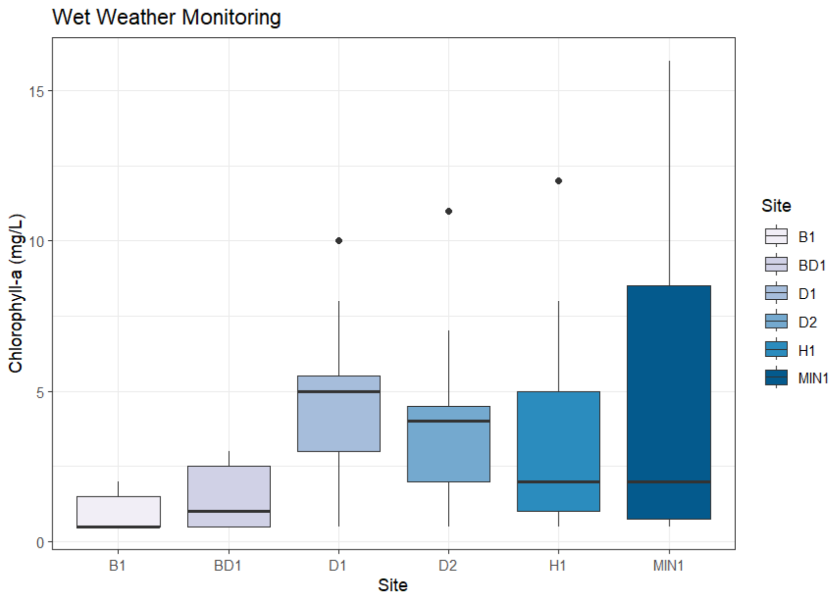

Figure 256: Summary of chlorophyll-*a* (mg/L) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, chlorophyll-*a* levels at all the Estuarine sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events (Figure 257). Chlorophyll-*a* levels were highest at H1 in June 2022 (46 mg/L), followed by B1 in February 2023 (44 mg/L). The median chlorophyll-*a* for Estuarine sites (6 mg/L) during dry weather monitoring was 1200 mg/L times higher than the ANZECC (2000) guidelines.

During wet weather monitoring, chlorophyll-*a* levels at all the Estuarine sites exceeded the ANZECC (2000) guideline of 0.005 mg/L for all sampling events but were lower than dry weather monitoring events (Figure 258). Chlorophyll-*a* levels were highest at MIN1 in February 2022 with 16 mg/L, followed by 14 mg/L in August 2023. The median chlorophyll-*a* for Estuarine sites (2 mg/L) during wet weather monitoring was above the ANZECC (2000) guidelines.

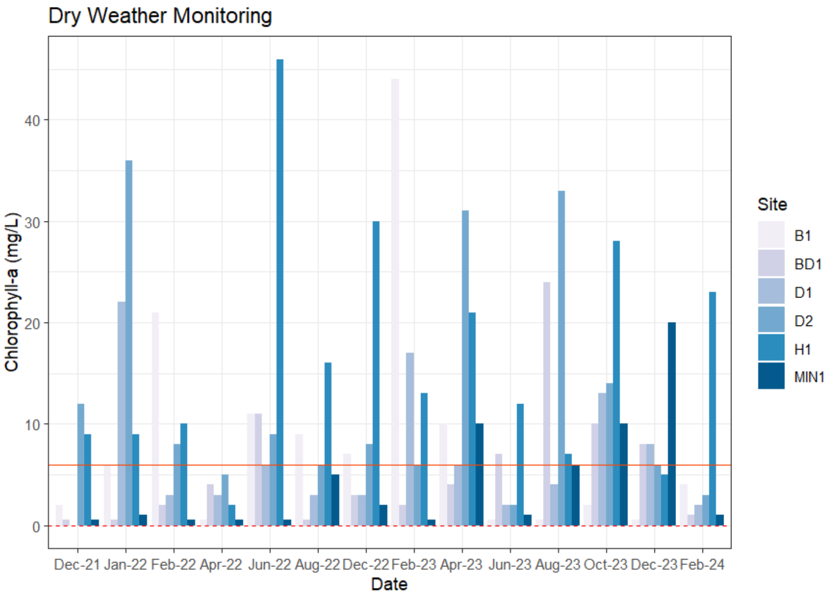

Figure 257: Chlorophyll-*a* (mg/L) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

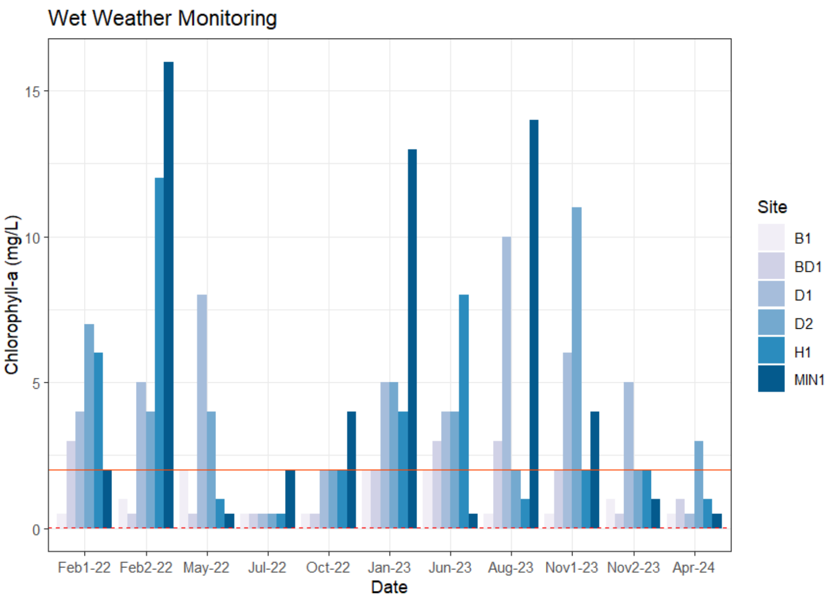

Figure 258: Chlorophyll-*a* (mg/L) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) guideline for lowland rivers is shown as the dashed red line. The solid orange line represents the median for this catchment.

Enterococci

Enterococci concentrations were variable across all Estuarine sites during dry weather monitoring for the 2021-24 period. However, all sites experienced events where *Enterococci* was elevated, as shown by the outliers present (Figure 259).

During wet weather monitoring, variability also occurred within each site. However, ranges still largely overlapped for all sites, and the highest range was recorded at B1 (Figure 260).

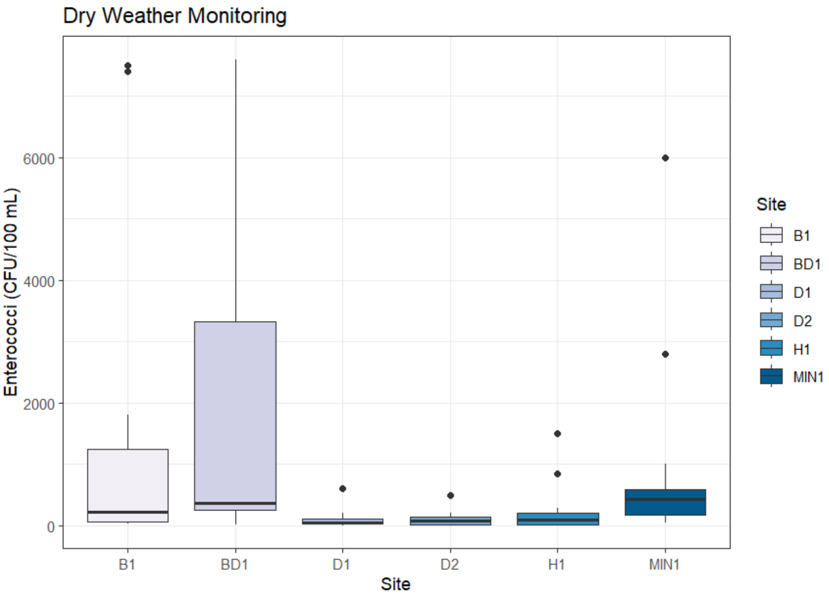

Figure 259: Summary of *Enterococci* (CFU/100 mL) at Estuarine sites during dry weather monitoring events from December 2021 to April 2024.

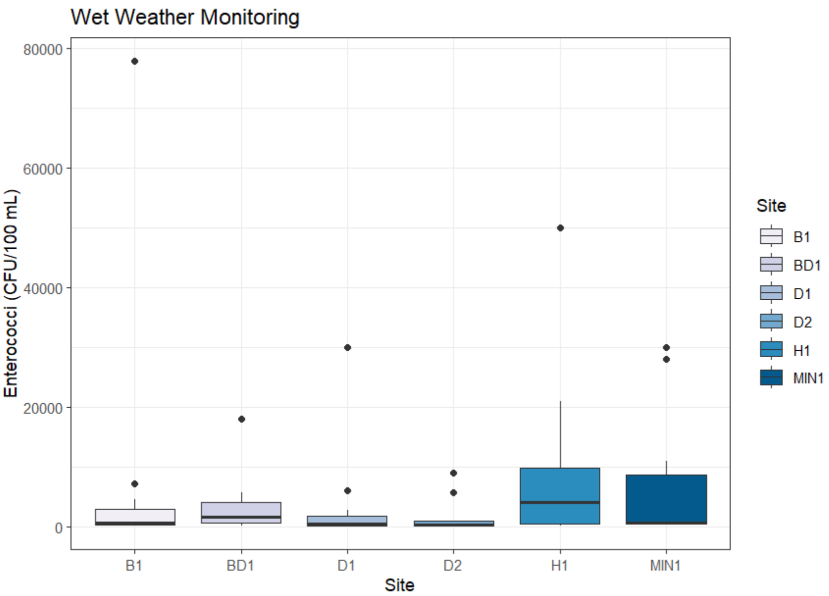

Figure 260: Summary of *Enterococci* (CFU/100 mL) at Estuarine sites during wet weather monitoring events from December 2021 to April 2024.

During dry weather monitoring, *Enterococci* at the Estuarine sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 32 occasions (Figure 261). This included at B1 on six occasions (in January 2022, April 2022, August 2022, February 2023 and 2024, and June 2023), and BD1 on two occasions (in January and June 2022). At D1, the primary guideline was exceeded on six occasions (in January 2022, February 2023 and 2024, April 2023, June 2023, and December 2023). D2 was above the guideline on seven occasions (in December 2021 and 2023, February 2022 and 2023, April 2022, June 2023, and October 2023). For site H1, the primary guideline was exceeded on six occasions (in February 2022 and 2023, April 2022 and 2023, October 2023, and December 2023). At MIN1, Enterococci levels were in excess of the primary guideline on five occasions (in January, February, April, June, and August 2022).

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 32 occasions. This included at B1 on seven occasions (in December 2021, 2022, and 2023, February 2022, April 2023, August 2023, and October 2023). BD1 was non-compliant on 11 occasions (in December 2021, 2022, and 2023, February 2022, 2023, and 2024, April 2022 and 2023, August 2022 and 2023, and October 2023). D1 exceeded the secondary contact guidelines in October 2023, as did D2 in February 2024, and H1 on three occasions (in December 2021, January 2022, and August 2023). At MIN1, Enterococci levels were in excess of the secondary guideline on nine occasions (in December 2021, 2022, and 2023, February 2023 and 2024, April 2023, June 2023, August 2023, and October 2023).

The median *Enterococci* for Estuarine sites (140 CFU/100 mL) during dry weather monitoring was above the primary contact ANZECC (2000) guidelines, but did not exceed the secondary contact guidelines.

During wet weather monitoring, *Enterococci* levels at the Estuarine sites were non-compliant with the ANZECC primary contact guideline (35 CFU/100 mL) on 12 occasions (Figure 262). This included at B1 on two occasions (in February 2022 and June 2023), at BD1 in February 2022, and at D1 on three occasions (in February 2022, July 2022, and August 2023). The primary guideline was also exceeded at D2 on four occasions (during both February 2022 events, July 2022, and January 2023), at H1 in April 2024, and at MIN1 in February 2022.

Enterococci levels were non-compliant with the ANZECC secondary contact guideline (230 CFU/100 mL) on 50 occasions. This included at B1 on nine occasions (in February 2022, May 2022, July 2022, October 2022, January 2023, August 2023, both November 2023 events, and April 2024). At BD1, the secondary guideline was exceeded on ten occasions (including in February 2022, May 2022, July 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024). For site D1, the secondary guideline was exceeded on six occasions (in May 2022, October 2022, January 2023, both November 2023 events, and April 2024). At D2, Enterococci levels were in excess of the secondary guideline on six occasions (in July 2022, October 2022, August 2023, both November 2023 events, and April 2024). For site H1, the secondary guideline was exceeded on nine occasions (in February 2022, May 2022, July 2022, October 2022, January 2023, June 2023, August 2023, and both November 2023 events). At MIN1, the primary guideline was exceeded on ten occasions (in February 2022, May 2022, July 2022, October 2022, January 2023, June 2023, August 2023, both November 2023 events, and April 2024).

The median *Enterococci* for Estuarine sites (655 CFU/100 mL) during wet weather monitoring was above the primary and secondary contact ANZECC (2000) guidelines, which is approximately 35 times higher than the primary and three times higher than the secondary contact guidelines. The maximum wet weather value recorded at B1 in October 2022 (78,000 CFU/100 mL). This indicates a significant source of *Enterococci* to the system.

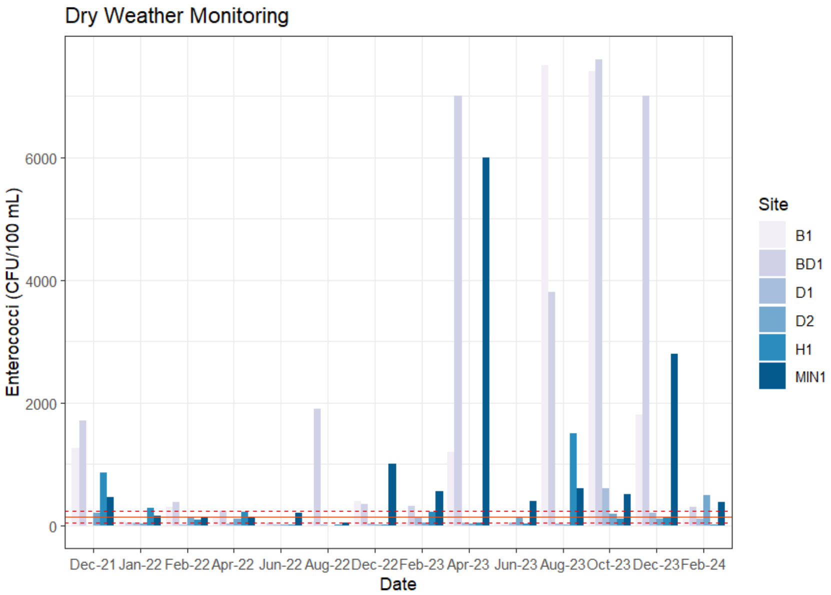

Figure 261: *Enterococci* (CFU/100 mL) at Estuarine sites during dry weather monitoring events from December 2021 to February 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

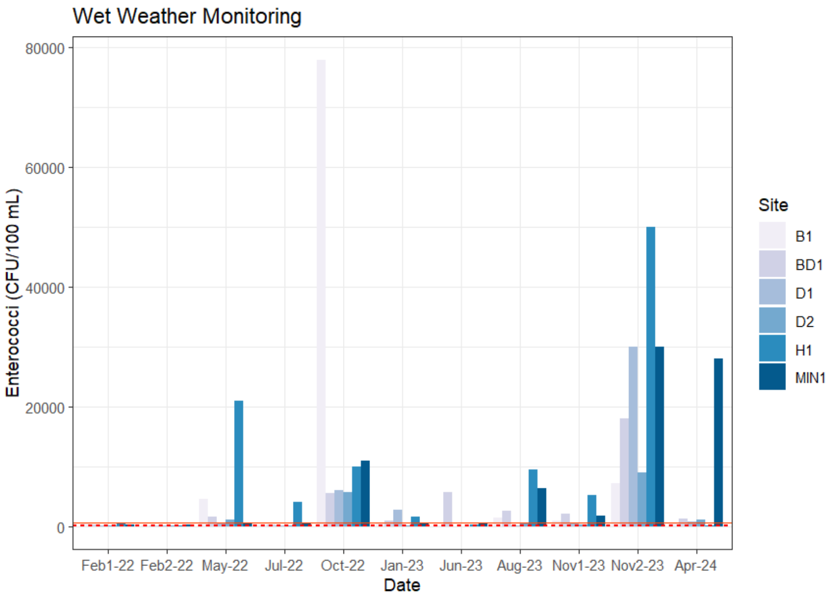

Figure 262: *Enterococci* (CFU/100 mL) at Estuarine sites during wet weather monitoring events from February 2022 to April 2024. The appropriate ANZECC (2000) primary and secondary contact guidelines shown as the dashed red lines. The solid orange line represents the median for this catchment.

Discussion

Water quality across the waterways of the Lake Illawarra catchment showed variations between sites and over time in response to dry and wet weather monitoring events, and this is linked with catchment land use and the degree of urbanisation. Comparison of median water quality results from the waterway sites with the appropriate ANZECC (2000) guidelines shows all sites were non-compliant with at least one water quality guideline throughout the monitoring period.

A longitudinal trend was evident, particularly when overall site grades are analysed. Water quality in the streams and rivers of the Lake Illawarra catchment ranged from ‘good’ to ‘fair’, with most sites experiencing ‘fair’ water quality (Figure 2). The relatively healthy scores experienced by waterways within the Lake Illawarra catchment are influenced by naturally vegetated areas present at the headwaters of streams that flow into Lake Illawarra. However, sites within the upper regions of the Lake Illawarra catchment still experience impacted water quality due to rural land use pressures and the presence of stock near waterways, with elevated nutrients and biological indicators such as *Enterococci*.

Moving downstream, land use becomes more intense, shifting from bushland, to farmland and to the urban environment. The downstream transition to more intense land use corresponds to a reduction in water quality. This deteriation of water quality is most evident at Mullet Creek and Macquarie Rivulet. The uppermost site (SCC5) on Macquarie Rivulet recorded the highest water quality grade of all of the sampling sites, with a grade of B+ (good water quality). The headwaters of the Mullet Creek catchment (M5 and F1) were graded with scores of B and B+ respectively and are consided to experience fair to good water quality. Downstream, Mullet Creek sites transition to lower scores of C- at M2. However, M1 received a score of B-. The lowest water quality grade was C- (fair water quality), and this was observed at four sites (BD1, M2, MIN1, and SCC2), all of which were in the lower catchment sections. At the southern end of Lake Illawarra, sites SCC4, SCC3, SCC2 and SCC1 recorded scores ranging from C+ to C-.

During the 2021-2024 monitoring period, median pH was compliant (excluding on one occasion at M5) and median electrical conductivity was largely non-compliant in waterways across the Lake Illawarra catchment. These water quality parameters are often elevated in urban waterways (including those in Sydney, e.g., Reid and Tippler, 2019), with dissolution from extensive concrete infrastructure in urban landscapes potentially contributing to such elevation (e.g., Tippler *et al*., 2014). Electrical conductivity was particularly high across the majority of sites and sampling events within the Lake Illawarra catchment, however, this is due to the influence of saline water as the estuary is brackish.

Dissolved oxygen was frequently non-compliant with the ANZECC (2000) guidelines at most sites, with many sites exhibiting dissolved oxygen levels well below the lower guideline value of 85%. This poses a concern for aquatic species, including fish, invertebrates, and aerobic microorganisms, which depend upon oxygen dissolved in the water for efficient functioning. High nutrient levels, as observed across all sites within the Lake Illawarra catchment, can result in eutrophication, whereby excess plant and algal growth occurs, and available oxygen is depleted in waterways as these materials decompose (Tippler *et al.*, 2012). The sites with the lowest median dissolved oxygen during dry weather monitoring were MIN1 (33.30%), SCC1 (43.20%), M2 (43.40%), RE1 (43.50%), and SCC3 (48.60%). During wet weather monitoring, median dissolved oxygen was lowest at BD1 (53.25%) and H1 (57.20%).

Median turbidity was compliant with the region-specific guideline across all sites. However, turbidity was variable at all sites and outlier events where turbidity was elevated occurred across the monitoring period.

Turbidity can be elevated where there is increased erosion of fine sediment and reduced where banks are reinforced with concrete or other hard materials that are resistant to erosion. However, using hard materials to stabilise banks acts to direct higher flows downstream, which increases erosive power of stormwater flows as they travel through unconsolidated reaches.

Most sites experienced elevated nutrients that did not comply with the ANZECC (2000) guidelines. This included high non-compliance for total nitrogen, ammonia, NOx, total phosphorus, and phosphate and across both dry and wet weather monitoring (with increased non-compliance during wet weather events). This highlights that waterways within the Lake Illawarra catchment are a notable source of nutrients to this system. Nutrient levels were in line with those recorded in urban catchments in the wider Sydney region. For comparison, Tippler *et al*. (2012) found average TN and TP to be 1.2 mg/L and 0.15 mg/L, respectively, in highly urban waterways across the Georges River catchment. High flows and the presence of frequent flushing due to elevated rainfall, runoff and stormwater can introduce nutrients, pollutants, and sediments (often at very high concentrations) to waterways. This increase in nutrient availability can increase microbial activity, which often results in oxygen depletion. The combination of high nutrients and low dissolved oxygen results in the stream or pools going into a eutrophic state (Yang *et al*., 2008). This is highlighted by the low dissolved oxygen results observed across the Lake Illawarra catchment monitoring sites.

Median concentrations of chlorophyll-*a* did not comply at all sites during the monitoring period and were consistently elevated above the ANZECC (2000) guidelines at all sites. For example, the median chlorophyll-*a* for Estuarine sites (6 mg/L) during dry weather monitoring was 1200 mg/L times higher than the ANZECC (2000) guidelines. During dry weather monitoring, H1 (12.50 mg/L) had the highest median levels, and during wet weather monitoring D1 (5.00 mg/L) was the most significant contributor of chlorophyll-*a*. Environmental conditions, including warmer temperatures, low rainfall to reduce flushing of the system, and high light penetration to promote photosynthesis, in addition to high nutrient availability (which was common across all Lake Illawarra sites) to support plant and algal growth, contribute to elevated levels of chlorophyll-*a* in waterways.

Monitoring sites across the Lake Illawarra catchment also frequently exceeded the ANZECC (2000) primary and secondary contact guidelines for *Enterococci*. During dry weather monitoring, one site (RE1) was compliant with the guidelines, 17 sites recorded Enterococci that exceeded the ANZECC (2000) primary contact guideline, and three sites exceeded the secondary contact guideline. The highest median *Enterococci* values for dry weather monitoring were observed at SCC2 (750 CFU/100 mL), MIN1 (425 CFU/100 mL), and SCC4 (260 CFU/100 mL). During wet weather monitoring, one site recorded *Enterococci* that exceeded the ANZECC (2000) primary contact guideline (M5), and the remaining 20 sites exceeded the secondary contact guideline. The highest median *Enterococci* values during wet weather monitoring were at H1 (4000 CFU/100 mL), SCC4 (2100 CFU/100 mL), and BD1 (1600 CFU/100 mL). This highlights the link between rainfall events, stormwater impacts, and elevated *Enterococci* concentrations.

Analysis of Bacteroides using molecular markers was conducted twice during the 2022-2023 period at ten targeted sites. This included analysis of human bacteroides, which can reflect evidence of human faecal contamination such as sewage leaks and stormwater, and animal bacteroides (all animals excluding rumiants), which show evidence of faecal contamination of water sources by animals (Bernhard and Field, 2000; Reischer *et al.*, 2006; Stapleton *et al*., 2009). Microbial faecal contamination by ruminants (which are herbivorous mammals with more than one stomach such as cows and deer) was also assessed. Animal bacteroides, particularly the occurrence of ruminant bacteroides, were also detected across the Lake Illawarra catchment. The highest detected animal bacteroide levels occurred at SCC5 (37,000 copies/mL) in August 2023, whereas the highest concentration in April 2023 was at M5 (2300 copies/mL). This is also reflected in the high ruminant bacteroides value (25,000 copies/mL and 16,000 copies/mL) at these two sites respectively. This is in line with expectations as agricultural land use and livestock, including cows, are found in the Macquarie Rivulet and Mullet Creek catchments. It also likely the high density of feral deer in the Illawarra is contributing to this.

Human bacteroides were also detected (but at lower concentrations relative to animal bacteroides) across the ten sites sampled. The highest level of human bacteroides was detected at RE1 in August 2023, with 29 copies/mL. Sources of human bacteroides include potential sewage leaks and stormwater runoff into waterways. Whilst large development is occurring within the Lake Illawarra catchment, the impact of rural activities is still significant, and this is highlighted by these findings.

For each catchment there was an overall trend of a reduction in water quality moving downstream. However, sites in the upper reaches of each catchment also showed non-compliance with ANZECC (2000) guidelines. For example, within the Mullet Creek catchment during dry weather median pH and NOx were highest in the upper reaches, median dissolved oxygen was lowest and *Enterococci* was highest in the mid-catchment, and the lower reaches had the highest median electrical conductivity (which is expected as this site is estuarine), ammonia, total nitrogen, total phosphorus, total suspended solids, and chlorophyll-*a*. Turbidity and phosphate were low across the catchment. For wet weather monitoring, these trends were consistent, however, median dissolved oxygen was lowest, and NOx and *Enterococci* were highest in the lower sections of the catchment.

For the Macquarie Rivulet catchment during dry weather, median NOx was highest in the upper reaches, whereas the lower reaches had the highest median pH, electrical conductivity (which is expected due to estuarine conditions), dissolved oxygen, turbidity, total phosphorus, total suspended solids, phosphate, chlorophyll-*a*, and *Enterococci*. Ammonia and total nitrogen were highest at the entrance to Lake Illawarra (SCC4). For wet weather monitoring, these trends were consistent with dry weather monitoring, however, turbidity, total phosphorus, phosphate, total suspended solids, and *Enterococci* were highest at the entrance to Lake Illawarra.

For the Robins Creek catchment, the parameters that were highest during dry weather monitoring in the lower catchment were median pH, turbidity, NOx, and total suspended solids, whereas median dissolved oxygen was lower and median electrical conductivity, ammonia, total phosphorus, chlorophyll-*a*, and *Enterococci* were higher in the mid-catchment at R2. Total nitrogen and phosphate were consistent across these two sites. For wet weather monitoring, these trends were consistent, however, median dissolved oxygen, NOx, total suspended solids, and *Enterococci* were higher in the lower catchment.

For the Reid Creek catchment during dry weather monitoring, median electrical conductivity, turbidity, ammonia, NOx, total nitrogen, total phosphorus, total suspended solids, and chlorophyll-*a* were highest in the lower catchment (at RE1), whereas median pH, dissolved oxygen, and *Enterococci* were higher in the upper catchment (at R3). Phosphate was consistent across these two sites. For wet weather monitoring, these trends were consistent, however, median dissolved oxygen, NOx, and *Enterococci* were higher in the lower catchment.

For the Estuarine sites during dry weather monitoring, median electrical conductivity, dissolved oxygen, turbidity, ammonia, NOx, total nitrogen, total phosphorus, total suspended solids, chlorophyll-*a*, and *Enterococci* were highest in the lower catchment sites compared to the mid-catchment (at D2). The maximum pH was similar between the lower and mid-catchment sites, and phosphate was consistent across these two sites. For wet weather monitoring, these trends were consistent, however, median dissolved oxygen was higher in the mid-catchment.

Overall, these findings highlight that whilst urban areas reflect a significant contribution of contaminants to the sites in the lower region of the Lake Illawarra catchment, sites in the upper reaches of the catchment that experience rural land use also are sources of degraded water quality. Across all sites within the Lake Illawarra catchment, sites in the lower catchment area had consistently higher electrical conductivity (which is expected due to estuarine conditions), nutrient concentrations (including ammonia, NOx, total nitrogen, and total phosphorus), total suspended solids, turbidity, chlorophyll-a, and *Enterococci*. These sites are located in predominantly urban, peri-urban, and industrial areas of the catchment. During wet weather, there was an increase in nutrients (particularly NOx), total suspended solids, and *Enterococci* in lower catchment sites. This reflects nutrients and biological contaminants being washed downstream into the Lake Illawarra system following rainfall. Conversely, pH and NOx were higher in sites located in the upper reaches of the catchment, which have higher vegetation cover in the catchment but also includes rural land use.

During dry weather monitoring, the catchments with the highest median values that reflect a significant contribution to the Lake Illawarra catchment for each assessed parameter were Reid Creek for pH and turbidity, whereas electrical conductivity, ammonia, NOx, and *Enterococci* were highest for the Macquarie Rivulet catchment, and Estuarine sites had the lowest dissolved oxygen and the highest total nitrogen, total phosphorus, chlorophyll-*a*, and total suspended solids. Phosphate was low across all sites during dry weather monitoring. During wet weather monitoring, Mullet Creek had the highest median pH, whereas median turbidity, ammonia, NOx, total nitrogen, and *Enterococci* were highest at Reid Creek sites. Estuarine sites had the lowest dissolved oxygen and the highest electrical conductivity, total phosphorus, phosphate, and total suspended solids. Total nitrogen and chlorophyll-*a* were both elevated at sites within the Reid Creek and Estuarine catchments.

Degraded water quality reflects the pressures that urbanisation and industrialisation exert on waterways. The "urban stream syndrome" is used to describe the multiple environmental problems which typify the degradation of urban streams (Walsh *et al*., 2005). These symptoms include increased intensity of flow after rainfall, erosion, sedimentation, stream bed and bank scouring, and degraded water quality; all of which apply to waterways within the Lake Illawarra catchment. The driver of the urban stream syndrome is the proportion of catchment covered by impervious surfaces, such as roads, roofs, and car parks. Studies have shown that after 5% of a catchment is covered by impervious surfaces, the onset of stream degradation occurs (Walsh *et al*., 2006, Tippler *et al*., 2012, Belmer *et al*. 2015, 2016 and 2018). The Lake Illawarra catchment covers approximately 270 km^2, of which 54 km^2 (20%) is considered urban, 94 km^2 (35%) is rural, and 87 km^2 (32%) is naturally vegetated (Cardno Pty Ltd, 2012), however, increased development and population growth are occurring within this catchment (Wollongong City Council, 2022). The impacts of rural and agricultural land use can also impact water quality, for example contributing to elevated nutrient levels (such as ammonia, total nitrogen, total phosphorus, and total suspended solids), increased erosion due to stock access, and increasing the presence of faecal coliforms in waterways (Buck *et al.*, 2004). This is in line with conditions observed across the Lake Illawarra catchment, as nutrients, *Enterococci* and bacteroides (particularly from ruminants) were detected in the upper reaches of the catchment in rural land use areas.

Conclusions

It is evident from results of the monitoring program that the majority of sites across the Lake Illawarra catchment had elevated nutrient levels, electrical conductivity and low dissolved oxygen levels, at times orders of magnitude higher than the recommended ANZECC guidelines. Such conditions in urban and peri-urban waterways are common and strongly associated with the urban stream syndrome. Bacterial contamination was also frequent and significantly exceeded the ANZECC primary and secondary contact guidelines, particularly at Estuarine sites, which poses a health risk if exposure or contact were to occur. Bacteroides are also present, with higher levels of animal bacteroides present in the rural areas of the catchment where livestock are present.

The primary purpose of this monitoring program is to establish a robust baseline of waterway conditions. As this data grows, it becomes possible to pinpoint sources of pollution and to identify changes. Collection of this data over time will provide Wollongong and Shellharbour City Councils with a solid foundation on which to base data driven waterway management decisions.

Recommendations

This monitoring program seeks to provide Wollongong City and Shellharbour City Councils with baseline water quality monitoring data for a number of environmentally and aesthetically important urban and rural creeks within the Lake Illawarra catchment. It is recommended that Wollongong and Shellharbour City Councils continue to build upon their waterway management program, to assist with current and future environmental management and development decisions. This includes incorporating the assessment of aquatic macroinvertebrates, algal diatoms, nutrient speciation, and biological speciation into the water quality monitoring program. The inclusion of these parameters will assist to provide a more detailed snapshot of the condition of the waterways across the Lake Illawarra catchment.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates are widely used for biological assessment of rivers and streams. The popularity of macroinvertebrates in ecosystem disturbance studies stems from their high abundance and diversity, sensitivity to changes in water quality, flow regime and habitat conditions, ease of sampling, a relatively good understanding of their taxonomy, and ecological requirements, and an ability to detect long-term impacts.

Biological assessment provides information on the biological or ecological characteristics of a waterway and monitors changes resulting from water quality, changes in the physical habitat such as increased fine sediment deposition, or changes in hydrology or from biological interactions, such as the introduction of exotic species or diseases.

Stream biota have often been used to detect and measure the degree of impairment of stream ecosystems due to urbanisation (Walsh *et al*., 2004; Chessman, 2003; Tippler *et al*., 2012) and freshwater macroinvertebrates are widely adopted as effective and sensitive indicators of the ecological condition of freshwater ecosystems (Beavan *et al*., 2001; Paul and Meyer, 2001; Walsh *et al*., 2004). Identification of macroinvertebrates to the family and order level has been demonstrated to generate sufficient information for impact identification (Wright *et al*., 1995). It is recommended that aquatic macroinvertebrates be incorporated into the assessment of Lake Illawarra catchment waterways as part of a broad scale biological assessment of ecosystem health of the waterways.

Algal diatoms

Benthic diatoms are a form of algae with cell walls made of hydrated silicon dioxide and grow as single cells or form filaments and simple colonies. Benthic diatoms are a useful biological indicator of water quality conditions because, unlike macroinvertebrates, they are less influenced by instream habitat and respond subtly to changes in water quality, particularly nutrient enrichment (Dalu *et al*., 2020). To interpret results of diatom samples, the metrics of relative abundance, diversity, and Trophic Diatom Index (TDI) (Lecointe *et al*., 1993; Kelly and Whitton, 1995; Kelly, 1998) provide an assessment of the trophic status of freshwaters. The higher the TDI, the more eutrophic (i.e. nutrient enriched) the assessed water body.

Nutrient speciation

Various sources of contamination contribute nutrients to waterways, including from fertiliser, wastewater, stormwater runoff, leaking septic tanks, manure from livestock, animal wastes, and discharges from car exhausts. Excessive quantities of nutrients in waterways can result in eutrophication events, contribute to excessive plant growth and depleted oxygen conditions, which can have significant ecological consequences (ANZECC, 2000; Yuen and Chew, 2010; Day *et al.,* 2014). It is recommended that nutrient speciation is assessed as part of this monitoring program to increase understanding of sources and types of contamination and their availability across waterways within the Lake Illawarra catchment.

Biological speciation

Analysis of Bacteroidales can be used to assist to differentiate between sources of faecal contamination, including whether it is derived from human or animal sources (Bernhard and Field, 2000; Reischer *et al.*, 2006; Stapleton *et al*., 2009). This information is useful to better understand the potential sources of contamination that may be occurring within a catchment and waterway, and the risks that this may pose to waterways users. Bacteroidales were assessed during two monitoring events during the 2022-2023 period. It is recommended that biological speciation be analysed on a yearly basis to increase understanding of sources of potential contamination across waterways within the Lake Illawarra catchment.

References

ANZECC (Australian and New Zealand Environment and Conservation Council) (2000). *Australian and New Zealand guidelines for fresh and marine waters.* Australian and New Zealand Environment and Conservation Council, Canberra.

APHA (American Public Health Association) (1998). Standard methods for the examination of water and wastewater (20th ed.). Washington, DC: American Public Health Association.

Australian Government Bureau of Meteorology (BOM) (2024). Climate Statistics for Australian locations. http://www.bom.gov.au/climate/averages/tables/cw_067113.shtml

Beavan L, Sadler, J & Pinder, C (2001). The invertebrate fauna of a physically modified urban river. Hydrobiologia, 445: 97–108.

Beesley, L, Middleton, J, Quinton, B & Davies, PM (2019). Improving the ecological function of urban waterways: a compendium of factsheets. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia.

Belmer, N, Wright, IA & Tippler, C (2015). Urban Geochemical contamination of high conservation value swamps, Blue Mountains Australia, Water, Air and Soil Pollution.

Belmer, N, Wright, IA & Tippler, C (2016). Urban Swamp Syndrome: degradation of high conservation-value swamp from an urban catchment, Proceedings of the 8th Australian Stream Management Conference, Blue Mountains, New South Wales.

Belmer, N, Tippler, C & Wright, IA (2019). Aquatic Ecosystem Degradation of High Conservation Value Upland Swamps, Blue Mountains Australia, Water, Air and Soil Pollution 229:98.

Buck, O, Niyogi, DK & Townsend, CR (2004). Scale-dependence of land use effects on water quality of streams in agricultural catchments. Environmental Pollution, 130(2): 287-299.

Cairns, J Jr. & Pratt, JR (1993). A history of biological monitoring using benthic macroinvertebrates, in Freshwater Biomonitoring and Benthic Macroinvertebrates, Eds. (DM Rosenberg and VH Resh), Chapman and Hall, London and New York.

Cardno Pty Ltd (2012). Lake Illawarra Floodplain Risk Management Study. Prepared for Lake Illawarra Authority, Wollongong City Council & Shellharbour City Council.

Chessman, BC (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, BC (2003). New sensitivity grades for Australian river macroinvertebrates. Marine and Freshwater Research, 54: 95-103.

Chessman, BC, Thurtell, LA & Royal, MJ (2006). Bioassessment in a harsh environment: a comparison of macroinvertebrate assemblages at reference and assessment sites in an Australian inland river system. Environmental Monitoring and Assessment, 119: 303-330.

Chessman, BC, Gell, P, Newal, P, & Sonneman, J (2016). Standard Methods for Sampling Diatoms for the Monitoring and Assessment of Streams, The University of Adelaide, <https://www.adelaide.edu.au/diatoma/sampling/stm/>.

Clarke, KR & Ainsworth, M (1993). A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series, 92:205-219.

Clarke, KR (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117-143.

Dalu, T, Cuthbert, RN, Taylor, JC, Magoro, ML, Weyl, OLF, Froneman, PW & Wasserman, RJ (2020). Benthic diatom-based indices and isotopic biomonitoring of nitrogen pollution in a warm temperate Austral river system. Science of the Total Environment, 748: 142452.

Davies, PJ, Wright, IA, Jonasson, OJ & Findlay, SJ (2010). Impact of concrete and PVC pipes on urban water chemistry. Urban Water Journal, 7(4): 233–241.

Day, C, Petroechevsky, A, Pellow, B, Bevan, J, O'Dwyer, T, StLawrence, A & Smith, G (2014). Managing a priority outlier infestation of Cabomba caroliniana in a natural wetland in the Blue Mountains, NSW, Australia – could this be eradication? 19th Australasian Weeds Conference, Hobart, Australia.

Georges River Combined Councils' Committee (GRCCC) (2017). Georges Rivers River Health Report Card 2016-17.

Gooderham, J & Tsyrlin, E (2002). The Waterbug Book, A guide to Freshwater Macroinvertebrates of Temperate Australia, CSIRO publishing, Collingwood, Victoria.

Hawking, JH (1994). A preliminary guide to keys and zoological information to identify invertebrates from Australian freshwaters. Cooperative Research Centre for Freshwater Ecology Identification Guide No. 2. Cooperative Research Centre for Freshwater Ecology, Albury.

Kelly, M & Whitton, G (1995). The Trophic Diatom Index: A new index for monitoring eutrophication in rivers. Journal of Applied Phycology, 7(4): 433-444.

Kelly, M (1998). Use of the trophic diatom index to monitor eutrophication in rivers. Water Research, 32(1):236-242.

Krebs, C (1989). Ecological methodology. New York: Harper Collins.

Lecointe, C, Coste, M & Prygiel, J (1993). "Omnidia": Software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia, 269-270(1): 509-513.

Paul, MJ & Meyer, JL (2001). Streams in the urban landscape. Annual Review of Ecology and Systematics, 32: 333-365.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reid, DJ & Tippler, C (2019). Access to Natural Substrates in Urban Streams Does Not Counter Impoverishment of Macroinvertebrate Communities: a Comparison of Engineered and Non-engineered Reaches. Water Air and Soil Pollution, 230: 8.

Rosenberg, DM & Resh, VH (1993). Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York, London.

Shellharbour City Council (2022). Local Strategic Planning Statement.

Tippler, C, Wright, IA & Hanlon, A (2012). Is Catchment Imperviousness a Keystone Factor Degrading Urban Waterways? A Case Study from a Partly Urbanised Catchment (Georges River, South-Eastern Australia). Water Air and Soil Pollution, 223: 5331–5344.

Tippler, C, Findlay, SJ, Wright, IA, Davies, PJ, Evans, C & Ahmed, M (2014). Does seasonality influence freshwater macroinvertebrate communities in the temperate paradise of Sydney? Proceedings of the 6th Australian Stream Management Conference, Townsville July 2014.

Tippler, C, Wright, IA, Davies, PJ & Hanlon, A (2014). The influence of concrete on the geochemical qualities of urban streams. Marine and Freshwater Research, 65: 1009-1017.

Walsh, CJ, Leonard, AW, Ladson, AR & Fletcher, TD (2004). Urban stormwater and the ecology of streams. Cooperative Research Centre for Freshwater Ecology and Cooperative Research Centre for Catchment Hydrology, Canberra.

Walsh, CJ (2006). Biological indicators of stream health using macroinvertebrate assemblage composition: a comparison of sensitivity to an urban gradient. Marine and Freshwater Research, 57(1): 37–47.

Wollongong City Council (2022). Our Wollongong Our Future 2032 Community Strategic Plan.

Wright, IA, Chessman, BC, Fairweather, PG & Benson, LJ (1995). Measuring the impact of sewage effluent of an upland stream: the effect of different levels of taxonomic resolution and quantification. Australin Journal of Ecology, 20: 142–149.

Yuen, KIP & Chew, SF (2010). Ammonia production, excretion, toxicity, and defense in fish: A review. Frontiers in Physiology, 134: 1–20.

Appendix 1: Site Photographs

Figure 263: B1.

Figure 264: BD1.

Figure 265: D1.

Figure 266: D2.

Figure 267: H1.

Figure 268: M1.

Figure 269: M2.

Figure 270: DA1.

Figure 271: F1.

Figure 272: M5.

Figure 273: MIN1.

Figure 274: R1.

Figure 275: R2.

Figure 276: RE1.

Figure 277: R3.

Figure 278: SCC1.

Figure 279: SCC2.

Figure 280: SCC3.

Figure 281: SCC4.

Figure 282: SCC5.

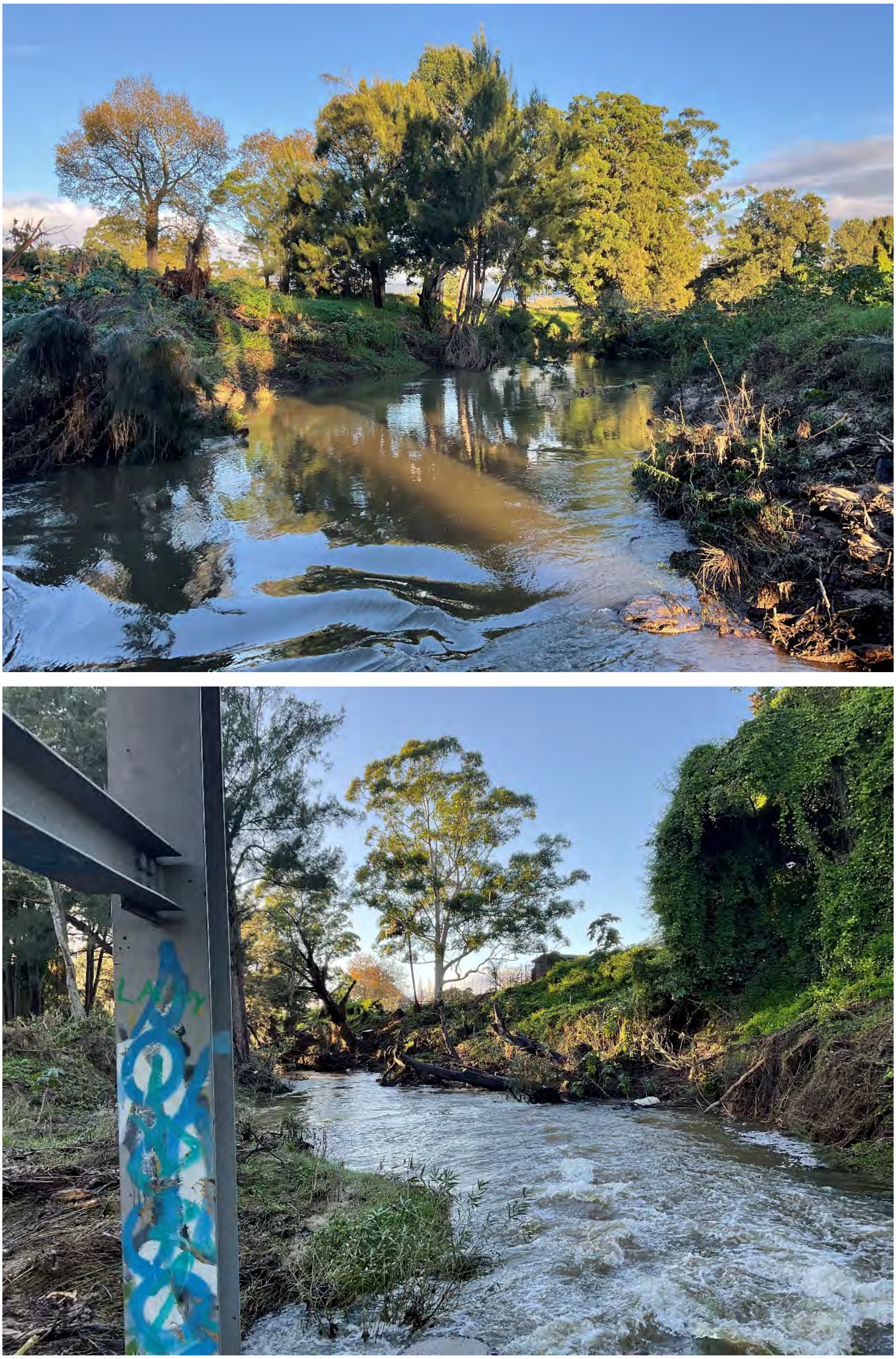

Figure 283: SCC6.

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