Sydney Water Aquatic Monitoring Program

Volume 1

Data Report 2023-24

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Sydney WATER

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Monitoring Services

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Executive Summary

Background

Sydney Water operates 23 wastewater systems and each system has an Environment Protection Licence (EPL) regulated by the NSW Environment Protection Authority (EPA). Each EPL specifies the minimum performance standards, and monitoring and reporting requirements.

The SWAM program (Sydney Water Aquatic Monitoring program) was endorsed by the EPA in April 2023 to replace the Sewage Treatment System Impact Monitoring Program (STSIMP, Sydney Water 2010). The overarching aim of the SWAM program is:

> *'To monitor the performance of Sydney Water's water resource recovery facility (WRRF) discharges and quantify the impacts (positive or negative) of these discharges, and sewer overflows and leakage, on the aquatic environment'.*

The outcomes of the STSIMP/SWAM programs are reported to the NSW EPA at regular intervals to fulfil EPL conditions (M5.1) and posted on Sydney Water's website.

The 2023-24 SWAM Data Report has been prepared to satisfy condition M5.1d of the EPLs. It consists of the following two volumes:

Volume 1 SWAM Data Report 2023-24 is the main volume of the 2023-24 report

It provides results using summary and inferential statistical methods to address sub-program specific objectives comparing the current year with relevant water/sediment quality objectives and the relevant historical record. It also provides a summary of treated wastewater quality and loads. This volume details the 'exceptions' where a significant trend is identified in the data (either positive or negative); the results exceed the EPL guideline limits and/or other relevant guidelines (ANZG 2018 or NHMRC 2008); or there is a likely receiving water impact caused by Sydney Water.

Volume 2 SWAM Data Report 2023-24 (Appendices).

It includes all wastewater and environmental monitoring data and statistical analysis summaries, and graphics. This volume is also supported by multiple electronic appendices of data summaries and raw data that have been shared with the EPA.

The format and structure of this SWAM 2023-24 Data Report has been revised to align with the new requirements (van Dam et al. 2023) where possible or where monitoring data permits. It incorporates a weight of evidence (WoE) approach in line with the *Australian and New Zealand Guideline for Fresh and Marine Water Quality* (ANZG 2018). The water quality and ecosystem health of the receiving environment was assessed using indicators/analytes from across the pressure, stressor and ecosystem receptor (P-S-ER) causal pathway elements. Three formal gated analysis workflows were followed in making these assessments:

- Gate 1: routine annual analysis
- Gate 2: determine the likelihood of receiving water impact caused by Sydney Water
- Gate 3: undertake more detailed analysis on cause, nature and magnitude of impacts.

Hawkesbury-Nepean River and tributaries

Pressure – WRRF effluent discharge quantity, quality and toxicity

Table ES-1-1 Summary of EPL concentration and load limit exceedances, together with statistically significant increasing and decreasing trends of Hawkesbury-Nepean River WRRFs

		Nutrients			Conventional analytes						Trace Metals										Others			
WRRF	Analytes	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC50 toxicity	Aluminium	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Selenium	Zinc	Diazinon	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Picton	Concentration	↗	→	↘	→		→		→															
	Load		(EPL limit exceedance)						(EPL limit exceedance)															
West Camden	Concentration	→	↗	→	→	→	→		→	→	→			→	→					→	→	→		
	Load																							
Wallacia	Concentration	→	↗	↗	→	→	→		→	→	→			→						→		→	→	
	Load																							
Penrith	Concentration	→	↗	↗	→		↗		→	→	→	→		↗	→					→		→		
	Load																							
Winmalee	Concentration	→	↘	↗	→	→	→		→	→	↗			↘	↘					→	→			
	Load																							
North Richmond	Concentration	↗ (EPL limit exceedance)	↗	↗	→		→		↗	→	↗			↗ (EPL limit exceedance)	→					→	→	→		
	Load																							
Richmond	Concentration	→	↗	↘	→	→	→		→	→														
	Load																							
St Marys	Concentration	↘	↗	↗	→	→	→		→	→	→			↗ (EPL limit exceedance)	→			↗		→	→	→		
	Load			(EPL limit exceedance)																				
Riverstone	Concentration	→	↘	→	→	→	→		→	→	→			→	→					→		→		
	Load			(EPL limit exceedance)																				
Quakers Hill	Concentration	↘	↘	↗	→	→	→		→	→	→	→	→	↗						→		→		
	Load			(EPL limit exceedance)																				
Rouse Hill	Concentration	→	↘	→	→	→	→		→	→	→			→	→					→				
	Load																							
Castle Hill	Concentration	→	↗	↘	→		→		→	→	↗ (EPL limit exceedance)	→		→	→					→	→	→		
	Load																							
West Hornsby	Concentration	→	↘	→	↘		→		→	→	→			→	→					↘		→		
	Load																							
Hornsby Heights	Concentration	→	↘	→	→		→		→	→	→			→	→					→	→	→		
	Load																							
Brooklyn	Concentration	→	→	↘	→		→		→	→														
	Load																							

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(EPL limit exceedance)	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

With the increasing pressure from a growing population and climate change, Sydney Water is challenged with:

- treating and discharging an increasing volume of wastewater
- aligning or managing treatment activities with more frequent and intense weather events.

Performance of WRRFs has been dominated by intense wet weather periods in the second half of the year between December 2023 and June 2024. The impact of wet weather, along with the reduced capacity of several Hawkesbury-Nepean facilities undergoing major capital upgrades has led to increasing trends in some analyte concentrations.

A total of six concentration EPL limit exceedances occurred from three Hawkesbury-Nepean WRRFs (90th percentile for ammonia nitrogen, average and 90th percentiles for copper at North Richmond; average and 90th percentile for copper at St Marys and average aluminium at Castle Hill) in 2023-24.

In addition, there were a total of three load EPL limit exceedances across four Hawkesbury-Nepean WRRFs (one total nitrogen, one total suspended solids and the combined total phosphorus bubble limit between Riverstone, Quakers Hill and St Marys WRRFs). This is a decrease from ten concentration exceedances from five facilities and four load exceedances recorded from the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Ammonia nitrogen concentrations showed an increasing trend in the discharge from two of the fifteen Hawkesbury-Nepean WRRFs (namely Picton and North Richmond). A decrease was observed in the discharge from Quakers Hill and St Marys WRRFs
- Total nitrogen concentrations showed an increasing trend in the discharge from seven WRRFs (West Camden, Wallacia, Penrith, North Richmond, Richmond, St Marys and Castle Hill), but a decrease in six (Winmalee, Riverstone, Quakers Hill, Rouse Hill, West Hornsby and Hornsby Heights)
- Total phosphorus concentrations showed an increasing trend in the discharge from six WRRFs (Wallacia, Penrith, Winmalee, North Richmond, St Marys, and Quakers Hill) but a decrease in four (Picton, Richmond, Castle Hill and Brooklyn)
- All nutrient analytes along with suspended solids, aluminium and copper showed an increasing concentration trend in the discharge from North Richmond WRRF
- Copper (from four WRRFs), aluminium (from three WRRFs) and nickel (from one WRRF) showed an increasing trend in the discharge from the Hawkesbury-Nepean WRRFs.

Stressor and ecosystem receptor – water quality, phytoplankton and macroinvertebrates

Table ES-1-2 Summary of statistically significant trends in the Hawkesbury-Nepean River WRRFs' discharge, receiving water quality and chlorophyll-a, comparison with EPL and guideline (ANZG 2018)

			Nutrient analytes					Physico-chemical analytes						
WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity	Chlorophyll-a
Picton	WRRF discharge to waterway		↗		→		↘							
	Tributary	Upstream tributary (N911B)	→	→	→	→	→	→	→	→	→	→	→	→
		Downstream tributary (N911)	→	→	→	→	→	→	→	→	→	→	→	→
	River	Upstream river (N92)	→	→	→	→	→	→	→	↗	→	→	→	→
		Downstream river (N91)	→	→	→	→	→	→	→	→	→	→	→	→
West Camden	WRRF discharge to waterway		→		↗		→							
	Tributary	Upstream tributary (N7824A)	→	→	→	→	→	→	→	↘	→	→	→	→
		Downstream tributary (N7824)	→	→	→	↗	↗	→	→	→	→	→	→	→
	River	Upstream river (N78)	→	→	→	→	→	→	→	→	→	→	→	→
		Downstream river (N75)	→	→	→	→	→	→	→	→	→	→	→	→
Wallacia	WRRF discharge to waterway		→		↗		↗							
	River	Proxy upstream river (N67)	→	→	→	→	→	→	→	→	→	→	→	→
		Downstream river (N641)	→	→	→	→	→	→	→	→	→	→	→	→
Penrith	WRRF discharge to waterway		→		↗		↗							
	Tributary	Upstream tributary (N542)	↗	→	→	→	→	→	↘	↘	↘	→	→	→
		Downstream tributary (N541)	→	→	→	→	→	→	→	→	→	→	→	→
	River	Upstream river (N57)	→	↗	↗	↘	→	↗	→	→	→	→	→	→
		Downstream river (N53)	→	→	→	→	→	→	→	→	→	→	→	→
Winmalee	WRRF discharge to waterway		→		↘		↗							
	Tributary	Proxy upstream tributary (N462)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Downstream tributary (N461)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	River	Upstream river (N48A)	→	↗	↗	→	→	→	→	→	→	→	→	→
		Downstream river (N464)	→	→	→	↗	↗	→	→	→	→	→	→	→
North Richmond	WRRF discharge to waterway		↗		↗		↗							
	Tributary	Upstream tributary (N412)	→	→	→	→	→	→	↗	↗	→	→	→	→
		Downstream tributary (N411)	→	→	→	→	→	→	→	→	→	→	→	→
	River	Upstream river (N42)	→	→	→	↗	↗	↗	→	→	→	→	→	↗
		Downstream river (N39)	→	↗	↗	→	↗	→	→	→	→	→	→	→
Richmond	WRRF discharge to waterway		→		↗		↘							
	Tributary	Upstream tributary (N389)	→	→	→	→	→	→	→	→	→	→	→	→
		Downstream tributary (N388)	→	→	→	→	→	↗	→	→	→	→	→	→
St Marys	WRRF discharge to waterway		↘		↗		↗							
	Tributary*	Upstream tributary (NS242)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		Downstream tributary (NS241)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Tributary	Upstream river (NS26)	→	→	→	→	→	→	→	↗	→	→	→	→
		Downstream river (NS23A)	→	→	→	→	→	→	→	→	→	→	→	→

			Nutrient analytes					Physico-chemical analytes						
WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity	Chlorophyll-a
Riverstone	WRRF discharge to waterway		→		↘		→							
	Tributary	Upstream tributary (NS082)	→	**→**	**→**	→	**→**	→	→	→	→	→	→	**→**
		Downstream tributary (NS081)	→	**→**	**→**	→	**→**	→	→	→	→	→	→	**→**
Quakers Hill	WRRF discharge to waterway		↘		↘		↗							
	Tributary	Upstream tributary (NS090)	→	**→**	**→**	→	**→**	→	→	**→**	→	→	→	→
		Downstream tributary (NS087)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**	→
Rouse Hill	WRRF discharge to waterway		→		↘		→							
	Tributary	Upstream tributary (NC53)	→	**→**	**→**	→	**→**	→	→	**→**	→	→	→	→
		Downstream tributary (NC516)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**	↘
Castle Hill	WRRF discharge to waterway		→		↗		↘							
	Tributary	Upstream tributary (NC8)	→	**→**	**→**	→	**→**	→	→	→	→	→	→	→
		Downstream tributary (NC75)	→	**↗**	**↗**	→	**→**	→	→	→	↘	→	**→**	↘
West Hornsby	WRRF discharge to waterway		→		↘		→							
	Tributary	Upstream tributary (NB83)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**	→
		Downstream tributary (NB825)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**	→
Hornsby Heights	WRRF discharge to waterway		→		↘		→							
	Tributary	Upstream tributary (NB43)	→	**→**	→	→	→	→	→	→	→	→	→	→
		Downstream tributary (NB42)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**	→

Tributary : Unnamed tributary of South Creek*

NA: Statistical comparison not conducted due to only one financial year of data

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline or EPL limit in 2023-24				

Table ES-1-3 Statistical analysis outcomes – upstream and downstream site comparison for water quality, chlorophyll-a and macroinvertebrates

WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity	Chlorophyll-a	Macroinvertebrates
Picton	Tributary	Upstream vs downstream (N911B vs N911)	D	D	D	-	-	-	-	-	-	-	-	-	D
	River	Upstream vs downstream (N92 vs N91)	D	-	-	D	D	-	-	-	-	-	-	-	-
West Camden	Tributary	Upstream vs downstream (N7824A vs N7824)	D	D	D	D	-	U	D	D	U	D	U	U	D
	River	Upstream vs downstream (N78 vs N75)	D	D	D	D	D	-	-	-	-	-	-	-	-
Wallacia	River	Proxy upstream vs downstream (N67 vs N641)	-	U	U	-	-	U	-	D	D	-	-	-	D
Penrith	Tributary	Upstream vs downstream (N542 vs N541)	U	D	-	U	U	U	D	-	-	-	U	U	U
	River	Upstream vs downstream (N57 vs N53)	D	-	-	-	-	-	-	-	-	-	-	-	-
Winmalee	Tributary	Proxy upstream vs downstream (N462 vs N461)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	D
	River	Upstream vs downstream (N48A vs N464)	-	-	-	D	D	-	-	-	-	-	-	-	-
North Richmond	Tributary	Upstream vs downstream (N412 vs N411)	D	D	D	D	D	D	-	D	-	-	-	-	D
	River	Upstream vs downstream (N42 vs N39)	-	-	-	-	-	-	-	-	-	-	-	-	-
Richmond	Tributary	Upstream vs downstream (N389 vs N388)	-	-	-	-	-	-	D	D	-	-	-	-	-
St Marys	Tributary*	Upstream vs downstream (NS242 vs NS241)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
	Tributary	Upstream vs downstream (NS26 vs NS23A)	-	D	D	-	-	-	-	-	-	-	-	-	U
Riverstone	Tributary	Upstream vs downstream (NS082 vs NS081)	-	-	-	-	-	-	-	-	-	-	-	-	-
Quakers Hill	Tributary	Upstream vs downstream (NS090 vs NS087)	-	D	D	-	-	-	D	D	-	-	U	-	U
Rouse Hill	Tributary	Upstream vs downstream (NC53 vs NC516)	D	D	D	U	U	-	D	D	-	-	-	-	-
Castle Hill	Tributary	Upstream vs downstream (NC8 vs NC75)	-	D	D	D	-	D	-	-	U	-	U	-	D
West Hornsby	Tributary	Upstream vs downstream (NB83 vs NB825)	-	D	D	-	-	D	-	-	-	D	U	-	-
Hornsby Heights	Tributary	Upstream vs downstream (NB43 vs NB42)	-	D	D	D	D	D	-	D	D	D	U	-	D

Tributary: Unnamed tributary of South Creek*

NA: Statistical comparison not conducted due to only one financial year of data

Water quality and Chlorophyll-a

D	Downstream higher ($p<0.05$)	U	Upstream higher ($p<0.05$)	-	No difference ($p>0.05$)

Macroinvertebrates

D	Downstream impact, SIGNAL lower ($p<0.05$)	U	Upstream impact, SIGNAL lower ($p<0.05$)	-	No difference ($p>0.05$)

Based on statistical analysis comparing the 2023-24 monitoring period to trends from the previous two to nine years trends and, the upstream and downstream site comparison outcomes were mixed and highly variable by individual site or site pairs. The impact of increased or decreased nutrient concentrations in WRRF discharges was not often reflected in the corresponding nutrient concentration trend at downstream receiving water sites. The change in nutrient concentrations in the discharge was also not reflected (impact or benefit) on downstream phytoplankton, as indicated by chlorophyll-a.

Median total ammonia nitrogen concentrations were within the ANZG (2023) 95% species protection limit at nearly all upstream (19 of 20) and downstream (20 of 20) sites in 2023-24. Oxidised nitrogen and total nitrogen concentrations exceeded the ANZG (2018) guideline limit at nearly all upstream (19 of 20) and downstream (20 of 20) sites. Total nitrogen also exceeded at nearly all upstream (18 of 20) and downstream (20 of 20) sites. Total phosphorus exceeded at the majority of upstream (14 of 20) and downstream (13 of 20) sites and chlorophyll-a at approximately half of the upstream (11 of 20) and downstream (10 of 20) sites.

Statistical analysis confirmed localised impact from WRRF discharges at the majority of the downstream tributary sites in comparison to the upstream site for key nutrients. Such impact was rarely evident at downstream Hawkesbury-Nepean River sites into which these tributaries flow.

The ecosystem health impact in terms of phytoplankton as chlorophyll-a was not evident at any downstream site. The ecosystem health in terms of macroinvertebrates was impacted at six of the 14 downstream sites (Picton, West Camden, Winmalee, North Richmond, Castle Hill and Hornsby Heights) but there was no indication that impacts extended to the main river.

Altogether, the following key observations were made on the 2023-24 Hawkesbury-Nepean River water quality and ecosystem health monitoring results:

Temporal trends: increasing or decreasing trend in 2023-24 compared to previous years

- The total ammonia nitrogen concentration in the downstream receiving water (both tributary and river) remained steady in 2023-24 despite increasing trends in the discharge from Picton and North Richmond WRRFs, and decreasing trends in the discharge from St Marys and Quakers Hill WRRFs.
- Total ammonia nitrogen concentrations increased significantly at the Boundary Creek upstream control site of Penrith WRRF in 2023-24, which was associated with two separate sewer overflow incidents.
- The increasing or decreasing trend in the total nitrogen concentration in the WRRF discharge was not reflected at the majority of downstream receiving water sites (11 out of 13 cases):
  - downstream total nitrogen receiving water concentrations remained steady despite a significant increase in the total nitrogen concentration in the discharge from West Camden, Wallacia, Penrith, Richmond and St Marys WRRFs.
  - downstream total nitrogen receiving water concentrations remained steady despite a significant decrease in the total nitrogen concentration in the discharge from Winmalee, Riverstone, Quakers Hill, Rouse Hill, West Hornsby and Hornsby Heights WRRFs.
- The increasing or decreasing trend in total nitrogen concentration in the WRRF discharge was aligned with a corresponding increase or decrease in total nitrogen at the downstream receiving water site for two out of 13 cases:
  - downstream receiving water concentration in the Hawkesbury River site increased significantly in line with the increased total nitrogen concentration in the discharge from

North Richmond WRRF. However, the trend in total nitrogen at the downstream tributary site was steady indicating the increase in the Hawkesbury River was not related to North Richmond WRRF.

  - downstream receiving water concentration increased significantly in line with the increased total nitrogen concentration in discharge from Castle Hill WRRF.

- Trends in total phosphorus concentration in the WRRF discharge had no observed effect on most downstream receiving water concentrations (eight of nine cases):
  - downstream receiving water concentrations remained steady despite an increase in the total phosphorus concentration in the discharge from Wallacia, Penrith, North Richmond, St Marys and Quakers Hill WRRFs in 2023-24
  - downstream receiving water concentrations remained steady despite a decrease in the total phosphorus concentration in the discharge from Picton, Richmond and Castle Hill WRRFs
- The downstream Nepean River site at Winmalee Lagoon was an exception where the phosphorus concentration increased in line with the increased concentration in the discharge from Winmalee WRRF, although this was not validated for the two downstream tributary sites because of insufficient data.

Comparison with the guideline (ANZG 2018): 2023-24 median or 50th percentile values

- Median total ammonia nitrogen concentrations were within the ANZG (2023) toxicant default guideline value for 95% level species protection at nearly all upstream/downstream receiving water sites in 2023-24. The only exception was the upstream tributary site of St Marys WRRF.
- Median oxidised nitrogen concentration exceeded the ANZG (2018) guideline value at 39 of the 40 upstream or downstream monitoring sites. The only exception was the Matahil Creek site upstream of West Camden WRRF where oxidised nitrogen was within the guideline limit.
- Median total nitrogen concentrations exceeded the guideline at 38 of the 40 upstream or downstream monitoring sites. The exceptions were the tributary sites upstream of Picton and Hornsby Heights WRRFs where median concentrations were below the guideline.
- Median total phosphorus concentrations exceeded guideline value at 14 of the 20 downstream tributary/river sites in 2023-24. The guideline was exceeded at 13 of the 20 upstream monitoring sites.
- Median chlorophyll-a concentrations exceeded the ANZG (2018) guideline at 21 of the 40 upstream or downstream tributary/river sites in 2023-24.

Upstream versus downstream comparison (2023-24)

- The 2023-24 total ammonia nitrogen concentrations were significantly higher at the respective downstream receiving water sites in comparison to the upstream sites for Picton, West Camden and North Richmond WRRFs indicating a link with the elevated concentrations/loads in the discharge.

- Oxidised nitrogen and/or total nitrogen concentrations were significantly higher at the downstream sites for the majority of WRRFs (10 of 14 WRRFs) compared to upstream sites, confirming a link with the discharge from these facilities.
- Filterable and total phosphorus concentrations were significantly higher at the downstream receiving sites of six WRRFs compared to upstream, indicating a possible link with the corresponding phosphorus concentrations/loads in the discharge. For two WRRFs (Penrith and Rouse Hill) upstream phosphorus concentrations were higher than downstream indicating other upstream catchment influences such as sewer overflows, stormwater or urbanisation.
- Dissolved oxygen concentrations (and saturation) at the downstream sites were significantly higher than upstream at eight of 14 WRRFs indicating a benefit of the discharge. Similarly, turbidity at the upstream sites was significantly higher than downstream at six of 14 WRRFs indicating a benefit of discharges with low suspended particles.
- Chlorophyll-a concentrations at the upstream sites were significantly higher than downstream for two WRRFs (West Camden and Penrith) indicating localised conditions that favour phytoplankton growth (e.g. low flow, high nutrient availability).
- Stream health outcomes, as indicated by macroinvertebrates, showed localised ecosystem impacts in tributaries downstream of six of 14 WRRFs. These included Picton, West Camden, Winmalee, North Richmond, Castle Hill and Hornsby Heights. For Penrith, St Marys and Quakers Hill WRRFs, the upstream ecosystem health was poorer compared to downstream health.

Gate 2 synthesis

From the gate 1 analyses, six WRRFs in the Hawkesbury-Nepean River catchment demonstrated potential adverse ecological impacts as a result of Sydney Water treated discharges in downstream receiving waters. A summary of each WRRF gate 2 synthesis table is provided below.

Picton WRRF

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as chlorophyll-α		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Total ammonia nitrogen	↗	D	D	-	-	D	-	Increased total ammonia nitrogen in Picton WRRF discharges triggered a subsequent increase in downstream receiving water concentration of both Stonequarry Creek and Nepean River. Stream health as indicated by macroinvertebrates was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D	-					
Total nitrogen	→	D	-					
Filterable total phosphorus		-	D					
Total phosphorus	↘	-	D					
Conductivity		-	-					
Dissolved oxygen		-	-					
Dissolved oxygen saturation		-	-					
pH		-	-					
Water temperature		-	-					
Turbidity		-	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

West Camden WRRF

Analytes	Pressure: Effluent	Stressors – Water quality: Tributary (us vs ds)	Stressors – Water quality: River (us vs ds)	Ecosystem Receptors – Phytoplankton as chlorophyll-α: Tributary (us vs ds)	Ecosystem Receptors – Phytoplankton as chlorophyll-α: River (us vs ds)	Ecosystem Receptors – Macroinvertebrates: Tributary (us vs ds)	Ecosystem Receptors – Macroinvertebrates: River (us vs ds)	Gate 2 synthesis
Total ammonia nitrogen	→	D	D					The elevated nitrogen in the discharge from West Camden WRRF increased the downstream receiving water concentration at both Matahil Creek and the Nepean River. In 2023-24, seven out of 17 total ammonia nitrogen results were above the ANZG 2023 toxicant guideline for 95% species protection. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation (multivariate analysis) was carried out (Gate 3 analysis).
Oxidised nitrogen		D	D					
Total nitrogen	↗	D	D					
Filterable total phosphorus		D	D					
Total phosphorus	→	-	D					
Conductivity		U	-	U	-	D	-	
Dissolved oxygen		D	-					
Dissolved oxygen saturation		D	-					
pH		U	-					
Water temperature		D	-					
Turbidity		U	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

Winmalee WRRF

Analytes	Pressure: Effluent	Stressors – Water quality: Tributary (us vs ds)	Stressors – Water quality: River (us vs ds)	Ecosystem Receptors – Phytoplankton as chlorophyll-α: Tributary (us vs ds)	Ecosystem Receptors – Phytoplankton as chlorophyll-α: River (us vs ds)	Ecosystem Receptors – Macroinvertebrates: Tributary (us vs ds)	Ecosystem Receptors – Macroinvertebrates: River (us vs ds)	Gate 2 synthesis
Total ammonia nitrogen	→	NA	-					Increased phosphorus concentration in Winmalee WRRF discharges triggered a subsequent increase in receiving water phosphorus. Downstream ecosystem health in terms of macroinvertebrates has deteriorated with no further evidence from Winmalee discharge impact. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		NA	-					
Total nitrogen	↘	NA	-					
Filterable total phosphorus		NA	D					
Total phosphorus	↗	NA	D					
Conductivity		NA	-	NA	-	D	-	
Dissolved oxygen		NA	-					
Dissolved oxygen saturation		NA	-					
pH		NA	-					
Water temperature		NA	-					
Turbidity		NA	-					

NA - Statistical comparison not conducted due to only one financial year of data

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

North Richmond WRRF

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as chlorophyll-α		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Total ammonia nitrogen	↗	D	-	-	-	D	-	The increased nutrient concentration in the discharge from North Richmond WRRF resulted in a subsequent increase in the downstream receiving water nutrient concentrations. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D	-					
Total nitrogen	↗	D	-					
Filterable total phosphorus		D	-					
Total phosphorus	↗	D	-					
Conductivity		D	-					
Dissolved oxygen		-	-					
Dissolved oxygen saturation		D	-					
pH		-	-					
Water temperature		-	-					
Turbidity		-	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

Castle Hill WRRF

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as chlorophyll-α	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Total ammonia nitrogen	→	-	-	D	The increased nitrogen concentration in the discharge from Castle Hill WRRF resulted in a subsequent increase in the downstream receiving water nitrogen concentration. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D			
Total nitrogen	↗	D			
Filterable total phosphorus		D			
Total phosphorus	↘	-			
Conductivity		D			
Dissolved oxygen		-			
Dissolved oxygen saturation		-			
pH		U			
Water temperature		-			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

Hornsby Heights WRRF

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as chlorophyll-α	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Total ammonia nitrogen	→	-	-	D	Nutrient concentrations in the downstream receiving water were significantly higher than upstream, which does not reflect the decreased or steady trends in the WRRF discharge concentrations. Ecosystem health (macroinvertebrates) was impacted at the downstream site. Further analysis (Gate 3) to be carried out.
Oxidised nitrogen		D			
Total nitrogen	↘	D			
Filterable total phosphorus		D			
Total phosphorus	→	D			
Conductivity		D			
Dissolved oxygen		-			
Dissolved oxygen saturation		D			
pH		D			
Water temperature		D			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(yellow)	EPL limit exceedance	(grey)	Analyte not monitored		

Georges River and tributaries

Pressure – WRRF effluent quantity, quality and toxicity

Table ES-1-4 Summary of EPL concentration and load limit exceedances, together with statistically significant increasing and decreasing trends of Georges River WRRFs

WRRF	Analytes	Conventional analytes	
		Biochemical oxygen demand	Total suspended solids
Fairfield	Concentration	→	→
	Load		
Glenfield	Concentration	→	→
	Load		
Liverpool	Concentration EPA ID 15 (Chipping Norton Discharge)	→	→
	Concentration EPA ID 76 (Recycled Water Reuse)	→	→
	Concentration EPA ID 81 (Liverpool Discharge)	→	→
	Load		

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

Georges River discharges are primarily influenced by rainfall and have experienced increasing pressure from climate change.

During the 2023-24 monitoring period, there were no concentration EPL limit exceedances. There was also no biochemical oxygen demand and total suspended solids trend change from the previous 2022-23 monitoring period. There are no load limits applicable to enclosed waters under the Malabar EPL.

Stressor and ecosystem receptor – water quality, phytoplankton and macroinvertebrates

The receiving water quality, phytoplankton as chlorophyll-a and macroinvertebrates data for three upstream and downstream monitoring sites for Glenfield WRRF were collected for the first time during the 2023-24 period. Statistical analysis will be included in SWAM reports from 2024-25 to further validate these trends.

Nearshore marine waters

Pressure – WRRF effluent quantity, quality and toxicity

Table ES-1-5 Summary of EPL concentration and load limit exceedances, together with statistically significant increasing and decreasing trends for the nearshore marine discharging WRRFs

WRRF	Analytes	Nutrients			Conventional analytes					Trace Metals								Others					
		Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Chlorpyrifos	Cyanide	Diazinon	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Warriewood	Concentration	–	–	–	–	→	–	→	→	→	–	–	→	–	–	–	–	–	→	–	–	→	–
	Load	W	W	W	W	–	W	W	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cronulla	Concentration	→	–	–	→	→	→	→	→	→	–	–	→	–	–	–	→	→	→	→	→	→	–
	Load	–	W	W	W	–	W	W	–	–	W	W	W	W	W	W	W	–	–	–	–	–	W
Wollongong	Concentration	–	–	–	↗	–	–	↗	–	→	–	–	↘	–	–	–	–	–	–	→	→	–	–
	Load	–	W	W	E	–	W	E	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Shellharbour	Concentration	→	–	–	↘	→	–	→	→	→	–	–	→	–	–	–	–	–	–	→	→	→ (E)	–
	Load	–	W	W	W	–	W	W	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Bombo	Concentration	→	–	–	→	→	–	→	→	→	–	–	→	–	–	–	–	–	–	→	→	→	–
	Load	–	W	W	W	–	W	W	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
E	EPL limit exceedance	W	Within EPL limit	–	Analyte not required in EPL or no concentration limit

Similar to the Hawkesbury-Nepean River WRRF discharges, Sydney Water is challenged with increasing pressure from a growing population and climate change in WRRF discharges to the nearshore marine environment.

During the 2023-24 monitoring period, there was one concentration EPL limit exceedance (nonylphenol ethoxylate 90th percentile) at Bombo WRRF and two load EPL limit exceedances (one biochemical oxygen demand and one suspended solids) from Wollongong WRRF. This is an improvement from the single concentration exceedances and four load exceedances recorded in the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Biochemical oxygen demand and suspended solids concentrations increased in Wollongong WRRF discharge
- Biochemical oxygen demand concentration decreased in Shellharbour WRRF discharge
- Copper concentrations decreased in Wollongong WRRF discharge.

Stressor and ecosystem receptor – water quality, microalgae and invertebrates

Assessment of the 2023-24 monitoring data from the Shellharbour WRRF and two control sites indicated a relatively stable equilibrium in the rocky-intertidal community structure. These results also suggest no measurable impact had developed in the intertidal rock platform community near the outfall at Barrack Point from wastewater discharges from the Shellharbour WRRF.

A water quality pilot program for nearshore sites with intertidal rock platforms (i.e. Shellharbour, Warriewood and Bombo) is being implemented in 2024-25.

Offshore marine waters

Pressure – WRRF effluent quantity, quality and toxicity

Table ES-1-6 Summary of EPL concentration and load limit exceedances, together with statistically significant increasing and decreasing trends for the offshore marine discharging WRRFs

		Nutrients		Conventional analytes				Trace Metals								Others			
WRRF	Analytes	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Chlorpyrifos	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
North Head	Concentration				→	→	→	→			→					→	→	→	
	Load																		
Bondi	Concentration				→	↘	→	↘									→		→
	Load																		
Malabar	Concentration				↗	↗	→	→									→		→
	Load																		

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

There were no concentration or load EPL limit exceedances from the offshore WRRF discharges during the 2023-24 monitoring period, and no change from the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Increasing oil and grease and suspended solids concentrations in the final effluent from Malabar WRRF
- Decreasing suspended solids and aluminium concentrations at Bondi WRRF

Stressor – ocean receiving water quality

- Of the 11 chemicals assessed in 2023-24, modelled total nitrogen, total phosphorus, aluminium and copper concentrations in the receiving waters in the initial dilution zones of the deepwater ocean outfalls exceeded the ANZG (2018) guideline values for the protection of 95% of marine species.

Stressor – ocean sediment quality

- The total organic carbon content (%) of the sediment was less than 1.2% for all samples collected from Malabar, North Head and Bondi outfall locations, below the NSW EPA specified 99th percentile trigger value.
- Average levels of fine sediments in 2023-24 were comparable to those recorded in past years, with no apparent build-up of fine particles. This indicates that metal concentrations in the sediment were unlikely to have increased at the deepwater outfall locations.

Ecosystem receptor – ocean sediment ecosystem health

- The benthic community structure was assessed at the Malabar deepwater outfall location in the 2023-24 surveillance year.
- Taxonomic compositions suggested that Polychaetes and Crustaceans continued to dominate the number of taxa collected at this site. While the total number of individuals was lower than the previous year, there has not been a sustained decline or increase in the main taxonomic groups over the 24 years of monitoring.

1. Introduction

1.1. Background

Sydney Water operates 23 distinct wastewater network systems or Wastewater Treatment Systems, (WTSs) across the Greater Sydney, Blue Mountains and Illawarra region. Generally, each WTS consists of a Water Resource Recovery Facility (WRRF) and its reticulation system. The Malabar WTS includes three Georges River WRRFs (Fairfield, Glenfield and Liverpool), while the Wollongong WTS includes the Bellambi and Port Kembla WRRFs. Altogether, the 28 WRRFs provide an integrated wastewater treatment service to more than 5 million people (Figure 1-1).

One of Sydney Water's principal objectives is to protect the environment by conducting its operations in compliance with the principles of ecologically sustainable development. We are supported in this capacity by a comprehensive regulatory framework. The principal statutory instrument for each WTS is an Environment Protection Licence (EPL) issued by the NSW Environment Protection Authority (the EPA) under the Protection of the Environment Operations Act 1997 (POEO Act). Each EPL specifies licence conditions including limits and monitoring requirements. Limits include restrictions on the volume, loads and concentrations of constituents in effluent discharged from WRRFs to the environment.

In addition to wastewater discharge monitoring, each EPL also requires Sydney Water to undertake environmental monitoring as detailed in the Sydney Water Aquatic Monitoring (SWAM) program (Sydney Water 2023), or any replacement document approved in writing by the EPA.

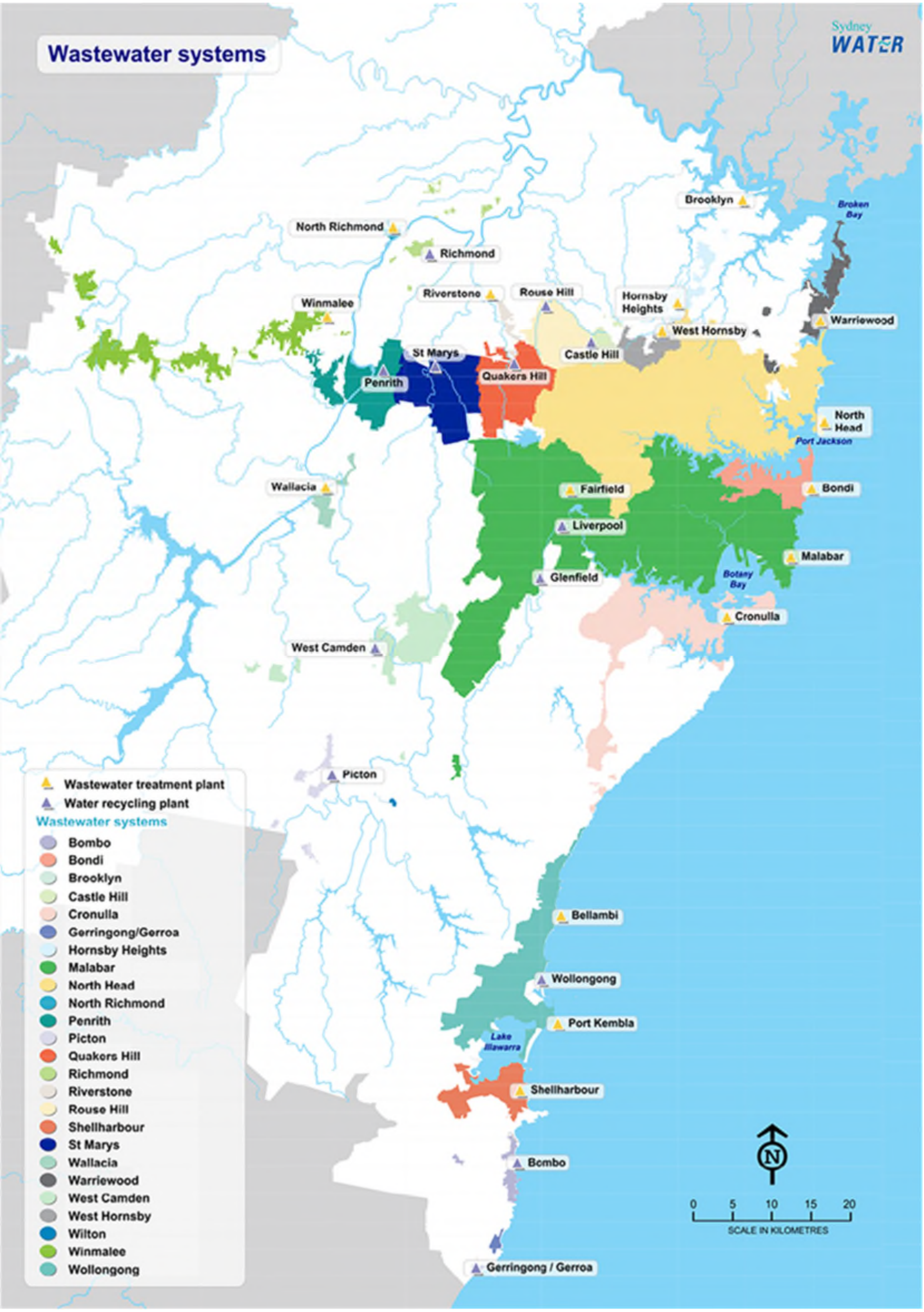
The physical environment in which we conduct our discharge operations varies widely across our area of operations. Monitoring activities cover a broad range of receiving water environments including freshwater (tributary creeks and rivers), estuarine, nearshore and offshore marine environments. The WTSs are distinct in terms of the nature of the discharge characteristics, process and management objectives. This distinctiveness is considered in the design of the monitoring programs targeting each respective system.

The Sydney, Blue Mountains and Illawarra region is a major centre of economic, industrial and agricultural activity with high density residential growth. These diverse activities all contribute to the environmental health of the region. Sydney Water's activities represent just one input to the complex system of local riverine, estuarine and ocean environments. Our challenge is to identify the effects of our wastewater operations against the background of diverse human activities. We aim to address this challenge by implementing well-designed monitoring that targets key impact indicators sensitive to our activities.

1.2. Sydney Water Aquatic Monitoring Program

The Sydney Water Aquatic Monitoring (SWAM) program was developed by a review panel in consultation with the EPA, Department of Climate Change, Energy, the Environment and Water (DCCEEW) and Sydney Water. The review panel also included independent specialists with complementary expertise across marine science, freshwater science, biostatistics, and relevant state and national water quality policies and/or guidelines. A key focus of the review of the earlier program was to ensure that a revised monitoring program was able to differentiate the impacts of

Sydney Water's activities from the impacts of all other anthropogenic activities occurring concurrently.



Notes: Gerringong/Gerroa and Wilton systems are included for completeness. The respective EPLs are held by Veolia Water. Wastewater treatment plant and Water recycling plant are now renamed as Water Resource and Recovery Facility

Figure 1-1 Wastewater treatment system across greater Sydney

The review looked at the design of the monitoring program, as well as the statistical analysis and annual reporting structure. The findings and recommendations from the reviews are detailed in van Dam et al. (2023).

The SWAM program was endorsed by the EPA in April 2023 to replace the Sewage Treatment System Impact Monitoring Program (STSIMP, Sydney Water 2010). The STSIMP was operational for 15 years (July 2008 to June 2023).

The SWAM program is now referenced in each EPL. The key monitoring and reporting requirements are being gradually implemented from July 2023.

The overarching aim of the SWAM program is:

> *'to monitor the performance of Sydney Water's WRRF discharges and quantify the impacts (positive or negative) of these discharges, and sewer overflows and leakage, on the aquatic environment'*.

A key focus of the SWAM program is alignment with the ANZG (2018) water quality management framework (WQMF) to represent the nationally agreed process for managing, assessing and monitoring water quality. Amongst other aspects, it incorporates a weight of evidence (WoE) approach to water quality assessment that promotes the measurement of indicators from across the pressure, stressor and ecosystem receptor (P-S-ER) causal pathway elements (van Dam et al., 2023). For example, WRRF discharge quantity, quality and toxicity represent pressure indicators, while concentrations of key discharge constituents in the receiving waters represent stressor indicators, and phytoplankton and macroinvertebrate parameters represent ecosystem receptor indicators. Data from across these multiple P-S-ER lines of evidence are to be used to determine whether WRRF discharges are impacting the aquatic environment. An overview of P-S-ER elements, monitoring sub-programs and status of implementation to date is summarised in Table 1-1.

Table 1-1 Summary of the Sydney Water Aquatic Monitoring (SWAM) program and status of implementation

<table>
<tr><th>Pressure</th><th>Catchment / Zone</th><th>Sub-program</th><th>P-S-ER [a]</th><th>Overview</th><th>Status of implementation</th></tr>
<tr><td rowspan="6">WRRF discharges</td><td rowspan="2">Hawkesbury-Nepean River and tributaries</td><td>Hawkesbury-Nepean River WRRF effluent quantity, quality and toxicity</td><td>P</td><td>Treated wastewater quantity, quality and toxicity for 15 WRRFs as per specific EPL requirements</td><td>Ongoing as per EPL and approved variation</td></tr>
<tr><td>Hawkesbury-Nepean River water quality and ecosystem health</td><td>S, ER</td><td>Water quality and chlorophyll-a (3-weekly) and macroinvertebrates (bi-annually), upstream and downstream of WRRF discharges
Water quality, chlorophyll-a and phytoplankton at 10 (long-term) sites known to be prone to high phytoplankton growth</td><td>Implemented fully.
Monitoring commenced from July 2023:
Water quality at 52 sites
Chlorophyll-a at 50 sites
Macroinvertebrates at 39 sites
Two additional sites from St Marys sub-catchment were added from late 2023 for all three categories above</td></tr>
<tr><td rowspan="2">Georges River and tributaries</td><td>Georges River WRRF effluent quantity, quality and toxicity</td><td>P</td><td>Treated wastewater quantity and quality</td><td>Ongoing as per EPL and approved variation</td></tr>
<tr><td>Georges River water quality and ecosystem health [b]</td><td>S, ER</td><td>Water quality and chlorophyll-a (3-weekly) and macroinvertebrates (bi-annually) at three sites, upstream and downstream of Glenfield WRRF discharge
Monitoring for Liverpool and Fairfield WRRF discharges will be added at a later date, following monitoring feasibility studies</td><td>Partially implemented:
Monitoring commenced from July 2023 at three sites upstream and downstream of Glenfield WRRF
Feasibility studies or new monitoring program for the Fairfield and Liverpool WRRFs yet to be designed</td></tr>
<tr><td>Other freshwater</td><td>Reference sites water quality and ecosystem health</td><td>S, ER</td><td>Water quality (3-weekly) and macroinvertebrates (biannually) at seven reference sites without urban or rural influences on water quality. Monitoring data are used to re-calibrate macroinvertebrate SIGNAL-SG scores</td><td>Implemented
Monitoring reduced to seven sites from July 2023 as recommended</td></tr>
</table>

Pressure	Catchment / Zone	Sub-program	P-S-ER [a]	Overview	Status of implementation
	Nearshore marine	Nearshore marine WRRF effluent quantity, quality and toxicity	P	Treated wastewater quantity, quality and toxicity for eight WRRFs as per specific EPL requirements	Ongoing as per EPL and approved variation
		Nearshore marine water quality and ecosystem health [c]	S, ER	Water quality and intertidal macroalgae and macroinvertebrates (annually) at nine sites as groups of one outfall and two reference sites for three WRRFs Water quality and subtidal macroalgae and macroinvertebrates (annually) at 24 sites as a gradient of 0 m, 50 m, 100 m, 200 m, 500 m and 1 km from each outfall for one WRRF and three untreated cliff face discharges	Partially implemented: Pilot monitoring to commence (late 2024) at nine sites, plus one extra reference site for the Shellharbour outfall (water quality, macroalgae and macroinvertebrates). Surveys by Unmanned Aerial Systems (UAS) and automated software to show changes in the biological communities over time. Feasibility study on water quality and subtidal macroalgae and macroinvertebrates yet to be designed or planned
	Offshore marine	Offshore marine WRRF effluent quantity, quality and toxicity	P	Treated wastewater quantity, quality and toxicity for three WRRFs as per specific EPL requirements.	Ongoing as per EPL and approved variation
		Offshore receiving water quality	S	Water quality based on measured effluent concentrations and modelled dispersion of the effluent plume using ocean reference station data	Partially implemented All recommended approach yet to implement
		Offshore sediment quality and ecosystem health	S, ER	Surveillance Year: Sediment quality and benthic infauna (annually) at 18 sites and two sites respectively, at outfall and control locations Assessment Year: Sediment quality and benthic infauna (aligned with the Independent Pricing	Implemented. 2023-24 was a Surveillance year and 2024-25 is an Assessment Year. Monitoring commenced based on new requirement i.e. additional analytes

Pressure	Catchment / Zone	Sub-program	P-S-ER [a]	Overview	Status of implementation
				and Regulatory Tribunal reporting cycle) at 18 sites, at outfall and control locations	
Wet and dry weather overflows and leakage [d]	Estuaries, lagoons and beaches	Dry weather overflows – volume, frequency and trends	P	Determine total number of overflows and volume per system (where applicable in EPLs) and Sewer Catchment Area Management Plan (SCAMP), and the proportion that reach receiving waters	Ongoing and extended as per new requirements
		Dry weather leakage detection	P	Assessment of 226 sewer catchments for sewer leakage at least once per year	Monitoring program continued at all sites
		Wet weather overflows – modelled volume, frequency and trends	P	Annual model runs to determine overflow frequency and volume information	Ongoing as usual
		Water quality and ecosystem health	S, ER	To be determined following completion of Wet Weather Overflow Monitoring Program (WWOM)	Not implemented WWOM now completed, yet to design or plan relevant monitoring programs
		Recreational water quality	S	To be determined following completion of WWOM	Joint monitoring programs continued by Sydney Water and DCCEEW WWOM now complemented, yet to review the current monitoring programs

a P-S-ER: Refers to whether the sub-program is measuring pressure (P), stressor (S) and/or ecosystem receptor (ER) indicators.

b Only developed for Glenfield WRRF at present; additional studies required to develop monitoring details for Liverpool and Fairfield WRRFs.

c Only being developed for nine intertidal sites for the Shellharbour, Warriewood and Bombo WRRFs. Additional studies required to develop for the other nearshore WRRFs.

d A complete set of sub-programs for assessing wet and dry weather overflows and dry weather leakage will be developed using recommendations from the WWOM report (Sydney Water 2024c). This might include separate sub-programs for wet weather overflows and dry weather overflows and leakage, and is also likely to capture inland areas (i.e. freshwater).

1.3. Report objectives and structure

The SWAM Annual Data Report 2023-24 has been prepared to meet condition M5.1d of Sydney Water's EPLs. This is the first year of the SWAM report that includes data collected under the revised monitoring programs. The structure and format of the report have been modified following STSIMP recommendations (van Dam et al. 2023) to fully align with the new SWAM program objectives.

1.3.1. Scope and objectives

The aim of the SWAM data report is to provide data summaries and trends of Sydney Water's treated wastewater discharge and overflow data with respect to regulatory limits. More importantly, it aims to assess the environmental monitoring data including water quality, phytoplankton and macroinvertebrates to determine the impacts of Sydney Water's wastewater operations, and compare these with the established guidelines or protocols to determine the general status of each monitoring site.

The more detailed scope or specific objectives of the SWAM 2023-24 data report are to:

- detail the monitoring program design, sites, sampling methodology, analytes and indicators
- present annual wastewater discharge quality, quantity, load and toxicity data with respect to EPL limits, and identify temporal trends of current year against the previous nine years
- present the trends in wastewater overflow, leakage and recycled water data with a special attention to compliance with EPL conditions and continuous improvement initiatives
- present the trends in water quality, phytoplankton and macroinvertebrate data against previous years' results
- identify exceptions and catchment/zone specific summary results outside EPL limits and water quality guidelines or to identify significant upward or downward trends
- assess WRRF specific and catchment specific impact from discharges on water quality, phytoplankton and macroinvertebrates and other indicators (sediment quality and infauna)
- summarise data and trends that are collected to determine the State of Environment (SoE) and where possible identify the links with Sydney Water's wastewater overflows.

The SWAM data report includes analyses and assessment on receiving water environments using indicators from across the pressure, stressor and ecosystem receptor (P-S-ER) causal pathway elements where data is available. This year, we commenced formal gated analysis workflow to clearly and consistently step through the process of analysing and interpreting the results with the aim of identifying whether Sydney Water's operations have resulted in an impact and, if so, the nature/magnitude and causes of the impact.

1.3.2. Format and structure

The format and structure of this SWAM 2023-24 Data Report has been revised to align with the new requirements (van Dam et al. 2023) where possible or where monitoring data permits.

The report has been structured and formatted as follows:

1. ***Supporting common sections*** such as introduction, scope, monitoring programs and analytical methods, glossary, references.

- ***Main sections*** to assess the impact of Sydney Water's wastewater operations. These sections present and assess the monitoring results using the following principles or rules:
  - Ordering of the monitoring program/sub-program results based on pressure (WRRF discharges), followed by region/zone (i.e. "catchment to coast" approach) i.e. inland catchment first then the ocean catchments:

  a. Hawkesbury-Nepean River

  b. Georges River

  c. Nearshore marine waters

  d. Offshore marine environment.

- For each sub-program related to WRRF discharges, presenting the results for each WRRF discharge:

  a. Hawkesbury-Nepean River WRRFs, ordered from their location in upstream to downstream for the Hawkesbury-Nepean River catchment (Picton WRRF to Brooklyn WRRF inclusive)

  b. Nearshore and Offshore discharging WRRFs, ordered from North to South (e.g. North Head, Bondi and Malabar for the offshore discharging WRRFs).

- For each Inland WRRF discharges, ordering the results according to the pressure, stressor and ecosystem receptor data:

  a. Pressure – Wastewater quality and discharge load analytes grouped first in the order of significance and then presented alphabetically:

     i. Nutrients

     ii. Major conventional analytes

     iii. Trace metals

     iv. Other chemicals and organics (including pesticides).

  b. Stressor – Water quality analytes grouped first in the order of significance and then presented alphabetically:

     i. Nutrients and toxicants

     ii. Physico-chemical water quality

     iii. Trace metals.

  c. Ecosystem receptor – Ecosystem health indicators

     i. Phytoplankton

     ii. Macroinvertebrates.

- For each nearshore and offshore WRRF discharges, ordering the results for the pressure indicator using the above approach. However, the stressor and ecosystem receptor indicators are presented together for these two sub-programs (nearshore and offshore).

- Ordering of the monitoring results for the Pressure – Wastewater overflows are grouped into three broad categories:
  a. Wet weather overflows
  b. Dry weather overflows
  c. Dry weather leakage monitoring program.

2. ***A separate synthesis section*** provides a summary of what the combined monitoring results reveal about the impact of Sydney Water's operations on the aquatic environment. This focuses on each catchment/region/zone (e.g. riverine, nearshore and offshore)
3. ***Sections on SoE type*** monitoring programs including those sites or sub-programs that can't be directly linked to the impact from our wastewater operations

- ***The main results and discussion sections*** remain succinct, with key or exception results (e.g. where differences are detected) and associated figures and tables being presented in the main report, and tables and figures of all results being provided in Volume 2 and electronic appendices.

The 2023-24 SWAM Data Report consists of the following two volumes of reports:

1. Volume 1 SWAM Data Report 2023-24 is the main volume of the 2023-24 report.

- It provides results using summary and inferential statistical methods to address sub-program specific objectives comparing the current year with relevant water/sediment quality objectives and the relevant historical record.
- Three formal gated analysis workflows were followed:
  – Gate 1: routine annual analysis
  – Gate 2: determine the likelihood of receiving water impact caused by Sydney Water
  – Gate 3: undertake more detailed analysis on the cause, nature and magnitude of impacts.
- This volume details the 'exceptions' where a significant trend is identified in the data (either positive or negative) or the results exceed the EPL guideline limits and/or other relevant guidelines (ANZG 2018, NHMRC 2008 etc).
- Limited commentaries were provided to describe the results especially on those exceptions identified or where Sydney Water impacts were detected.

2. Volume 2 SWAM Data Report 2023-24 (Appendices)

- Includes all wastewater and environmental monitoring data and statistical analysis summaries, and graphics.
- This volume is also supported by multiple electronic appendices of data summaries and raw data that have been shared with the EPA.

2. Monitoring programs

This chapter describes all monitoring programs including site details, analytes and method of sampling and analyses. Sampling and analyses are undertaken in accordance with internal work instructions or methods, ensuring quality of data through quality control measures. For more details see Chapter 2.10.

Sydney Water Laboratory Services is NATA certified to *ISO 9001:2015 Quality management systems, ISO 14001: 2015 Environmental Management Systems and Occupational Health & Safety Management System AS/NZS 4801: 2001.* All analytical work is performed to the requirements of *AS ISO/IEC 17025: 2015 General requirements for the competence of testing and calibration laboratories.*

2.1. Wastewater discharge quantity, quality and toxicity

2.1.1. Rationale

Currently, there are 28 WRRFs operating in the greater Sydney catchment. Discharge quantity, quality and locations of these facilities vary widely from the inland riverine environment to nearshore or offshore deep ocean outfalls.

The EPLs for each WRRF specify the effluent quantity, quality and toxicity monitoring requirements. Requirements are referenced in Sydney Water's Water Resource Recovery Facilities Compliance Monitoring Plan (Sydney Water 2024). These requirements vary between WRRFs and can also be varied for each WRRF from time to time. There could be changes to the analyte suite in future for assessing discharge quality as a result of comprehensive sampling studies recommended by van Dam et al. (2023).

Treatment levels and monitoring requirements for the four key groups of WRRFs are specified in Table 2-2. Data on the quantity, quality and toxicity of each WRRF discharge are representative of the condition of the pressure (P) in the P-S-ER approach to monitoring of the impacts of Sydney Water's WRRF discharges on the aquatic environment (see Section 1.3).

2.1.2. Aim and objectives

The aim and specific objectives for this monitoring sub-program are presented in Table 2-1.

Table 2-1 Aim and objective for the wastewater discharge quantity, quality and toxicity monitoring sub-program

Aim	Objectives
To characterise and assess the quantity, quality and toxicity of the WRRF discharges, as specified in their respective Environment Protection Licences.	• To compare WRRF discharge quantity, quality and toxicity with relevant EPL limits (where available), for the current year
	• To compare WRRF discharge quantity, quality and toxicity over the relevant historical record.

Table 2-2 Summary of wastewater discharge quantity, quality and toxicity monitoring program

Wastewater catchment or receiving water	Discharge and treatment level	Operating WRRFs		Monitoring requirements
Hawkesbury-Nepean River and tributaries	Routine discharges are treated to high standard i.e. tertiary treatment with disinfection	Picton# West Camden# Wallacia# Penrith# Winmalee North Richmond Richmond# St Marys#	Quakers Hill# Riverstone Castle Hill# Rouse Hill# Hornsby Heights West Hornsby Brooklyn	In-situ online monitoring: volume of discharges (treated and partially treated) Wastewater quality: ammonia nitrogen, total nitrogen, total phosphorus, residual chlorine (for WRRFs with disinfection systems), faecal coliforms, suspended solids and biochemical oxygen demand (BOD) every six days toxicity testing with Ceriodaphnia dubia, every month (excluding Picton); metal and organic contaminants, every month Minor WRRF specific variations and other requirements as per EPL
Georges River and tributaries	Occasional discharges, and treatment level varies from primary or secondary level with disinfection	Glenfield* Fairfield* Liverpool#*		In-situ online monitoring: volume of discharges (treated and partially treated). Wastewater quality: biochemical oxygen demand (BOD), suspended solids, daily when discharging
Nearshore marine environment (outfalls)	Routine and infrequent discharges; treatment level varies from primary to tertiary level with disinfection	Warriewood Cronulla Wollongong# - Bellambi* - Port Kembla* Shellharbour Bombo#		In-situ online monitoring: volume of discharges (treated and partially treated). Wastewater quality: biochemical oxygen demand (BOD), oil and grease, suspended solids, every six days; toxicity testing by sea urchin sperm and eggs (excluding Wollongong), every month; metal and organic contaminants, every month where applicable. Minor WRRF specific variations and other requirements as per EPL
Offshore marine environment (deep ocean outfalls)	Routine discharges and primary treatment	North Head Bondi Malabar		As above for outfall plants

 # These facilities are also called Water Recycling Plants (WRPs), where in addition to discharges to the environment a smaller or greater proportion of the treated wastewater is recycled onsite or elsewhere. For the purpose of simplicity in plots, tables and interpretations all facilities are termed as WRRFs in this document

** Part of larger WRRFs, wastewater is discharged during wet weather only.*

2.1.3. Monitoring approach

Design and sites

Hawkesbury-Nepean River WRRFs

The discharge monitoring sites for each WRRF are specified in the relevant EPL. Currently, there are 15 WRRFs operating in the greater Hawkesbury-Nepean River catchment (Figure 2-1). Listed generally from upstream to downstream, they include: Picton, West Camden, Wallacia, Penrith, Winmalee, North Richmond, Richmond, St Marys, Quakers Hill, Riverstone, Castle Hill, Rouse Hill, West Hornsby, Hornsby Heights and Brooklyn. All WRRFs except Brooklyn discharge to freshwater environments, with Brooklyn discharging to an estuarine environment.

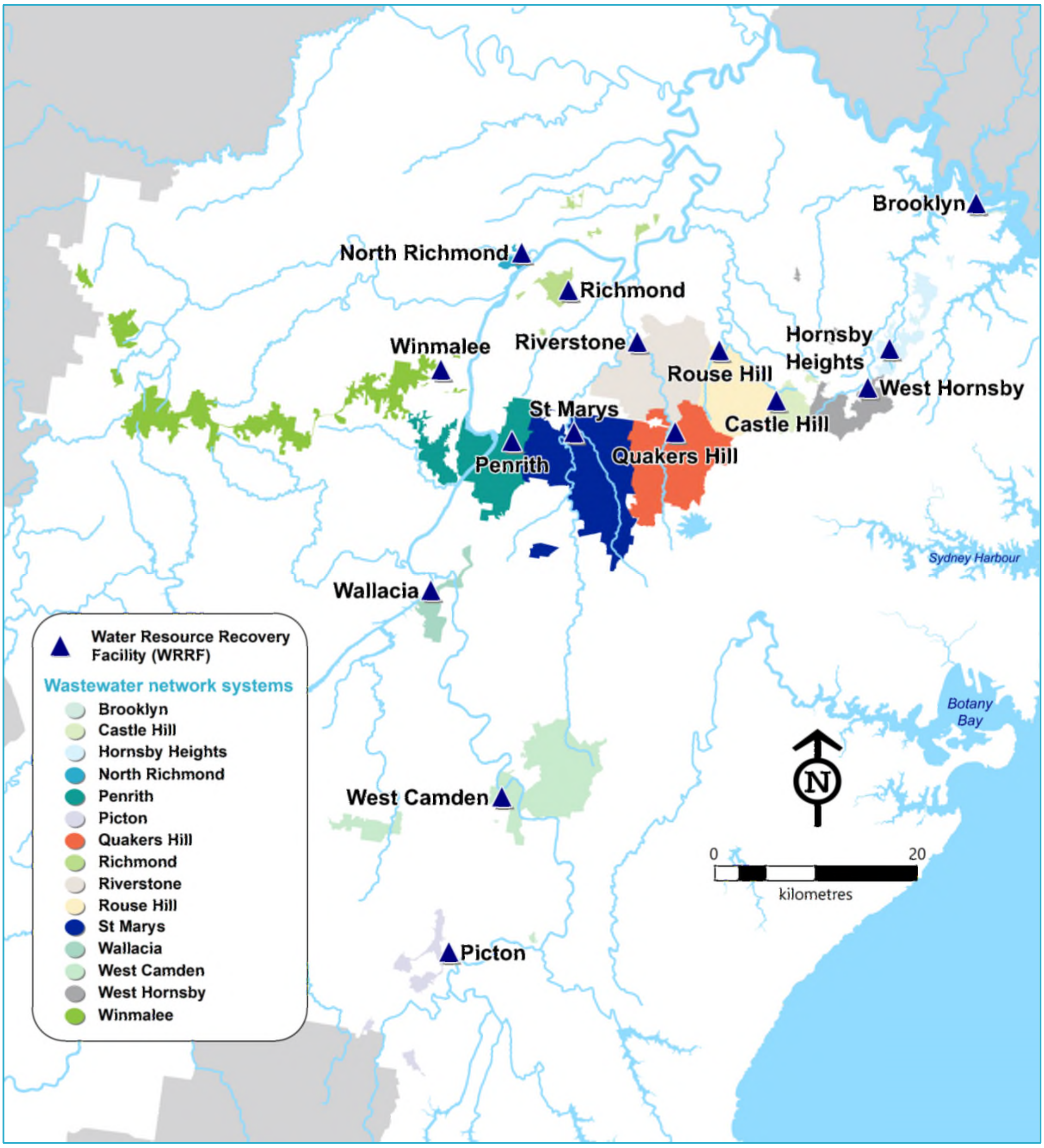


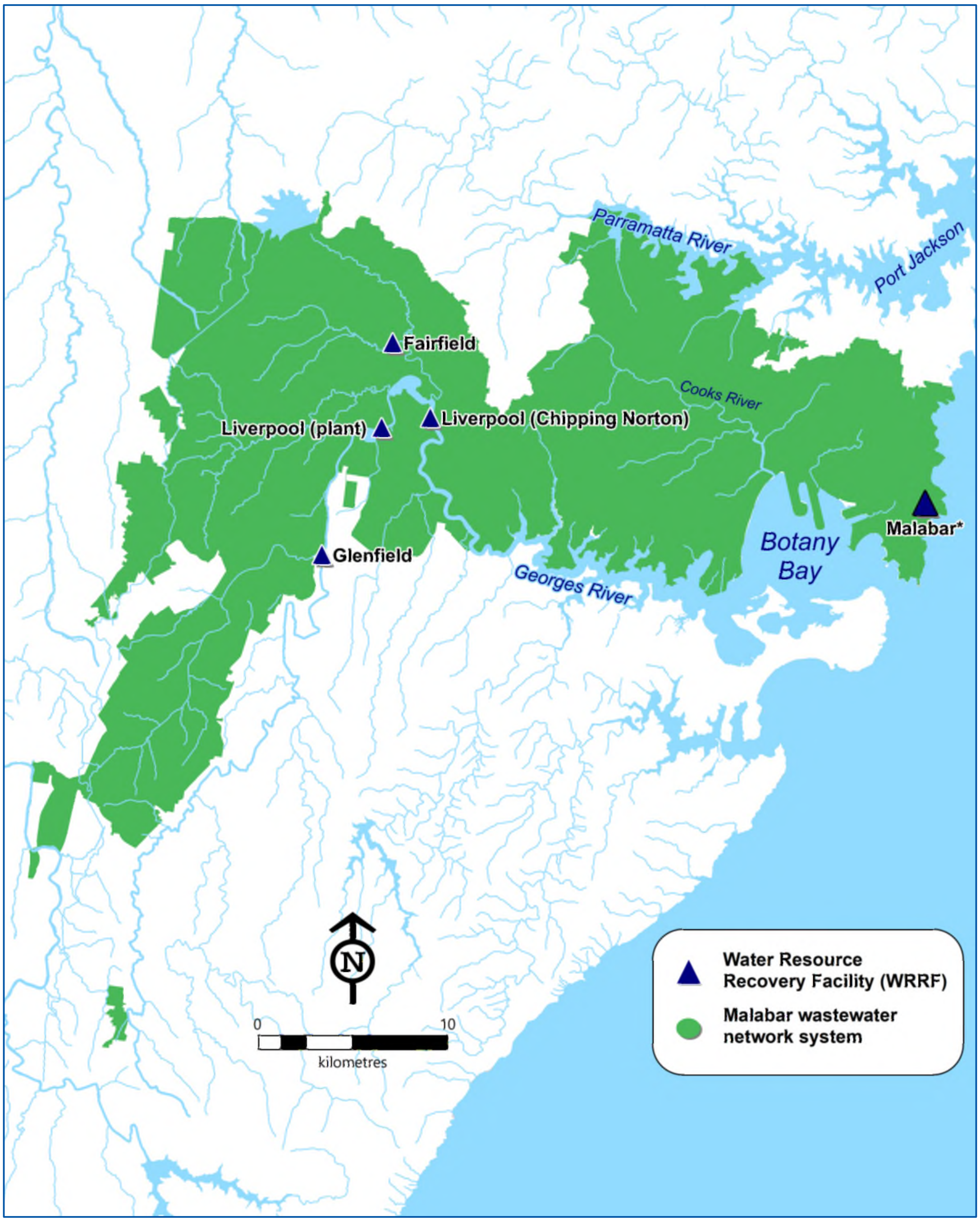
Figure 2-1 Location of WRRFs in the Hawkesbury-Nepean River catchment

Georges River WRRFs

Three WRRFs operate in the Georges River catchment (Figure 2-2). Listed from upstream to downstream, they include: Glenfield, Liverpool and Fairfield. Glenfield WRRF is located in the freshwater reaches of the Georges River, upstream of Liverpool Weir.

Liverpool WRRF is located just below Liverpool Weir, which marks the upper tidal/estuarine limit of the Georges River. Chipping Norton is Liverpool WRRF's second discharge location located at the North Georges River Submain, downstream of Prospect Creek.

Fairfield WRRF is located in Orphan School Creek, which turns into Prospect Creek and flows into the Georges River (seaward end of Chipping Norton Lakes), approximately 7 km downstream of the WRRF. Most of the treated wastewater from these WRRFs is diverted to the Malabar WRRF, and only discharge partially-treated wastewater during wet weather.



** 96% of wastewater from Malabar system discharged to ocean via deep ocean outfall, the remaining 4% (2023-24) discharged to Georges River in wet weather*

Figure 2-2 Location of WRRFs in the Georges River catchment

Nearshore WRRFs

Sydney Water discharges wastewater of differing quality into the marine environment. These outfalls are categorised by the location of discharge and include deep ocean outfalls, nearshore outfalls, cliff face outfalls and shoreline outfalls.

The locations of the nearshore, cliff face and shoreline WRRFs are shown in Figure 2-3. Sydney Water's licence permits discharges within the effluent mixing zone i.e. a zone in which the salinity is below that of normal seawater. The mixing zone dilutions for each of the shoreline, cliff face and shoreline WRRF discharges are shown in Table 2-3.

There are two nearshore outfalls Shellharbour (secondary treated) and Wollongong (tertiary treated). Both outfalls have diffusers fitted with duckbill valves to minimise saline and sediment intrusion. The Wollongong outfall is about 1000 m long extending offshore in water about 20 m deep and has 400 neoprene duckbill valves. The Shellharbour outfall is about 220 m long extending offshore in water about 8 m deep and has 200 neoprene duckbill valves.

There are seven cliff face outfalls. North Head (two outfalls), Malabar (four outfalls) and Wollongong only operate in an emergency as a backup to deep ocean or nearshore outfalls, while Vaucluse, Diamond Bay 1 and Diamond Bay 2 continuously discharge untreated wastewater with a combined average daily volume of 4 ML/day. Vaucluse is situated at the base of an 80 m high cliff and discharges approximately 2.8 ML of untreated wastewater daily. Diamond Bay 1 (DB1) is situated south of Rosa Gully at the base of a 25-30 m high cliff and discharges 0.7 ML of untreated wastewater daily. Diamond Bay 2 is located 250 m south of DB1 at the base of a 25-30 m high cliff and discharges 0.5 ML of untreated wastewater daily.

Additionally, there are six shoreline outfalls. Bellambi and Port Kembla shoreline outfalls discharge primary treated wastewater, but only operate in wet weather when required. Bombo, Cronulla, Warriewood and Brooklyn discharge effluent on a continuous basis. Bombo and Warriewood discharge secondary treated wastewater while Cronulla and Brooklyn discharge tertiary treated wastewater. Bombo, Cronulla and Warriewood outfalls are located at depths of 3-6 m. Brooklyn outfall is located in the Hawkesbury River at 14 m depth on the second pylon of the old road bridge adjacent to Kangaroo Point.

Table 2-3 Summary of discharge information for each nearshore, cliff face and shoreline outfalls

WRRF	Outfall	Water Depth	Median dilution within 50 m of discharge	Mixing zone dilution
Wollongong	1 km offshore	20 m	75	
Shellharbour	220 m offshore	8 m	100	250 within 300 m
N/A	Vaucluse	1 m		1000 within 500 m
N/A	Diamond Bay 1 & 2	1 m		1000 within 500 m
Bellambi	Bellambi Pt	5 m	50	
Port Kembla	Red Pt	5-8 m	50	400 within 300 m
Bombo	Bombo Headland	5 m	50	
Cronulla	Potter Pt	6 m	50	
Warriewood	Turimetta Head	3 m	100	350 within 300 m
Brooklyn	Kangaroo Pt	14 m	160	400-800 within 10 m

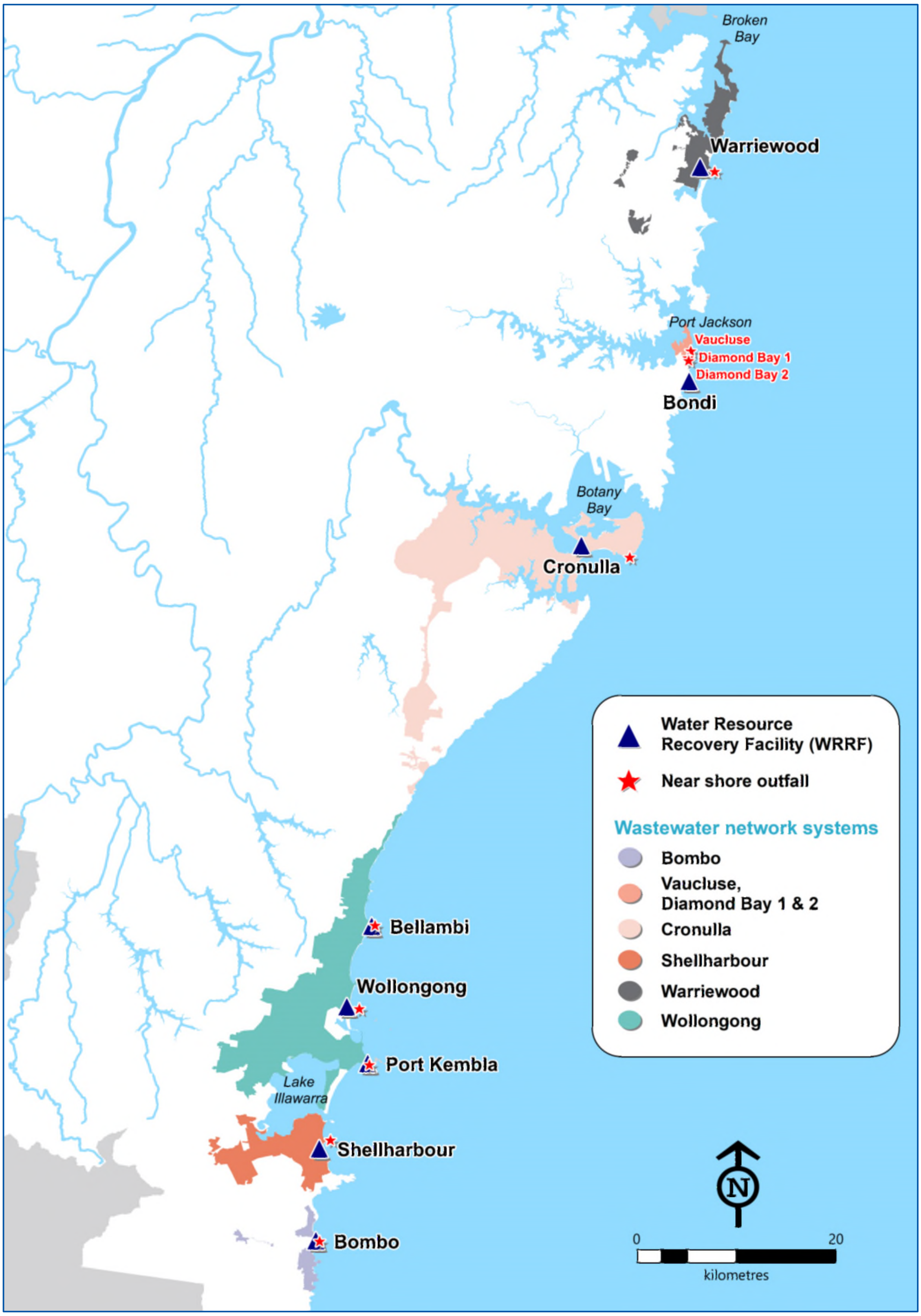


Figure 2-3 Location of WRRFs discharging to the nearshore marine environment (includes nearshore, cliff face and shoreline discharges)

Offshore WRRFs

There are three deepwater ocean outfalls that discharge primary treated wastewater (Figure 2-4). The Malabar diffuser system consists of 28 diffusers and one sludge riser approximately 25 m apart in 80 m of water. This is located approximately 3.6 km from the shore. The Bondi diffuser system consists of 26 diffusers and one sludge riser approximately 20 m apart in 60 m of water. This is located approximately 2.2 km from the shore. The North Head diffuser system consists of 36 diffusers and one sludge riser approximately 21 m apart in 60 m of water. This is located approximately 3.7 km from the shore.

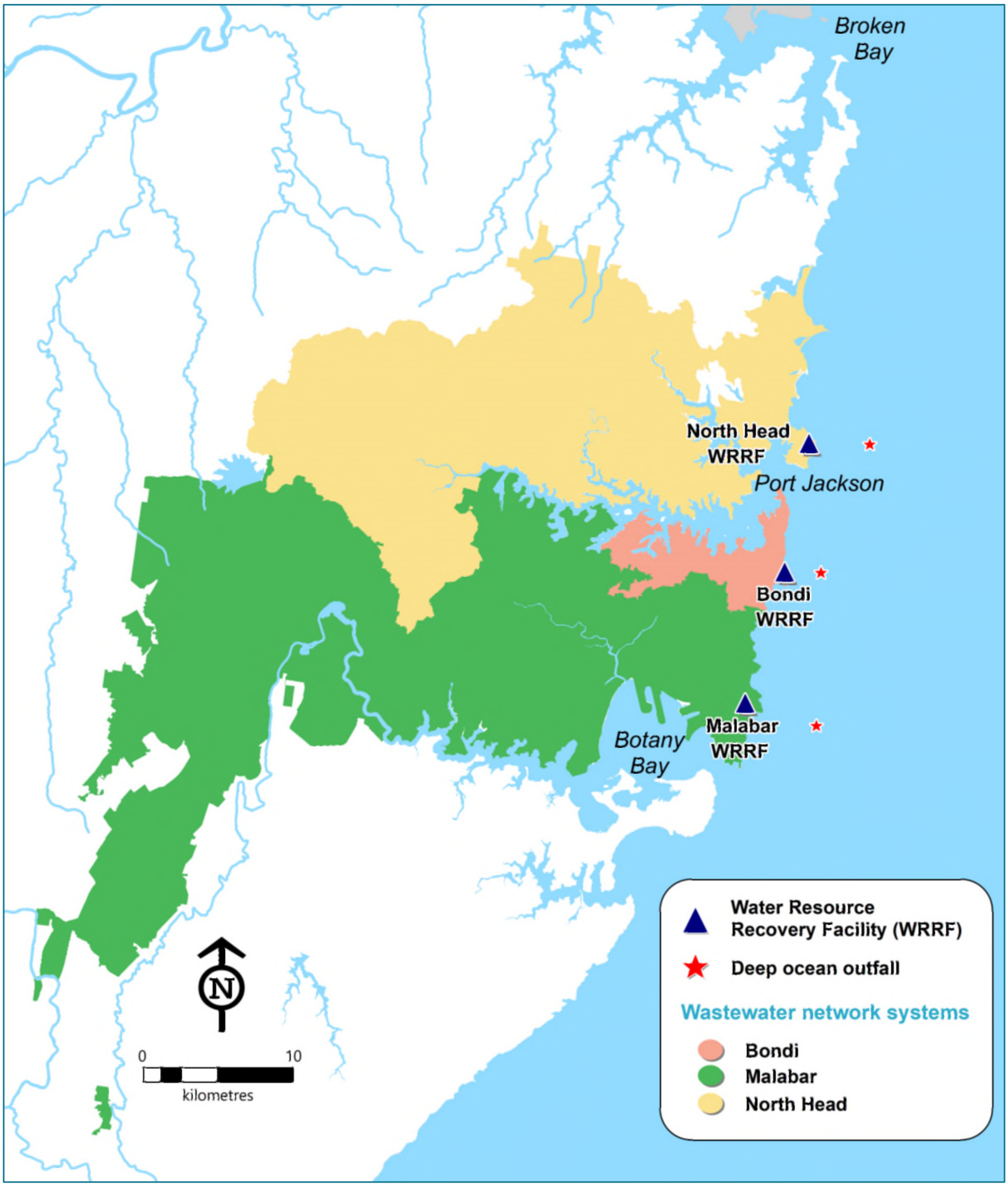


Figure 2-4 Location of WRRFs discharging to the offshore marine environment

Analytes, indicators and sampling

Relevant quantity, quality and toxicity indicators and associated parameters and details (e.g. sampling frequency and method) for each WRRF are specified in the relevant EPL and summarised in Sydney Water's Water Resource Recovery Facilities Compliance Monitoring Plan (Sydney Water 2024), which is reviewed and updated annually.

Details of each EPL can be accessed via links to individual NSW EPA EPLs Environment & Heritage | PRPOEO (nsw.gov.au).

A summary of the tests conducted on wastewater and details of the specific method used in respective laboratory analyses is presented in Table 2-4.

Table 2-4 List of analytes and methods for wastewater quality monitoring

Analytes	Detection limit	Unit of measurement	Reference
Nutrients			
Ammonia nitrogen (low level)	0.01	mg/L	APHA (2017) 4500-NH3 H
Ammonia nitrogen (high level)	0.1	mg/L	As above
Total nitrogen (by FIA)	0.05	mg/L	APHA (2017) 4500- Norg/NO3- I/J
Total phosphorus	0.01	mg/L	APHA (2017) 4500-P – H/J
Major conventional analytes			
Biochemical oxygen demand^	2	mg/L	APHA (2017) 5210B
Chlorine residual (total)	0.04	mg/L	APHA (2017) 4500-Cl G
Faecal coliforms	1	cfu/100mL	APHA (2017) 9222D
Oil and grease	5	mg/L	APHA (2017) 5520D
Total suspended solids	2	mg/L	APHA (2017) 2540D
pH	0.01	pH units	APHA 4500H+B & Instrument manual
Toxicity testing			
Ecotoxicological Endpoint: 48 hrs. Water Flea EC_{50} immobilisation	n/a	% wastewater	Based on methods described by USEPA (2002a) and ESA SOP 101 and adapted for use with the locally collected *Ceriodaphnia dubia* by Bailey et al. (2000).
Ecotoxicological Endpoint: 1 hr. Sea Urchin EC_{50} fertilisation	n/a	% wastewater	Based on methods described by USEPA (2002b) and ESA SOP 104 and adapted for use with *H. tuberculata* by Simon and Laginestra (1997) and Doyle et al. (2003).
Trace metals			
Aluminium	5	µg/L	USEPA (2014) 6020B
Cadmium	0.1	µg/L	USEPA (2014) 6020B

Analytes	Detection limit	Unit of measurement	Reference
Chromium	0.2*	µg/L	USEPA (2014) 6020B
Copper	0.5*	µg/L	USEPA (2014) 6020B
Iron	5*	µg/L	USEPA (2014) 6020B
Lead	0.1*	µg/L	USEPA (2014) 6020B
Mercury	0.01	µg/L	USEPA (2005) 245.7(Rev2.0)
Nickel	0.2*	µg/L	USEPA (2014) 6020B
Selenium	0.2*	µg/L	USEPA (2014) 6020B
Zinc	1*	µg/L	USEPA (2014) 6020B
Other chemicals and organics (including pesticides)			
Cyanide	5	µg/L	APHA (2017) 4500CN-C and E
Diazinon and Parathion	0.1	µg/L	USEPA (1998) 8141B
Ethyl chlorpyrifos and Malathion	0.05	µg/L	USEPA (1998) 8141B
Heptachlor	0.005	µg/L	USEPA (1998) 8081B
Aldrin, Dieldrin, Endosulfan (a, b), Lindane, pp-DDE (4, 4), pp-DDT (4, 4) and Total Chlordane	0.01	µg/L	USEPA (1998) 8081B
Hydrogen sulphide (un-ionised)	30*	µg/L	APHA (2017) 4500-S2- D & H
Nonyl phenol ethoxylates	5	µg/L	Naaim et al. 1996
Total PCBs	0.1	µg/L	USEPA (2000) 8082A

** method detection limit changed in recent years (2016-17)*

^ Sydney Water commenced Biochemical Oxygen Monitoring from September 2020. Historically Sydney Water have monitored Carbonaceous Biochemical Oxygen Demand in WRRF discharges.

2.2. Hawkesbury-Nepean River water quality and ecosystem health

2.2.1. Rationale

The Hawkesbury-Nepean River system is one of the longest coastal rivers in eastern Australia with a catchment area of approximately 22,000 km^2. The river drains most of the fastest growing developing areas to the west of Sydney. This development and associated activities in the catchment can adversely affect the health of the river due to a range of factors, including altered water regime, habitat modification and inputs of contaminants such as nutrients and metals. Treated wastewater is discharged to the river system from 15 Sydney Water WRRFs. However, there are also numerous other point and diffuse sources of pollution to the river, such as sewage effluent from council sewage treatment plants (STPs), stormwater and agricultural runoff.

Distinguishing the impacts associated with Sydney Water's WRRF discharges to the Hawkesbury-Nepean River system from other pressures requires a strong focus on monitoring of stressors and ecosystem receptors both upstream and downstream of the WRRF discharges, where possible. However, it is also known that impacts of nutrient inputs on phytoplankton do not necessarily occur immediately downstream of WRRF discharges, as physical factors like stream/river morphology, flow rate and light penetration are also important determinants of the potential for phytoplankton growth. Thus, maintaining a surveillance on locations known to be susceptible to high phytoplankton growth is still important, even if the exact causes of such events cannot be fully separated.

Acknowledging the above context, Sydney Water's Hawkesbury-Nepean River water quality and ecosystem health sub-program integrates the water quality, phytoplankton and stream health monitoring components together. This sub-program is intended to monitor:

- the direct aquatic environmental impacts of Sydney Water's WRRF discharges
- the State of Environment (SoE) at key long-term monitoring sites
- phytoplankton dynamics at selected riverine and creek sites, that are known to be susceptible to high phytoplankton growth, and represent each zone of the Hawkesbury-Nepean River system.

2.2.2. Aim and objectives

The aims of this sub-program are to:

- Assess the direct impacts of Sydney Water's Hawkesbury-Nepean River WRRF discharges on water quality, and ecosystem health as measured by responses of phytoplankton and macroinvertebrates.
- Characterise water quality and phytoplankton community characteristics at selected sites in the Hawkesbury-Nepean River and tributaries susceptible to higher algal abundances.

Specific objectives for each of the above aims, focusing on the relevant stressors (i.e. the physico-chemical water quality analytes) and the ecosystem receptors (i.e. phytoplankton metrics including chlorophyll-a, and macroinvertebrates), are presented in Table 2-5.

Table 2-5 Aims and objectives for the Hawkesbury-Nepean River water quality and ecosystem health sub-program

Aim	Objective
1. Assess the direct impacts of Sydney Water's Hawkesbury-Nepean River WRRF discharges on (a) water quality and (b) ecosystem health as measured by responses of phytoplankton and macroinvertebrates.	*Stressors:* a. To compare physico-chemical water quality, including nutrients, for each WRRF downstream/upstream site pair with relevant water quality objectives (where available), for the current year. b. To investigate the joint relationship between all physico-chemical water quality parameters, including nutrients, and chlorophyll-a, to identify the most meaningful parameters impacting water quality for each paired site grouping and comparing the current year with the relevant historical record. c. To compare downstream with upstream site physico-chemical water quality, including nutrients, for each downstream/upstream site pair for the current year and over the relevant historical record.
	Ecosystem receptors (phytoplankton): d. To compare chlorophyll-a concentrations for each WRRF downstream/upstream site pair with relevant water quality objectives, for the current year. e. To compare downstream with upstream site chlorophyll-a concentrations for each WRRF downstream/upstream site pair for the current year and over the relevant historical record. f. To assess spatial and temporal trends in the chlorophyll-a dataset for each WRRF downstream/upstream site pair over the relevant historical record. g. Where significant differences in upstream-downstream chlorophyll-a concentrations are detected for the current year, further investigate the potential drivers (e.g. by comparing with water quality data).
	Ecosystem receptors (macroinvertebrates): h. To compare downstream macroinvertebrate SIGNAL-SG score for the current year with the acceptable range of variability derived from its paired upstream site, for the relevant historical record. i. To compare downstream with upstream site macroinvertebrate SIGNAL-SG scores for each downstream/upstream site pair for the current year and over the relevant historical record. j. To assess temporal trends in the macroinvertebrate dataset for each WRRF downstream/upstream site pair over the relevant historical record. k. Where significant differences in upstream-downstream SIGNAL-SG scores or multivariate community analysis are detected for the current year, further investigate the ecological response and potential drivers (e.g. by comparing with water quality data).
2. Characterise water quality and phytoplankton	For each selected site: a. To compare physico-chemical water quality, including nutrients, and chlorophyll-a concentrations with relevant water quality objectives (where available), for the current year.

Aim	Objective
community structure at selected sites in the H-N River susceptible to higher algal abundances.	b. To investigate the joint relationship between all physico-chemical water quality parameters, including nutrients, and chlorophyll-a, over the relevant historical record. c. To compare physico-chemical water quality, including nutrients, and chlorophyll-a concentrations over the relevant historical record.
	For each site where full phytoplankton analysis is done: d. compare phytoplankton metrics with relevant water quality objectives (where available), for the current year. e. to investigate the joint relationship between all phytoplankton metrics over the relevant historical record. f. compare the phytoplankton metrics (i.e. total algal biovolume, blue-green algal biovolume, toxic blue-green algal counts) over the relevant historical record.

2.2.3. Monitoring approach

Design and sites

Aim 1 – assessment of direct impacts of WRRF discharges

The design focuses on comparisons of stressors and ecosystem receptors from, where possible, paired sites upstream and downstream of 14 WRRF discharges, to directly assess the impacts of the discharges. Based on local factors, there are several variations to the design, as noted below:

- For five WRRFs (Picton, West Camden, Penrith, Winmalee and North Richmond), paired sites are located both on the tributary/creek into which the discharge point is located, as well as on the Hawkesbury-Nepean River at the confluence of the tributary.
- For eight WRRFs, paired sites are located only in the branch river or respective tributary/creek where these discharges (Wallacia, Richmond, Riverstone, Quakers Hill, Rouse Hill, Castle Hill, West Hornsby and Hornsby Heights).
- For Winmalee, the unnamed stream to which Winmalee WRRF discharges is ephemeral, this prevents the upstream-downstream design applied to other WRRF discharge points. Below the Winmalee WRRF discharge point, two sites are placed on the receiving stream, one site 300 m downstream and another site 3 km downstream. In the stream reach between these two sites, there are only a few houses and no other anthropogenic influences that could confound the assessment of Winmalee. A secondary paired assessment sites are placed above (upstream) and below (downstream) the junction or confluence of the unnamed stream with the Hawkesbury-Nepean River is also conducted for Winmalee.
- For St Marys WRRF, monitoring at an unnamed creek, upstream and downstream of discharge commenced from November 2023. These are in addition to the existing paired sites upstream and downstream of the unnamed creek at South Creek.
- Although Brooklyn WRRF is located on the Hawkesbury-Nepean River, it is located in the lower estuary within the tidal zone and is not conducive to the same design as that employed for the inland WRRFs. Consequently, monitoring for Brooklyn WRRF is considered under the Nearshore marine water quality and ecosystem health sub-program, a separate SWAM sub-program and monitoring plan (noting, monitoring at this site was not recommended in the STSIMP review due to the treatment level, receiving environment, mixing and dilution (van Dam et al. 2023 and Sydney Water, 2023).

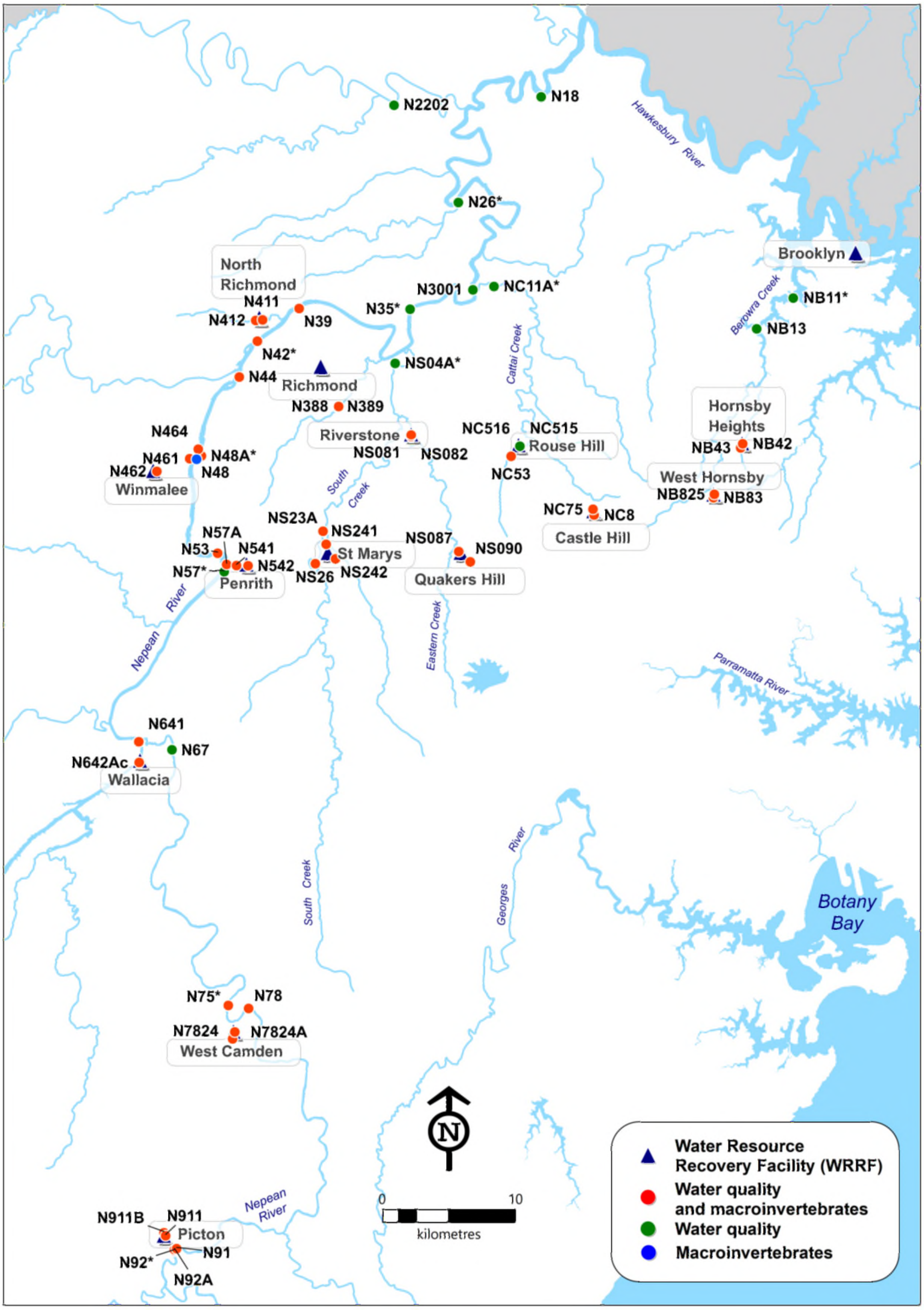
In total, there are 45 monitoring sites to address Aim 1 (Figure 2-5, Table 2-6). Where possible, water quality, chlorophyll-a and macroinvertebrates are all monitored at the same location. Where this cannot occur due to habitat suitability or access constraints, sites are located as close together as logistically possible. As a result, water quality, chlorophyll-a and macroinvertebrates are monitored at 43, 40 and 42 sites, respectively for Aim 1, as listed in Table 2-6. The design has been configured such that representative water quality data are available for all sites that are monitored for the ecosystem receptor indicators (chlorophyll-a and macroinvertebrates). For example, in some cases, water quality data need to be collected from the locations where both the chlorophyll-a and macroinvertebrate data are collected (e.g. N92 and N92A; N57 and N57A). In other cases, water quality data from one location are sufficiently representative of both locations:

i. water quality from N48A and macroinvertebrates from N48, 500 m apart in one of the two split branches of Nepean River bypassing Winmalee lagoon

ii. water quality from NC516 and macroinvertebrates from NC515 in Second Ponds Creek (20 m apart).

Aim 2 – assessment of sites susceptible to high phytoplankton growth

The design focuses on assessment of stressors and ecosystem receptors chlorophyll-a as an indicator of phytoplankton at 18 sites and phytoplankton cell count/biovolume at ten long-term sites located throughout the Hawkesbury-Nepean River system that are known to be susceptible to high phytoplankton growth (Table 2-6, Figure 2-5). These sites include eight sites that also act as one of a site pair for directly assessing WRRF discharges under Aim 1, above, and 10 sites that are not part of the WRRF discharge site pairs. Unlike Aim 1, the focus of assessment for Aim 2 is on comparisons within sites rather than between two sites.



** phytoplankton biovolume/ cell counting site* *Sites for macroinvertebrates only: N48, NC515*

Figure 2-5 Receiving water monitoring sites for the Hawkesbury-Nepean River water quality and ecosystem health sub-program

Table 2-6 Receiving water monitoring sites for the Hawkesbury-Nepean River water quality and ecosystem health sub-program

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		SWAM (Sydney Water 2023)	
			Water quality [a]	Chlorophyll-a	Macroinvertebrates	Water quality & Chlorophyll-a	Full algal [b]	Latitude	Longitude
1	N92	Nepean River immediately upstream of Maldon Weir, upstream of all Sydney Water WRRFs, Reference site	✓	✓		✓	✓	-34.20373	150.63018
2	N92A	Nepean River immediately downstream of Maldon Weir, upstream of all Sydney Water WRRFs, Reference site	✓		✓			-34.202826	150.63027
3	N911B	Stonequarry Creek at Picton Farm, upstream of discharge gully	✓	✓	✓			-34.191368	150.622137
4	N911	Stonequarry Creek at Picton Farm, downstream of Picton WRRF discharge point	✓	✓	✓			-34.19336	150.62339
5	N91	Nepean River at Maldon Bridge, downstream of Stonequarry Creek and Picton WRRF	✓	✓	✓			-34.20221	150.63219
6	N78	Nepean River at Macquarie Grove Rd, upstream of Matahil Creek and West Camden WRRF	✓	✓	✓			-34.0413	150.6958
7	N7824A	Matahil Creek, upstream of West Camden WRRF	✓	✓	✓			-34.0566	150.6868
8	N7824	Matahil Creek, downstream of West Camden WRRF	✓	✓	✓			-34.0569	150.6835
9	N75	Nepean River at Sharpes Weir, downstream of Matahil Creek and West Camden WRRF	✓	✓	✓	✓	✓	-34.0415	150.677
10	N67	Nepean River at Wallacia Bridge, upstream of Warragamba River	✓	✓	✓			-33.867	150.636

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		SWAM (Sydney Water 2023)	
			Water quality [a]	Chlorophyll-a	Macroinvertebrates	Water quality & Chlorophyll-a	Full algal [b]	Latitude	Longitude
11	N642A [c]	Warragamba River upstream of Wallacia WRRF, downstream of Warragamba Dam e-flows discharge point	✓	✓	✓			-33.87311	150.61094
12	N641	Warragamba River at Nortons Basin Road downstream of Wallacia WRRF	✓	✓	✓			-33.85923	150.61112
13	N57	Nepean River at Penrith Rowing Club ramp, upstream of Penrith Weir and Penrith WRRF	✓	✓		✓	✓	-33.7432	150.684
14	N57A	Nepean River downstream of Penrith Weir and upstream of Penrith WRRF	✓		✓			-33.74039	150.68533
15	N542	Boundary Creek, upstream of Penrith WRRF	✓	✓	✓			-33.7419	150.70274
16	N541	Boundary Creek, downstream of Penrith WRRF	✓	✓	✓			-33.74149	150.69333
17	N53	Nepean River at BMG Causeway, downstream of Penrith WRRF	✓	✓	✓	✓		-33.715	150.657
18	N48	Nepean River at Smith Road, Princes farm, upstream of Winmalee WRRF			✓			-33.6690647	150.6629417
19	N48A	Nepean River at Smith Road, Princes farm (500m downstream) upstream of Winmalee WRRF	✓	✓		✓	✓	-33.666858	150.66703
20	N462	Unnamed Creek, 0.3 km downstream of Winmalee WRRF	✓	✓	✓			-33.67684	150.62926
21	N461	Unnamed Creek 3 km downstream of Winmalee WRRF	✓	✓	✓			-33.66856	150.65736

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		SWAM (Sydney Water 2023)	
			Water quality [a]	Chlorophyll-a	Macroinvertebrates	Water quality & Chlorophyll-a	Full algal [b]	Latitude	Longitude
22	N464	Nepean River (Winmalee Lagoon) at Springwood Road, downstream of Winmalee WRRF, before Shaws Creek	✓	✓	✓			-33.6633	150.663
23	N44	Nepean River at Yarramundi Bridge, downstream of Winmalee WRRF			✓[d]	✓		-33.6146	150.698
24	N42	Hawkesbury River upstream of North Richmond WRRF, downstream of Grose River	✓	✓	✓	✓	✓	-33.5868	150.723
25	N412	Redbank Creek, upstream of North Richmond WRRF	✓	✓	✓			-33.57592	150.7133
26	N411	Redbank Creek, downstream of North Richmond WRRF	✓	✓	✓			-33.5756	150.71892
27	N39	Hawkesbury River at Freemans reach, downstream of North Richmond WRRF, upstream of South Creek	✓	✓	✓	✓		-33.57	150.747
28	N389	Rickabys Creek, upstream of with confluence of unnamed creek below Richmond WRRF discharge	✓	✓	✓			-33.63535	150.77792
29	N388	Rickabys Creek, downstream of confluence of unnamed creek, below Richmond WRRF discharge	✓	✓	✓			-33.63533	150.77833
30	NS26	South Creek, upstream of St Marys WRRF	✓	✓	✓			-33.7428	150.758
31	NS242	Unnamed Creek, upstream of St Marys WRRF	✓	✓	✓			-33.738516	150.773599
32	NS241	Unnamed Creek, downstream of St Marys WRRF	✓	✓	✓			-33.7284842	150.76634

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		SWAM (Sydney Water 2023)	
			Water quality [a]	Chlorophyll-a	Macroinvertebrates	Water quality & Chlorophyll-a	Full algal [b]	Latitude	Longitude
33	NS23A	South Creek, downstream of St Marys WRRF	✓	✓	✓			-33.7333	150.766
34	NS082	Eastern Creek, upstream of Riverstone WRRF	✓	✓	✓			-33.6695	150.851
35	NS081	Eastern Creek, downstream of Riverstone WRRF	✓	✓	✓			-33.668	150.846
36	NS090	Breakfast Creek, upstream of Quakers Hill WRRF	✓	✓	✓			-33.7450	150.884
37	NS087	Breakfast Creek, downstream of Quakers Hill WRRF	✓	✓	✓			-33.7361	150.872
38	NS04A	Lower South Creek at Fitzroy pedestrian bridge, Windsor				✓	✓	-33.6088	150.824
39	N35	Hawkesbury River at Wilberforce, Butterfly farm, downstream of South Creek				✓	✓	-33.5730	150.838
40	NC53	Second Ponds Creek upstream of Rouse Hill WRRF at Withers Road	✓	✓	✓			-33.6716	150.9174
41	NC515	Second Ponds Creek, downstream of Rouse Hill WRRF			✓			-33.6648	150.9248
42	NC516	Second Ponds Creek, downstream of Rouse Hill wetland and bypass from Rouse Hill WRRF	✓	✓				-33.6649	150.92472
43	NC8	Cattai Creek, upstream of Castle Hill WRRF	✓	✓	✓			-33.7143	150.982
44	NC75	Cattai Creek, downstream of Castle Hill WRRF	✓	✓	✓			-33.7084	150.982
45	NC11A	Lower Cattai Creek at Cattai Road Bridge, 100m downstream of bridge				✓	✓	-33.5591	150.907

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		SWAM (Sydney Water 2023)	
			Water quality [a]	Chlorophyll-a	Macroinvertebrates	Water quality & Chlorophyll-a	Full algal [b]	Latitude	Longitude
46	N3001	Hawkesbury River Off Cattai State Recreation Area (SRA), downstream of Cattai Creek				✓		-33.5583	150.889
47	N26	Hawkesbury River at Sackville Ferry, downstream of Cattai Creek				✓	✓	-33.5007	150.876
48	N2202	Lower Colo River at Putty Road Bridge, Reference site				✓		-33.4325	150.829
49	N18	Hawkesbury River at Leets Vale, opposite Leets Vale Caravan Park, downstream of Colo River				✓		-33.428	150.948
50	NB83	Waitara Creek, upstream of West Hornsby WRRF	✓	✓	✓			-33.7045	151.079
51	NB825	Waitara Creek, downstream of West Hornsby WRRF	✓	✓	✓			-33.7028	151.08
52	NB43	Calna Creek, upstream of Hornsby Heights WRRF	✓	✓	✓			-33.6714	151.101
53	NB42	Calna Creek, downstream of Hornsby Heights WRRF	✓	✓	✓			-33.6688	151.103
54	NB13	Berowra Creek at Calabash Bay (Cunio Point)				✓		-33.5869	151.118
55	NB11	Berowra Creek, Off Square Bay (Oaky Point)				✓	✓	-33.5667	151.148

[a] *Refer to Table 2-7 for specific water quality analytes/parameters to be measured.*

[b] *Refer to Table 2-7 for specific phytoplankton parameters to be measured.*

[c] *Site may not be accessible on every sampling occasion.*

[d] *Site is to be retained as a macroinvertebrate site for 3-5 years until there are sufficient data available for N464 to act as a new Winmalee WRRF downstream site on the Hawkesbury River*

[e] *re-categorised to serve as upstream proxy site for the Wallacia WRRF*

Analytes, indicators and sampling

The full list of analytes and monitoring methods of Stressor analytes and Ecosystem Receptor indicators and associated monitoring parameters are listed in Table 2-7.

Water quality and macroinvertebrates are monitored, depending on the site, as listed in Table 2-6. The analytes and indicators have been selected on the basis of knowledge of the stressors present in WRRF discharges and key components of the aquatic ecosystem that are known to be responsive to WRRF discharges and that represent broadly accepted indicators of ecosystem health.

Water quality, chlorophyll-a and phytoplankton

Aim 1 – assessment of direct impacts of WRRF discharges

For water quality and chlorophyll-a, field measurements and samples are collected at an interval of three weekly ± four days i.e. 17 to 25 days. It may not be possible to sample all the sites along the river and tributaries on a single day. However, upstream and downstream site pair for each WRRF must be sampled on the same day (e.g. N57, N57A, N53, N542 and N541 for Penrith WRRF). River and tributary sites of a single zone e.g. Upper Nepean River, Stonequarry Creek and Matahil Creek should be sampled on the same day. It is preferable for upper and mid river zones to be sampled a day earlier and bottom reaches (boat run) a day after. A maximum of two days variability between sampling runs for the upstream and downstream reaches of the river can be considered in special circumstances.

At each site, two replicate samples are collected first for making a composite sample for analysis to minimise local variability. These temporary replicate samples are obtained either by one of two methods:

- collect two samples approximately 100 m apart e.g. river site sampled by boat or from the shore where water flow is not clearly visible
- collect two samples from one site approximately five minutes apart e.g. creek site where flowing water is clearly visible

Water samples are collected at a depth of 0.5 m below the water surface to avoid surface scum where feasible, and also above the sediment where the water depth is too low i.e. middle of water column.

Field measurements (Table 2-7) are taken at each site after sample collection on one of the replicate samples, especially dissolved oxygen that many change during mixing samples. Duplicates samples are then mixed into one sample for each site. These composited samples are analysed in Sydney Water laboratories by NATA (National Association of Testing Authorities) accredited methods for the selected analytes (Table 2-7).

Aim 2 – assessment of sites susceptible to high phytoplankton growth

Water quality and chlorophyll-a and/or full phytoplankton parameters are monitored, depending on the site, as listed in Table 2-6. Full phytoplankton parameters are chlorophyll-a, planktonic algal biovolume and cell count to genus level, with blue-green biovolume and toxic blue-green count subsequently derived from the biovolume and cell count of each genus. Sampling details for water quality and phytoplankton parameters are the same as described for Aim 1, above.

Macroinvertebrates

Macroinvertebrate samples are collected on a bi-annual basis every autumn and spring. At each site, samples are collected for up to four habitat types (pool edges, pool rock, macrophytes, and riffles). If not all habitats are present at a site during a sampling period, the corresponding habitat(s) from the other upstream/downstream site pair is not used in the analysis. If only one habitat is available from a site, a replicate sample for this habitat is collected.

Macroinvertebrates sample are sorted in the field using a specific rapid biological assessment (RBA) method developed by Chessman (1995) and subsequently refined by others (e.g. Chessman et al. 2007a, Besley and Chessman 2008), to obtain the range of animals present at each site. Sorted collections of freshwater macroinvertebrates are then returned to Sydney Water's laboratories for identification. All samples are examined using high magnification to identify and count all organisms up to genus level using published keys (Hawking 2000) or using descriptions and reference specimens maintained by the Sydney Water Laboratory (accreditation number 610 issued by NATA). The QA/QC procedures are consistent with those developed for the Monitoring River Health Initiative (Humphrey et al. 1998), and involve the regular assessment of sorters (once every 2 years) to a benchmark laboratory sorted 'truth' performed by experts.

A key metric used to analyse the macroinvertebrate data is the univariate biotic index known as the Stream Invertebrate Grade Number - Average Level, Sydney Genus (SIGNAL-SG). SIGNAL-SG is a biotic index that indicates the condition of a waterbody based on the response of the macroinvertebrate community to the presence of pollutants, particularly those associated with sewage pollution (Besley and Chessman 2008). The significant development effort that has gone into SIGNAL-SG (in addition to identifying macroinvertebrates to genus level) has resulted in a metric that possesses:

i. good specificity and relative sensitivity for detecting responses of macroinvertebrate communities to water quality perturbations, particularly sewage pollution, and

ii. relatively low dependence on other (i.e. non water quality) environmental variables.

For the purposes of statistical analysis, eight "replicates" for each site (four habitats x two sampling occasions) from one financial year (spring and autumn) are pooled.

Table 2-7 Stressor (analytes) and ecosystem receptor indicators, methods and other associated parameters for the Hawkesbury-Nepean River water quality and ecosystem health sub-program [a]

PSER element	Line of evidence	Indicator	Analyte / parameter				
			Analyte	Detection limits	Unit of measurements	Analyte method code / Reference	Place of measurement
Stressor	Physico-chemical	General water quality	General Comments		Comments	FS01,	Field
			Temperature	-	°C	FS010, APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
			Dissolved oxygen (DO)	-	mg/L and % sat	FS067, APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
			pH	0.01	pH unit	as above	Field
			Conductivity	-	µS/cm	as above	Field
			Turbidity	-	NTU	FS090, APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
Stressor	Chemical [b]	Nutrients and toxicants	Total ammonia nitrogen	0.01	mg/L	NU40, APHA (2017) 4500-NH3-H	Laboratory
			Oxidised nitrogen	0.01	mg/L	NU43, APHA (2017) 4500 NO3-I	Laboratory
			Total nitrogen	0.01	mg/L	NU57, APHA (2017) 4500- Norg/NO3-	Laboratory
			Filterable total phosphorus[c]	0.002	mg/L	NU60, APHA (2017) 4500-P-H	Laboratory
			Soluble reactive phosphorus	0.002	mg/L	NU54, APHA (2017) 4500-P-H	Laboratory

PSER element	Line of evidence	Indicator	Analyte / parameter				
			Analyte	**Detection limits**	**Unit of measurements**	**Analyte method code / Reference**	**Place of measurement**
			Total phosphorus	0.002	mg/L	NU57, APHA (2017) 4500- Norg/NO3-	Laboratory
Stressor	Chemical [b]	Total acid extractable metals and dissolved/ filterable metals	Aluminium (Al)	5	µg /L	TM66TW, TM66FW, TM66SDT and TM66SDF USEPA (2014) 6010	Laboratory
			Cobalt (Co)	0.1	µg /L	as above	Laboratory
			Copper (Cu)	0.5	µg /L	as above	Laboratory
			Nickel (Ni)	0.2	µg /L	as above	Laboratory
			Zinc (Zn)	1	µg /L	as above	Laboratory
Ecosystem receptor	Biodiversity	Phytoplankton communities	Chlorophyll-a	0.2	µg/L	MC02, APHA (2017) 10200-H ½	Laboratory
			Algal / phytoplankton biovolume and cell count to genus level [d]	-	mm3/L and cells/mL	MA70CENT, APHA (2017) 10200-F	Laboratory
		Macroinverte-brate communities	SIGNAL-SG, Community structure			Hawking 2000, Besley and Chessman 2008	Laboratory

[a] *Refer to Table 2-6 for details of sites at which analytes/indicators should be measured.*

[b] *The recommended suite of chemical analytes should be considered as interim and will be expanded in the future following the findings from a comprehensive study of treated wastewater, receiving water and associated screening-level risk assessments.*

[c] *for 2023-24 years only, to compare with the soluble reactive phosphorus.*

[d] *The variables, blue-green algal biovolume, toxic blue-green algal biovolume and toxic blue-green algal count are derived from the algal biovolume and cell count parameters.*

2.3. Georges River water quality and ecosystem health

2.3.1. Rationale

The Georges River drains a catchment of approximately 1000 km^2 to the south-west of Sydney. Treated wastewater is discharged to the river system from three Sydney Water WRRFs, at Glenfield, Liverpool and Fairfield. While the majority of treated wastewater from these WRRFs is diverted to Malabar WRRF, discharges of partially-treated wastewater to the Georges River can occur during wet weather. There are also numerous other point and diffuse sources of pollution to the river, including stormwater and agricultural runoff.

Distinguishing impacts associated with Sydney Water's WRRF discharges to the Georges River system from other pressures requires a strong focus on monitoring of stressors and ecosystem receptors both upstream and downstream of the WRRF discharges, where possible. This is straightforward for the Glenfield WRRF, which is located in a freshwater, non-tidal reach of the Georges River, but challenging for the Liverpool and Fairfield WRRFs, which are located in estuarine, tidal reaches, where the tidal influence prevents a typical upstream/downstream site design from being used. Moreover, unlike the standard use of macroinvertebrates as ecosystem receptor indicators for freshwaters, there are currently no such standard methods for estuarine invertebrates. The constraints associated with effective impact monitoring for the Liverpool and Fairfield WRRFs were discussed by van Dam et al. (2023).

Acknowledging the above context, Sydney Water's Georges River water quality and ecosystem health sub-program focuses on monitoring the direct aquatic environmental impacts of discharges from the Glenfield WRRF only. Impact monitoring for the Liverpool and Fairfield WRRF discharges will be added to the sub-program following the completion of feasibility studies to determine the most appropriate design, indicators (stressor and ecosystem receptor) and sampling and processing methods for assessing the impacts of discharges into tidal estuarine waters.

This monitoring sub-program will be reviewed periodically to include additional details or modification based on the outcomes from pilot studies, following consultation and approval with the EPA.

2.3.2. Aim and objectives

For the reasons detailed above, the aim of this sub-program focuses only on the Glenfield WRRF discharge, and is to:

- Assess the direct impacts of Sydney Water's Glenfield WRRF discharge on water quality, and ecosystem health as measured by responses of phytoplankton and macroinvertebrates.

Specific objectives for the above aim, focusing on the relevant stressors and the ecosystem receptors, are presented in Table 2-8. The aim and associated objectives will be updated when monitoring for the Liverpool and Fairfield WRRF discharges is added.

Table 2-8 Aims and objectives for the Georges River water quality and ecosystem health sub-program

Aim	Objective
Assess the direct impacts of Sydney Water's Glenfield WRRF discharge on (a) water quality and (b) ecosystem health as measured by responses of phytoplankton and macroinvertebrates.	*Stressors:* a. To compare physico-chemical water quality, including nutrients, for each WRRF downstream/upstream site pair with relevant water quality objectives (where available), for the current year. b. To investigate the joint relationship between all physico-chemical water quality parameters, including nutrients, and chlorophyll-a, to identify the most meaningful parameters impacting water quality for each paired site grouping and comparing the current year with the relevant historical record. c. To compare downstream with upstream site physico-chemical water quality, including nutrients, for each downstream/upstream site pair for the current year and over the relevant historical record.
	Ecosystem receptors (phytoplankton): d. To compare chlorophyll-a concentrations for each WRRF downstream/upstream site pair with relevant water quality objectives, for the current year. e. To compare downstream with upstream site chlorophyll-a concentrations for each WRRF downstream/upstream site pair for the current year and over the relevant historical record. f. To assess spatial and temporal trends in the chlorophyll-a dataset for each WRRF downstream/upstream site pair over the relevant historical record. g. Where significant differences in upstream-downstream chlorophyll-a concentrations are detected for the current year, further investigate the potential drivers (e.g. by comparing with water quality data).
	Ecosystem receptors (macroinvertebrates): h. To compare downstream macroinvertebrate SIGNAL-SG score for the current year with the acceptable range of variability derived from its paired upstream site, for the relevant historical record. i. To compare downstream with upstream site macroinvertebrate SIGNAL-SG scores for each downstream/upstream site pair for the current year and over the relevant historical record. j. To assess temporal trends in the macroinvertebrate dataset for each WRRF downstream/upstream site pair over the relevant historical record. k. Where significant differences in upstream-downstream SIGNAL-SG scores or multivariate community analysis are detected for the current year, further investigate the ecological response and potential drivers (e.g. by comparing with water quality data).

2.3.3. Monitoring approach

Design and sites

The design focuses on comparisons of stressors and ecosystem receptors from paired sites in the Georges River upstream and downstream of the Glenfield WRRF discharge to directly assess the impacts of the discharges (Table 2-9 and Figure 2-6).

Glenfield WRRF is a wet weather operating plant to store, treat and discharge excessive wastewater inflows from the Malabar WRRF. Effluent is treated to secondary standard before discharging to the Georges River. During extreme wet weather conditions if the inflow to the pump station (SP353) is above the pumping capacity, it overflows into Bunbury Curran Creek untreated. Under such conditions it is highly diluted.

Glenfield WRRF was included in the SWAM program from June 2023. A Georges River monitoring site upstream of the Glenfield WRRF discharge was assessed and selected (GR23B). A suitable monitoring site immediately downstream of the confluence of Bunbury Curran Creek was not identified due to access issues. Therefore, a monitoring site further downstream of Bunbury Curran Creek was selected as downstream site (GR23).

To understand the impact of Bunbury Curran Creek on the downstream site (GR23), an additional site was chosen downstream of the wastewater overflow on Bunbury Curran Creek (GR231A).

Table 2-9 Receiving water monitoring sites for the Georges River water quality and ecosystem health sub-program (Glenfield WRRF only)

Site code	Site description	Latitude	Longitude
GR23B	Georges River upstream of Glenfield WRRF, Southern end of plant	-33.985921	150.908956
GR231A	Bunbury Curran Creek, downstream of wastewater overflow point, Northern end of plant at rocky riffle zone	-33.978938	150.908997
GR23	Georges River at Cambridge Avenue, downstream of Glenfield WRRF and Bunbury Curran Creek	-33.969868	150.912139

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are the same as the Hawkesbury-Nepean River sub-program, with the exception of phytoplankton counts/biovolume, which are not required for these sites (Table 2-7).

Water quality (physico-chemical, nutrients, toxicants and metals), chlorophyll-a and macroinvertebrates are monitored at all sites. Sampling details are the same as described for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 2.2.3).

2.3.4. Fairfield and Liverpool and feasibility study

A feasibility study will be conducted to determine a suitable monitoring design and indicators to understand the impact of Fairfield and Liverpool WRRFs discharges on water quality and ecosystem health of the Georges River. Further details about this study will be included at a later date when available.

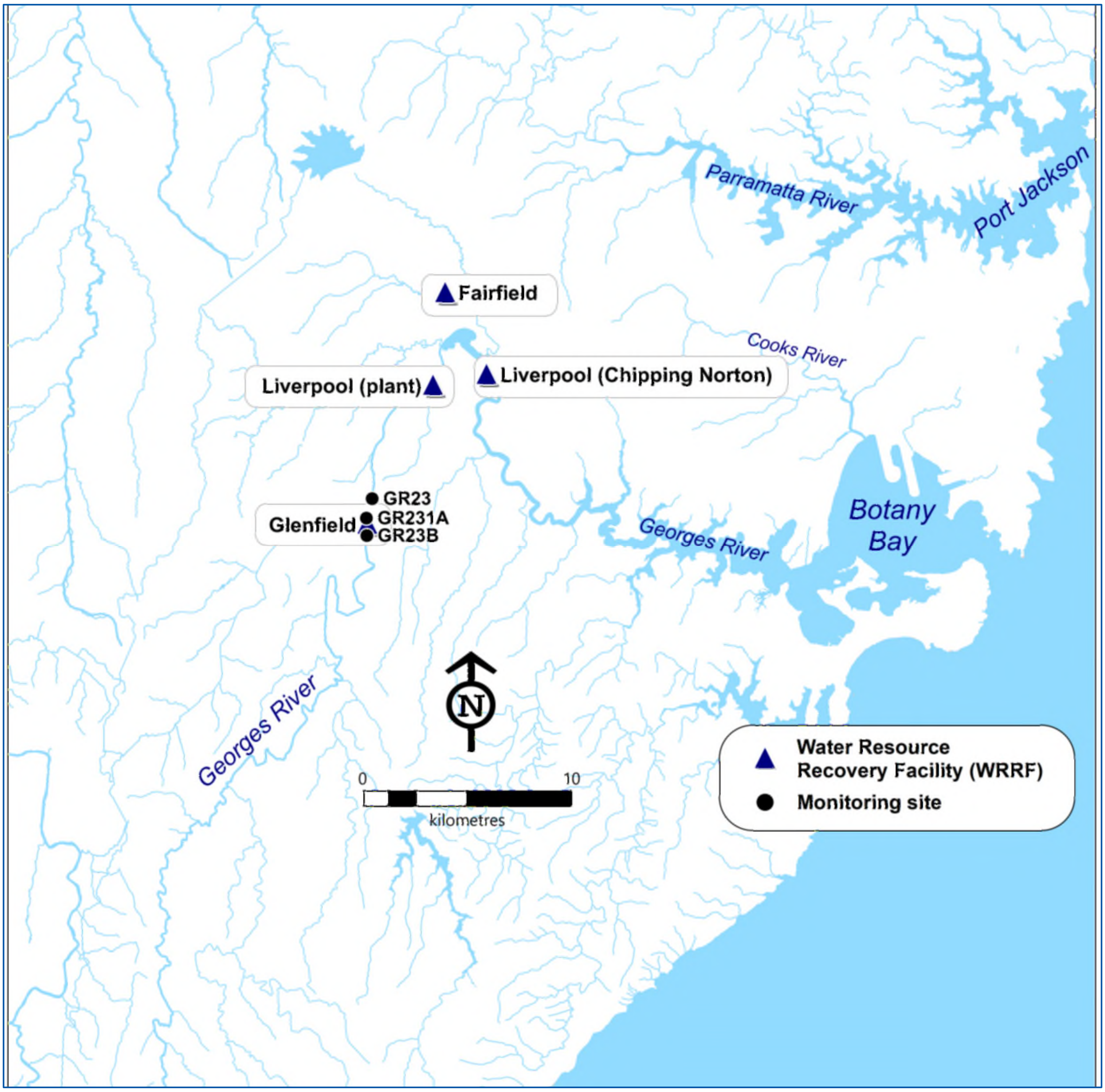


Figure 2-6 Site locations for Georges River water quality and ecosystem health sub-program (Glenfield WRRF only)

2.4. Freshwater reference sites water quality and ecosystem health

2.4.1. Rationale

Freshwater reference sites are included in the study design to understand how the water quality and ecosystem health of freshwater sites in the Hawkesbury-Nepean River and Georges River systems are potentially impacted by Sydney Water WRRF discharges compared with sites bushland areas without urban or rural influences on water quality. Macroinvertebrate data from these sites are also used to periodically calibrate the macroinvertebrate SIGNAL-SG biotic index used for both the Hawkesbury-Nepean River and Georges River (Glenfield WRRF only) water quality and ecosystem health monitoring sub-programs.

In addition to the overview below, details of the changes to the monitoring sub-program can be found in the STSIMP recommendations report (van Dam et al. 2023).

2.4.2. Aim and objectives

The aim and specific objective for the sub-program are presented in Table 2-10.

Table 2-10 Aim and objective for the reference sites water quality and ecosystem health sub-program

Aim	Objective
To maintain a baseline of water quality and macroinvertebrate communities at reference sites, to assist with assessing impacts of Sydney Water's WRRF discharges on macroinvertebrate communities.	To assess temporal trends in physico-chemical water quality and SIGNAL-SG for the relevant historical record.
To measure the general ambient condition of freshwater sites in the other* major rivers feeding the Sydney estuaries that may be impacted by wastewater overflows and stormwater	To assess temporal trends in SIGNAL-SG

** Hawkesbury-Nepean River has a separate program*

2.4.3. Monitoring approach

Design and sites

This sub-program consists of seven reference sites as listed in Table 2-11 and shown Figure 2-7. Two sites are located in both the Hawkesbury-Nepean River (N628, N451) and Georges River (GE510, GR24) catchments, while there is one site in each of the Hacking River, Lane Cove River and McCarrs Creek catchments.

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are same as the Hawkesbury-Nepean River sub-program, With the exceptions of chlorophyll-a and phytoplankton counts/biovolume, which are not required for these sites (Table 2-7).

Water quality (physico-chemical, nutrients, toxicants and metals) and macroinvertebrates are monitored at all sites. Sampling details are the same as described for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 2.2.3).

Table 2-11 Sites for the reference sites water quality and ecosystem health sub-program

Site code	Site description	Latitude	Longitude
GE510*	O'Hares Creek u/s confluence with Georges River	-34.0943667	150.8348658
GR24	Georges River at Ingleburn Reserve Weir	-34.0067166	150.8881742
PH22	Hacking River at McKell Avenue	-34.1524329	151.0286218
LC2421	Unnamed tributary of Devlin's Creek, Lane Cove River	-33.75087	151.08427
NP001	McCarrs Creek	-33.662873	151.250209
N628	Bedford Creek	-33.772116	150.499056
N451	Lynchs Creek	-33.65117	150.66492

latitude and longitude for macroinvertebrate monitoring: -34.094409 and 150.834893

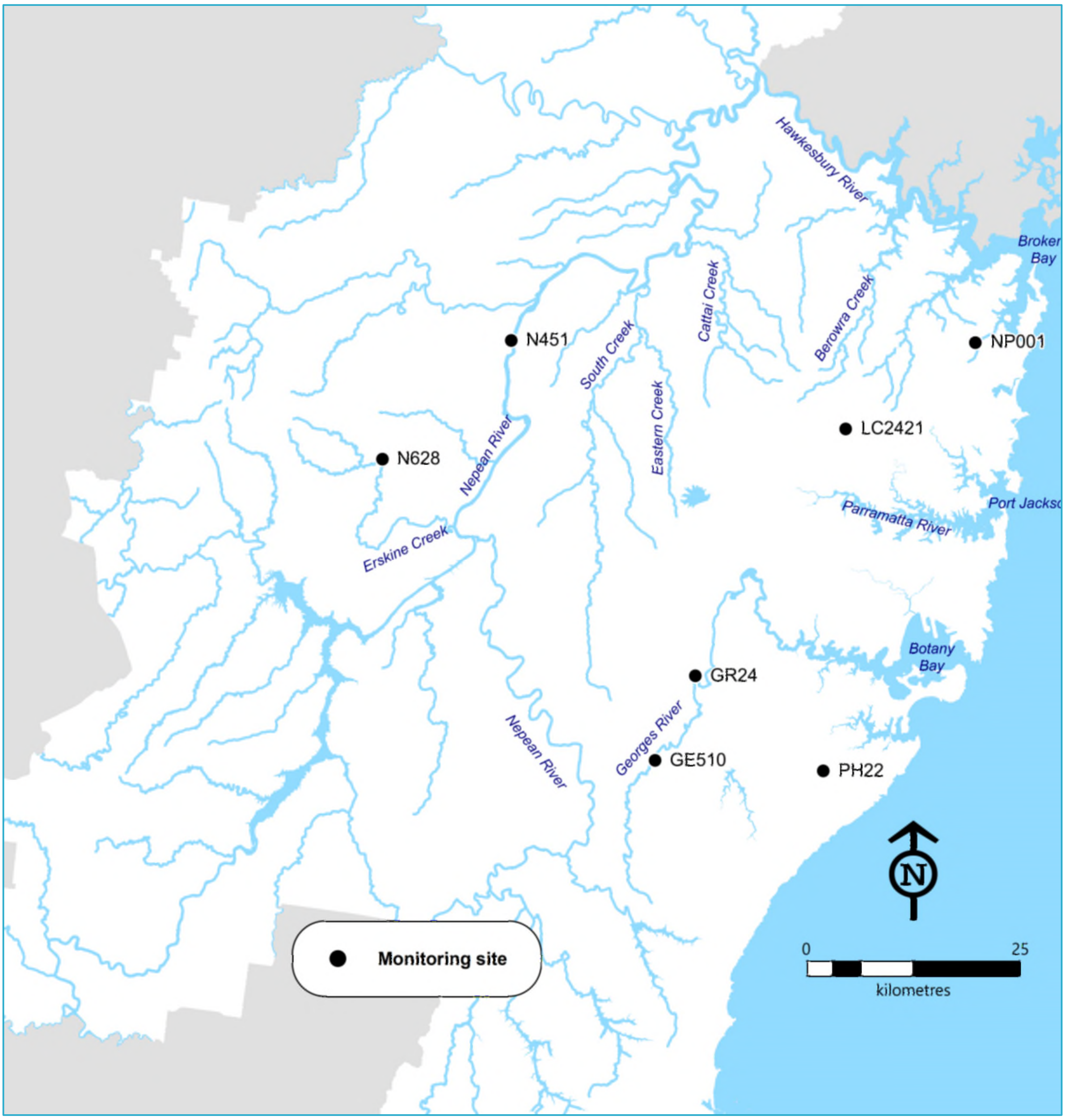


Figure 2-7 Site locations for the reference sites water quality and ecosystem health sub-program

2.5. Nearshore marine ecosystem health

2.5.1. Rationale

Sydney Water discharges wastewater of differing quality into the marine environment. These outfalls are categorised by the location of discharge and include:

- three deep ocean outfalls (North Head, Bondi and Malabar, discussed in sections 2.7.3 and 2.8.3)
- two nearshore outfalls (Shellharbour, Wollongong)
- ten cliff face outfalls (Malabar four, North Head two, Wollongong one, Vaucluse, Diamond Bay 1 and Diamond Bay 2) and
- six shoreline outfalls (Bellambi, Port Kembla, Bombo, Cronulla, Warriewood and Brooklyn).

Treatment levels at these nearshore, cliff face and shoreline discharges varies at different levels:

- tertiary treated (Cronulla and Brooklyn)
- secondary treated (Shellharbour, Wollongong, Bombo and Warriewood)
- primary treated (Bellambi and Port Kembla), only operate in wet weather
- untreated (Vaucluse and Diamond Bay)

Current EPLs allow for an impact within the mixing zone for each of these outfalls. However, Sydney Water's outfalls may impact the local aquatic ecology outside the mixing zone. Other studies of impacts of sewage discharges on intertidal biota in NSW have shown the responses by marine organisms are site specific and highly variable. The extent of the impact differs with level of treatment, type of disinfection process and the dilution of the effluent around the discharge site.

Distinguishing impacts associated with Sydney Water's WRRF discharges to the nearshore marine environment from other pressures requires a strong focus on monitoring of stressors and ecosystem receptors at outfall and reference sites, where possible. The sub-program is designed to monitor the direct aquatic environmental impacts of Sydney Water's WRRF discharges on the rocky intertidal and subtidal communities.

The Nearshore Marine Waters monitoring sub-program program was revised in the SWAM program (Sydney Water 2023) to include new sites and analytes. It requires method development and feasibility studies. Pending the findings from the feasibility studies, it will gradually be incorporated into future monitoring.

In 2023-24 we monitored one outfall (Shellharbour) using our traditional STSIMP monitoring method. As per previous years, monitoring of the other outfall sites was not possible due to safety concerns.

In 2024-25, we plan on trialling unmanned aerial vehicles (UAVs or drones) to survey shoreline outfalls that have rock platforms (Shellharbour, Bombo and Warriewood). We will also monitor Shellharbour using the current method. The suitability of the new method to be included in future monitoring will be determined following comparison of the data between both methods, and an overall review of the success of the new method (both sample collection and data analysis).

The monitoring method for the subtidal sites will be considered later in upcoming years.

2.5.2. Aim and objectives

The aim of the previous STSIMP nearshore marine water program is to assess any significant change in ecological communities (macroalgal % cover and macroinvertebrate counts) from Sydney Water's WRRFs discharging into the nearshore ocean environment.

The revised aim of SWAM Nearshore marine water sub-programs is to:

- Assess the direct impacts of Sydney Water's nearshore WRRF ocean discharges on (a) water quality and (b) ecosystem health (intertidal macro algae and invertebrates).
- Assess the direct impacts of Sydney Water's nearshore WRRF ocean discharges on (a) water quality and (b) ecosystem health (subtidal macroalgae and invertebrates).

Specific objectives for each of the above aims, focusing on the relevant stressors (i.e. the physico-chemical water quality analytes) and the ecosystem receptors (i.e. macro algae and invertebrates), are presented in Table 2-12.

Table 2-12 Aims and objectives for the nearshore marine water quality and ecosystem health

Aim	Objectives
1. Assess the direct impacts of Sydney Water's nearshore WRRF ocean discharges on (a) water quality and (b) ecosystem health (intertidal macro algae and invertebrates).	*Stressors:* a. To compare physico-chemical water quality, including nutrients, for each WRRF outfall and reference site with relevant water quality objectives (where available), for the current year. b. To investigate the joint relationship between all physico-chemical water quality parameters, including nutrients, to identify the most meaningful parameters impacting water quality for each WRRF outfall and reference site, and comparing the current year with the relevant historical record. c. To compare outfall with reference site physico-chemical water quality, including nutrients, for each site grouping (i.e. for each WWRF) for the current year and over the relevant historical record.
	Ecosystem receptors: d. To compare outfall and reference site ecological responses, (macroalgal % covers and macroinvertebrate counts) for each site grouping (i.e. for each WRRF) for the current year and over the relevant historical record. e. To assess spatial and temporal trends in the ecological dataset for each WRRF outfall and reference site grouping over the relevant historical record. f. Where significant differences in macroalgal % covers/macroinvertebrate counts or multivariate community analysis between outfall and reference sites are detected for the current year, further investigate the potential drivers (e.g. by comparing with water quality data).
2. Assess the direct impacts of Sydney Water's nearshore WRRF ocean discharges on (a) water quality and (b) ecosystem health (subtidal macro algae and invertebrates).	*Stressors:* a. To compare physico-chemical water quality, including nutrients, for each WRRF outfall and reference site with relevant water quality objectives (where available), for the current year. b. To investigate the joint relationship between all physico-chemical water quality parameters, including nutrients, to identify the most meaningful parameters impacting water quality for each WRRF outfall and reference site, and comparing the current year with the relevant historical record. c. To compare outfall with reference site physico-chemical water quality, including nutrients, for each site grouping (i.e. for each WWRF) for the current year and over the relevant historical record.
	Ecosystem receptors: d. To compare outfall and reference site ecological responses, (macroalgal and sessile invertebrate % covers) for each site grouping (i.e. for each WRRF) for the current year and over the relevant historical record. e. To assess spatial and temporal trends in the ecological dataset for each WRRF outfall and reference site grouping over the relevant historical record.

Aim	Objectives
	f. Where significant differences in macro algal % covers/sessile invertebrate covers or multivariate community analysis between outfall and reference sites are detected for the current year, further investigate the potential drivers (e.g. by comparing with water quality data).

2.5.3. Monitoring approach

In 2023-24 we monitored one outfall (Shellharbour) using our traditional STSIMP monitoring method.

In 2024-25 we plan on trialling unmanned aerial vehicles (UAVs or drones) to survey shoreline outfalls that have a rock platform (Shellharbour, Bombo and Warriewood). We will also monitor Shellharbour using the current method. Information on this pilot (intertidal) program and other proposed future program (subtidal) are included for information only. Data from this pilot or future program will be reported in up-coming years once completed.

Design and sites (STSIMP)

An earlier assessment on accessibility to the five key outfall sites identified a health and safety access issue to all but one outfall (Shellharbour). The rock platform at Turimetta Headland (Warriewood WRRF discharge area) is flat with frequent wave wash up to the vertical cliff. On the day of inspection, the waves were only about one metre and this was sufficient to produce regular inundation of the site. Similarly, Diamond Bay, Cronulla and Bombo discharge to inaccessible sites that cannot be safely measured. Hence, these sites are not assessed, and Shellharbour is the only outfall monitored (Figure 2-8).

Design and sites (SWAM)

Aim 1 – assessment of direct impacts of WRRF discharges on intertidal rock platforms

Monitoring to address Aim 1 is commencing first this year (2024-25).

The design to focus on comparisons of stressors and intertidal ecosystem receptors from, where possible, one outfall and two reference sites of three WRRF discharges, to directly assess the impacts of the discharges. The WRRFs assessed under this aim are Shellharbour, Warriewood and Bombo.

In total, ten monitoring sites are chosen to address Aim 1, that includes extra reference site for the Shellharbour outfalls (Table 2-13, Figure 2-8). The actual location of the sites will be available at a later date pending field inspection and feasibility. Where possible, water quality, macro algae and invertebrates are all monitored at the same location. Where this cannot occur, sites are located as close together as logistically possible. The design has been configured such that representative water quality data are available for all sites that are monitored for the ecosystem receptor indicators (macro algae and invertebrates).

Aim 2 – assessment of direct impacts of WRRF discharges on subtidal rock platforms

Monitoring for addressing Aim 2 will commence in later years pending development of a suitable method. The details are included here for completeness and future reference.

The design to focuses on comparisons of stressors and subtidal ecosystem receptors from, where possible, one outfall and multiple reference sites (50 m, 100 m, 200 m, 500 m, 1 km (TBC)) in a gradient away from WRRF and untreated effluent discharges, to directly assess the impacts of the discharges. The discharges assessed under this aim include Cronulla WRRF and untreated discharges from Vaucluse and Diamond Bay 1 and 2.

In total, there will be 24 monitoring sites that address Aim 2 (Table 2-13, Figure 2-8). Where possible, water quality, macro algae and invertebrates are all monitored at the same location. Where this cannot occur, sites are located as close together as logistically possible. The design has been configured such that representative water quality data are available for all sites that are monitored for the ecosystem receptor indicators (macro algae and invertebrates).

Wollongong and Brooklyn WRRFs are not included in the SWAM program due to the tertiary level of treatment and rapid dilution in the mixing zone that mean impacts from these discharges are unlikely (as recommended in van Dam et al. 2023). However, this will be regularly reviewed.

Table 2-13 Receiving water monitoring sites for the nearshore marine water quality and ecosystem health sub-program (pending the outcomes of a feasibility study)

No.	Site code	Site description	Aim 1 – Intertidal sites		Aim 2 – Subtidal sites		Latitude	Longitude
			Water quality [a]	Macro algae and invertebrates	Water quality [b]	Macro algae and invertebrates [b]		
1	TBC	**Shellharbour WRRF outfall** at Barrack Point	✓	✓			-34.5638	150.8736
2	TBC	Reference location 1: Northern side of Shellharbour Headland	✓	✓			-34.5796	150.8758
3	TBC	Reference location 2: Eastern side of Shellharbour Headland	✓	✓			-34.5800	150.8772
4	TBC	Reference location 3: to be established	✓	✓				
5	TBC	**Warriewood WRRF outfall**	✓	✓			-33.4176	151.1893
6	TBC	Reference	✓	✓			TBC	TBC
7	TBC	Reference	✓	✓			TBC	TBC
8	TBC	**Bombo WRRF outfall**	✓	✓			-34.3911	150.5179
9	TBC	Reference	✓	✓			TBC	TBC
10	TBC	Reference	✓	✓			TBC	TBC
11	TBC	**Cronulla WRRF outfall**			✓	✓	TBC	TBC
12	TBC	50 m			✓	✓	TBC	TBC
13	TBC	100 m			✓	✓	TBC	TBC
14	TBC	200 m			✓	✓	TBC	TBC

No.	Site code	Site description	Aim 1 – Intertidal sites		Aim 2 – Subtidal sites		Latitude	Longitude
			Water quality [a]	Macro algae and invertebrates	Water quality [b]	Macro algae and invertebrates [b]		
15	TBC	500 m			√	√	TBC	TBC
16	TBC	1km			√	√	TBC	TBC
17	TBC	**Vaucluse outfall**			√	√	TBC	TBC
18	TBC	50 m			√	√	TBC	TBC
19	TBC	100 m			√	√	TBC	TBC
20	TBC	200 m			√	√	TBC	TBC
21	TBC	500 m			√	√	TBC	TBC
22	TBC	1 km			√	√	TBC	TBC
23	TBC	**Diamond Bay 1 outfall**			√	√	TBC	TBC
24	TBC	50 m			√	√	TBC	TBC
25	TBC	100 m			√	√	TBC	TBC
26	TBC	200 m			√	√	TBC	TBC
27	TBC	500 m			√	√	TBC	TBC
28	TBC	1 km			√	√	TBC	TBC
29	TBC	**Diamond Bay 2 outfall**			√	√	TBC	TBC
30	TBC	50 m			√	√	TBC	TBC
31	TBC	100 m			√	√	TBC	TBC
32	TBC	200 m			√	√	TBC	TBC

No.	Site code	Site description	Aim 1 – Intertidal sites		Aim 2 – Subtidal sites		Latitude	Longitude
			Water quality [a]	Macro algae and invertebrates	Water quality [b]	Macro algae and invertebrates [b]		
33	TBC	500 m			✓	✓	TBC	TBC
34	TBC	1 km			✓	✓	TBC	TBC

[a] Sampling is proposed to be done from 0.5 m below the using a water sampling unmanned aerial vehicle (drone).

[b] Sampling is proposed to be done subtidally using a remotely operated vehicle.

TBC: site code to be confirmed.

Analytes, indicators and sampling (STSIMP, 2023-24)

Measurements are taken in spring each year under suitable weather and tidal conditions at the outfall and from two control sites. An underlying assumption of this study is that the extent of the impacted area is solely determined by the quality and/or volume of the wastewater discharge.

To assess if any significant ecological change has occurred, the littoral flora and fauna composition and abundance are measured as an indicator of ecological health. The littoral flora and fauna composition of natural communities at control sites were used to provide a baseline for calibrating the degree and the scale of any change.

Rocky-intertidal communities are comprised of macroalgae and macroinvertebrate animals. These organisms colonise a variety of man-made structures such as breakwaters, jetties, docks, groynes, dykes and seawalls (Crowe et al. 2000). Wave exposure influences the distribution and abundance of rocky-intertidal communities between exposed headlands and sheltered bays or inlets (Crowe et al. 2000). To control this natural influence, sites with similar levels of wave exposure were selected for analyses. Rocky-intertidal community structure was monitored from wave-exposed ocean headland locations on naturally occurring rock platforms that could be safely accessed at low tide.

At each site, community composition and enumeration were recorded yearly during the period of late winter to late spring. Monitoring in this period reduces the influence of annual recruitment of most species of settling larvae that mainly occurs in summer to autumn. Photographs of a 0.25 m^2 quadrat were taken within 2 hours either side of low tide. To help encapsulate variation between sites and across years, 14 randomly selected 0.25 m^2 quadrats were photographed between the low and high tide marks in the mid-littoral zone at each site visit. Using these photographs, counts were recorded for macroinvertebrate taxa and estimates of percentage cover were made for macro algae. The taxonomic level recorded was based on morphological characters that could be seen with the naked eye. Identification of macro invertebrate taxa and macroalgae were checked against taxonomic works of Edgar (1997) and Dakin (1987).

Seasonal variation is expected to be low because the dominant processes in the littoral community are competition for space and grazing through most of the year. Another controlling process on hot days in summer is potentially from desiccation from sun-exposure of the rock platform communities.

Analytes, indicators and sampling (SWAM, 2024-25)

Stressor analytes and ecosystem receptor indicators and associated monitoring parameters are listed in Table 2-14. Further details about the stressor analytes including methods, unit of measurements can be found in Table 2-7.

Aim 1 – assessment of direct impacts of WRRF discharges on intertidal rock platforms

Water quality, macro algae and invertebrates are monitored, depending on the site, as listed in Table 2-13. The analytes and indicators have been selected on the basis of knowledge of the stressors present in WRRF discharges and key components of the marine ecosystem that are known to be responsive to WRRF discharges and that represent broadly accepted indicators of ecosystem health. The stressor analyte suite is considered interim at this stage until comprehensive sampling studies are conducted for treated wastewater and receiving water in order to identify a more complete stressor analyte suite.

For water quality, field measurements and samples are collected at yearly intervals (in spring) using a drone sampling program (pending outcomes of a pilot proposed for the 2024-25 year). At each site, two samples will be collected approximately five minutes to 30 minutes depending on the time it takes to relaunch the drone. Water samples should be collected at a depth of 0.5 m below the water surface to avoid surface scum/debris where possible. Duplicates samples are then mixed into composite sample for each site for field measurement and laboratory analysis. Selective field measurements (Table 2-14) are taken at each site after sample collection. All samples are analysed at Sydney Water's laboratory by NATA (National Association of Testing Authorities) accredited methods for the selected analytes (Table 2-14). Further details of each analyte method are given in Table 2-15 and Table 2-7.

Macro algae and invertebrates are surveyed at yearly intervals (in spring) with high resolution and multispectral cameras mounted on a drone. Surveys are conducted as close to solar noon as possible to minimize shadows that can affect multispectral results. Multiple Red-Green-Blue (RGB) and multispectral images are collected from oblique and nadir (directly down) perspectives at a range of altitudes and processed as in Drummond and Howe (2018). The processing workflow for RGB images includes orthomosaic generation, image classification and quadrat analysis (macroinvertebrate counts/% cover and macro algal % cover). The processing workflow for multispectral images includes radiometric correction, NDVI orthomosaic generation, NDVI image thresholding and quadrat analysis (green, red and brown algae % cover).

Aim 2 – assessment of direct impacts of WRRF discharges on subtidal rock platforms

Water quality, macro algae and invertebrates will be monitored, depending on the site, as listed in Table 2-13 Receiving water monitoring sites for the nearshore marine water quality and ecosystem health sub-program (pending the outcomes of a feasibility study)

. The analytes and indicators have been selected on the basis of knowledge of the stressors present in WRRF discharges and key components of the marine ecosystem that are known to be responsive to WRRF discharges and that represent broadly accepted indicators of ecosystem health. The stressor analyte suite is considered interim at this stage until comprehensive sampling studies are conducted for treated wastewater and receiving water in order to identify a more complete stressor analyte suite.

For water quality, field measurements and samples are collected at yearly intervals (in spring) using an underwater remotely operated vehicle (ROV) sampling program (pending the outcomes of a feasibility study). At each site, two samples are collected, where possible, from just above the seafloor, and combined for a single measurement. Field measurements are taken at each site after sample collection. All samples are analysed in Sydney Water laboratories by NATA (National Association of Testing Authorities) accredited methods for the selected analytes (Table 2-7). Quality control samples are also collected and analysed. A duplicate is collected on each run and field blank/ trip blank is collected on alternate runs.

Macro algae and invertebrates are surveyed at yearly intervals (in spring) with high resolution mounted on an ROV. Multiple RGB images are collected from oblique and nadir (directly down) perspectives at a range of depths and processed as in Drummond and Howe (2018). The processing workflow for RGB images includes orthomosaic generation, image classification and quadrat analysis (macroinvertebrate counts/% cover and macro algal % cover).

Table 2-14 Receiving water Stressor (analytes) and ecosystem receptor indicators, methods and other associated parameters for nearshore marine water quality and ecosystem health sub-program[a]

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General water quality	pH, salinity and turbidity
	Chemical [b]	Nutrients and toxicants	Total ammonia nitrogen, oxidised nitrogen, total nitrogen, total phosphorus, soluble reactive phosphorus
	Chemical [b]	Metals (total acid extractable and dissolved)	aluminium, cobalt, copper, nickel, zinc
Ecosystem receptor	Biodiversity	Macroalgal communities	% cover of green, red and brown algae, community structure
		Macroinvertebrate communities	Counts or % cover, diversity indices, community structure

[a] Refer to Table 2-13 for details of sites at which analytes/indicators should be measured i.e. only intertidal monitoring sites

[b] The recommended suite of chemical analytes should be considered as interim, and needs to be more comprehensively determined through sampling studies for treated wastewater and receiving water and associated screening-level risk assessments.

Table 2-15 Further detail on salinity measurement

Analyte	Detection limits	Unit of measurement	Analyte method code / Reference	Place of measurement
Salinity	0.1	ppt	WC12, APHA (2017) 2510 B	Laboratory

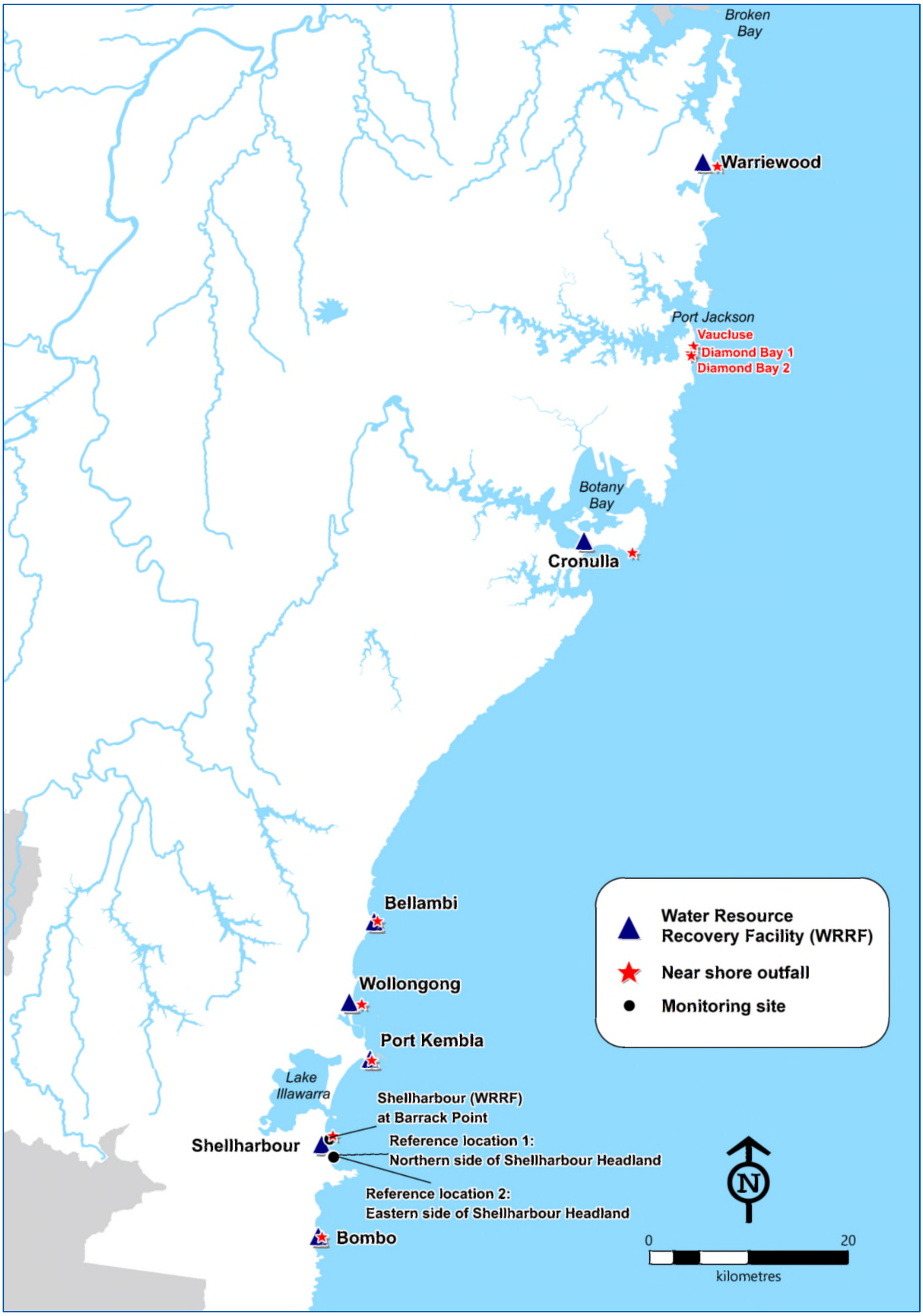


Figure 2-8 Site locations for nearshore marine ecosystem health sub-program

2.6. Ocean receiving water quality

2.6.1. Rationale

Sydney has three deepwater outfalls that are located 2-4 km offshore in 60-80 m of water. These deepwater ocean outfalls were constructed in 1989-1990 to provide more remote and rapid dilution of wastewater plumes. The location of the plume and dilution factors of the wastewater are critical to assess potential impacts from the discharges and these are mainly determined by ocean currents and density stratification of the water column. In order to assess the behaviour and model the outfall plumes on a routine basis, an ocean reference station (ORS) was established to collect wind and ocean current, temperature and wave data (Miller et al 1996).

Sydney Water has been collecting oceanographic data from the ocean reference station (ORS) since 1990. The ORS is positioned 3 km east of Bondi Beach at a depth of 67 m. Data from the ORS is collected and processed by Oceanographic Field Services under contract to Sydney Water. Apart from Sydney Water uses, the ORS is one of seven reginal moorings in New South Wales that contributes data to Australia's Integrated Marine Observing System (IMOS).

The data from ocean receiving water quality sub-program is used to make predictions of the dispersion and dilution of the wastewater plume from North Head, Bondi and Malabar deepwater ocean outfalls using numerical modelling of the data collected by the ocean reference station. Dilution factors derived from the plume modelling allowed comparison of modelled chemical concentrations of mixed wastewater at the edge of the near-field zone for each of the deepwater ocean outfalls to ANZG (2018) guideline values for protection of 95% of marine species as a line of evidence to understand in addition to sediment quality assessment. For example, this line of evidence informs that the modelled copper concentrations are deemed a concern due to a potential to accumulate in benthic sediment around all three outfalls. As such, a focus on copper in the sediment chemistry is appropriate when examining results.

2.6.2. Aim and objectives

The aim of this sub-program is to:

Assess the oceanographic processes that affect the advection and dispersion of Sydney Water's deep ocean WRRF discharges.

Specific objectives for the above aim, focusing on the relevant stressors (i.e. by comparing the modelled water quality diluted concentrations at the edge of the mixing zone against the ANZG (2018) water quality 95% protection of species), are presented in Table 2-16.

Table 2-16 Aims and objectives for the ocean receiving water quality sub-program

Aim	Objectives
Assess the oceanographic processes that affect the advection and dispersion of Sydney Water's	**Surveillance Years (annually in between assessment years)** a. To compare trends in contaminant concentrations at the boundary of the initial dilution zone to water quality guidelines over the relevant historical record.
	Assessment Years (aligned to IPART cycle)

Aim	Objectives
deep ocean WRRF discharges	b. To compare trends in contaminant concentrations at the boundary of the initial dilution zone to water quality guideline values over the relevant historical record. c. To estimate the location and initial dilution of wastewater plumes and particle settling with near-field models [a], d. To compare the interannual variability of waves including maximum wave height, significant wave height and significant wave period [b]. e. To summarise plume dilution and percentage of time exceeded over the current assessment year [c]. f. To model spatial distribution of negatively buoyant particles and time taken to settle during the current assessment year. g. To model sediment movement by currents during the current assessment year [a].

[a] supplied under the ORS Professional Service Contract (PSC)

[b] Under ORS PSC to provide an updated tabular summary of wave direction and percentage of time waves are estimated to induce sediment movement as shown in Table 3 of Tate et al. (2019) for the period 2006 to 2025.

[b] Under ORS PSC to provide an updated tabular summary statistics of monthly sediment movement as shown in Table 4 of Tate et al. (2019) for the period 2006 to 2025

[c] Supplied under ORS PSC to inform items a) and b) above

Items marked above as supplied under ORS PSC are further detailed in Attachment A Scope of Services Sections 3.7.5 and 3.7.6

2.6.3. Monitoring approach

Design and sites

Sydney Water has been collecting data from the oceanographic reference station 3 km east of Bondi Beach in 67 m of water since 1990. Since a major reconfiguration in 2006, the instrumentation is now bottom sea-bed mounted (Figure 2-10) with an Acoustic Doppler Current Profiler (ADCP) that returns current speed and direction data from every 2 m in the water column, 14 temperature sensors located every 4 m in the water column to estimate density, and two conductivity, temperature, and depth sensors (CTD) located ~10 m above the sea floor and ~10 m below the sea surface.

Data are collected every five minutes, and the equipment is serviced monthly with data being uploaded from the instruments at the same time. All data are quality checked prior to storage (SharePoint) and provided to EPA within approximately two weeks of servicing the system.

The data collected by the ORS is complemented by wind data from the Bureau of Meteorology station located at Sydney Airport and wastewater flow volume obtained from stations at the North Head, Bondi and Malabar WRRFs. Numerical modelling with this data is used to predict the location and dilution of deepwater ocean outfall plumes.

More than 90% of the dispersion of wastewater from the deepwater ocean outfalls occurs in the near-field. Therefore, the near-field model PLOOM was developed specifically for the Sydney Water deepwater ocean outfalls and has been calibrated and validated. PLOOM3 is the latest version that has been used to estimate behaviour of the WRRF discharges at North Head, Bondi and Malabar since 2006 with the major reconfiguration of instrumentation outlined above.

The model is run annually undertaking simulations every hour and the output includes distance to the boundary of the initial dilution zone (varies depending on ocean and discharge conditions), location and 3D trajectory of the wastewater plume, and dilution of the wastewater plume (combined with data on measured contaminant concentrations in the wastewater) to predict concentrations at the boundary of the initial dilution zone. Most guideline values apply at this boundary.

Further details on ORS and outfalls modelling system are included in the sub-section below (Deepwater Outfall Modelling System DOMS)

Analytes, indicators and sampling

The suites of stressor analytes and associated parameters assessed in the 2023-24 surveillance year are listed in Table 2-17.

Table 2-17 Stressor (analytes) and ecosystem receptor indicators and associated parameters modelled for the ocean receiving water quality sub-program

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Chemical	Nutrients	total nitrogen, total phosphorus
	Chemical [a]	Metals	General suite including (but not necessarily limited to) aluminium, copper, lead, zinc
	Chemical [a]	Organic contaminants	General suite including chlorpyrifos, endosulphan,

[a] *The recommended suite of chemical analytes should be considered as interim and needs to be more comprehensively determined through sampling studies for treated wastewater and receiving water and associated screening-level risk assessments.*

Deepwater Outfall Modelling System (DOMS)

The Deepwater Outfall Modelling System (DOMS) is an integrated numerical modelling and data collection program designed to meet Sydney Water licence requirements of Environment Protection Licence 378, and includes provision of (a) ocean reference station data to the EPA and (b) input data for a suite of numerical models that estimate the trajectory and dilution of effluent plumes from the three deepwater ocean outfalls (North Head, Bondi and Malabar) to help assess the water quality disturbance of these discharges and potential impact on the marine environment.

DOMS comprises:

- Wind data from Sydney Airport (or from Kurnell if Sydney Airport data are unavailable)
- Wave data from Long Reef (data from Port Kembla can be requested if Long Reef data are unavailable)
- Effluent flow data from each of the three WRRFs located at North Head, Bondi and Malabar
- Oceanographic data from the ocean reference station (ORS)
- Data checking, storage and routine delivery of data to the EPA

- The near-field numerical model PLOOM3, designed specifically for the Sydney deepwater ocean outfalls.

The ORS is an instrumented mooring designed to provide oceanographic data from the vicinity of the three deepwater ocean outfalls. The ORS is located approximately 3 km east of Bondi, in waters approximately 65 m deep (Figure 2-9).

By continuously monitoring the currents and water density, ORS data provide an integrated estimate of the ocean currents from all current-producing forces. This information is then used as boundary data to drive the numerical models.

The ORS comprises the following subsurface components (Figure 2-10):

- One x 600kHz RDI ADCP, bottom mounted. Five-minute data averaging, bin size = 2 m. The first data bin is located approximately 3 m above the sea floor.
- 13 x AQUA TEC temperature sensors at 4 m intervals from the sea floor to approximately 10 m below the sea surface. The lowest thermistor is approximately 1 m above the sea floor. The uppermost thermistor also contains a pressure sensor to assist in determining exactly where each thermistor lies in the water column (the mooring string will bend over in response to strong current and wave action). Data are recorded at 5-minute intervals.

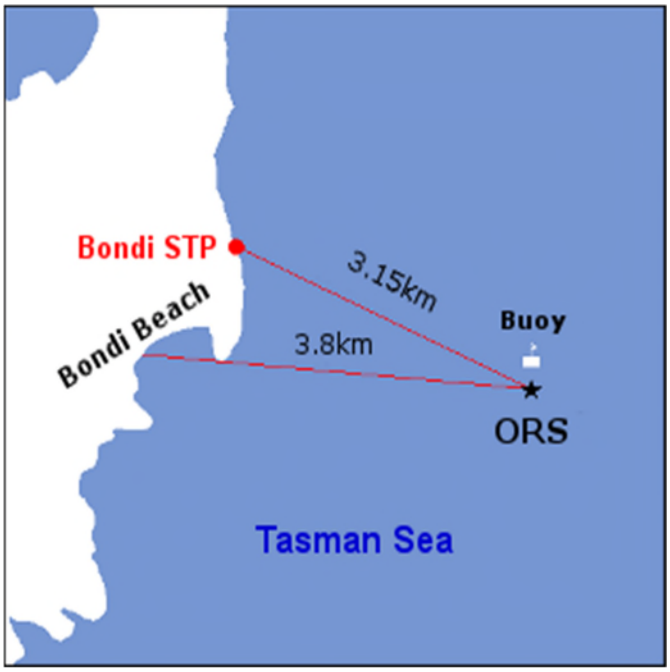


Figure 2-9 Location of ORS

- Approximately 11 m and 52 m above the sea floor are located SeaBird SBE37 CTDs, returning temperature, salinity and depth data. Data are recorded every 5 minutes.

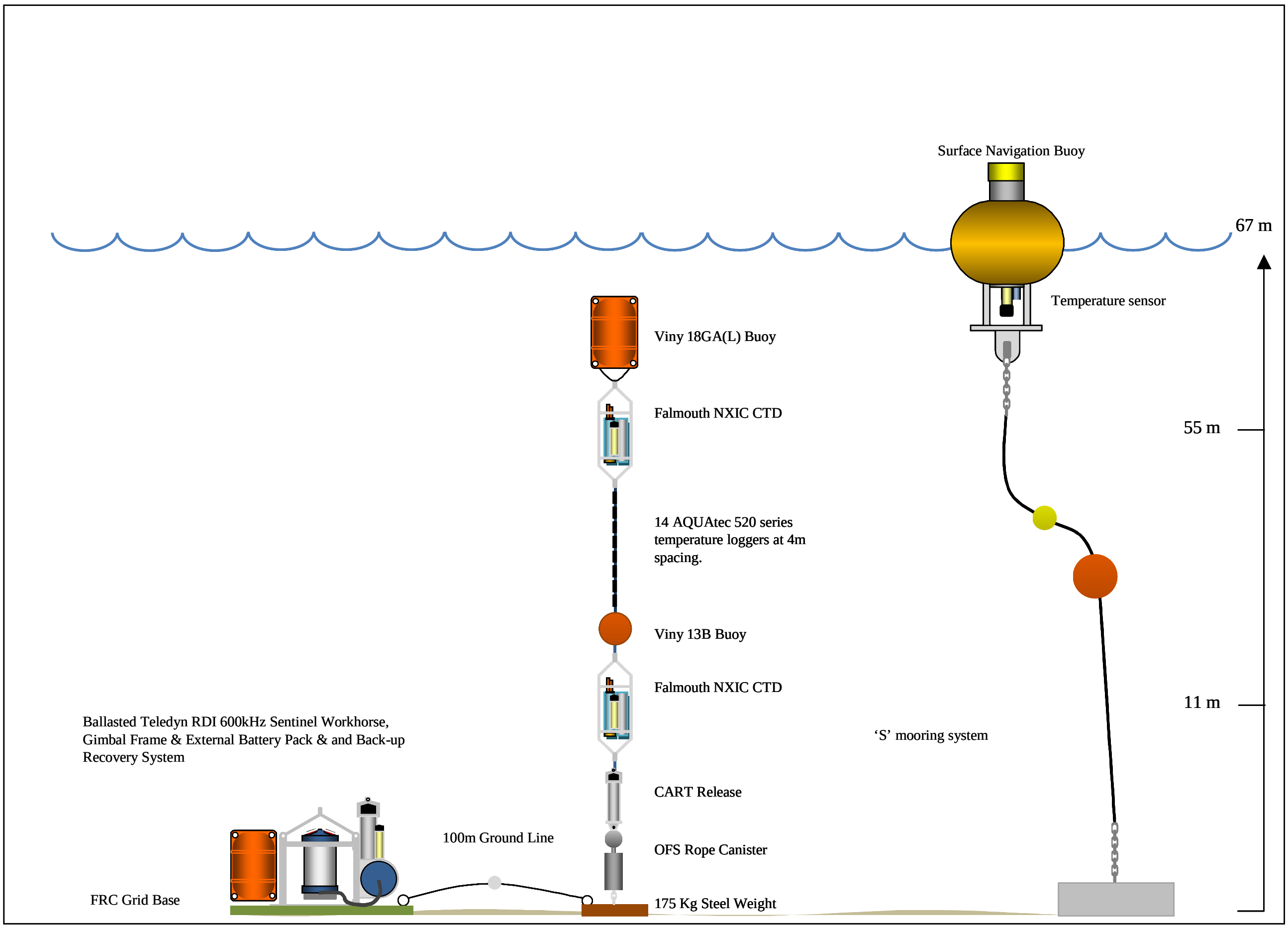


Figure 2-10 Configuration of the ORS Mk2

2.7. Ocean sediment quality and ecosystem health

2.7.1. Rationale

Sydney has three deepwater ocean outfalls that are located 2-4 km offshore in 60-80 m of water – North Head, Bondi and Malabar in order from north to south. Distinguishing impacts associated with Sydney Water's WRRF discharges to the offshore marine environment from other environmental gradients requires a strong focus on monitoring of stressors and ecosystem receptors at both outfall and control sites. Malabar has been subject to more sampling effort to investigate if any potential impact is spreading south. This is because Malabar has some of the highest discharges, including industrial waste, and the original plume modelling for particle settlement suggested that *"the bulk of the particulate matter settled parallel to the Sydney coast within 4 to 5 km of the outfall diffuser arrays 80% of time, with minimal settling beyond this distance extending up to 10 km from the diffuser arrays"* (Tate et al. 2019). Based on previous monitoring results (assessed in Sydney Water 2020a; Besley and Birch 2019) there has been no evidence of an impact from Malabar outfall at southern control locations. In 2023-24, monitoring of control locations during Surveillance years was added to the program to track any changes through time, as recommended (van Dam et al., 2023).

Deepwater ocean outfalls discharge effluent through multiple diffusers that spread it over 500 to 750 m, which achieves rapid dilution. The purpose of the diffusers is to release effluent into the ocean at concentrations that are unlikely to be toxic once mixing has occurred.

Effluent from the three deepwater ocean outfalls contains particulate matter to which contaminants may be attached. Under particular environmental conditions, negatively buoyant particles may settle, and this may lead to a possible accumulation of contaminants in the sediments. Ocean currents and internal ocean waves may be sufficiently large to re-suspend the sediments, with the potential release of contaminants into the water column over a widespread area.

Once mixing has occurred, three checks are undertaken to determine that the effluent is being released at non-toxic concentrations. Firstly, the diffusers are visually inspected using a remotely operated submersible equipped with a camera; this is a check to confirm that all diffusers are working. Secondly, the effluent is checked monthly to determine that it is not toxic at the concentrations achieved after mixing. These two checks are conducted under separate programs.

The first check is performed under Professional Services Contract. While the second check is performed under the monitoring plan titled 'Wastewater Treatment Plant Compliance and Operational Monitoring Plan'.

This monitoring sub-program represents the third check and satisfies requirements of new SWAM program (Sydney Water 2023).

Sydney Water's offshore sediment quality and ecosystem health sub-program is designed to monitor:

- the direct marine environmental impacts of Sydney Water's WRRF offshore discharges, and to investigate
- if any potential impact from Malabar outfall is spreading southwards.

In addition to the overview below, details of the changes to the monitoring sub-program can be found in the STSIMP Recommendations Report (van Dam et al. 2023).

2.7.2. Aim and objectives

The aims of this sub-program are to:

1. Assess the direct impacts of Sydney Water's deep ocean WRRF discharges on
   a. sediment quality and
   b. ecosystem health as measured by responses of sediment infauna.
2. Investigate if any potential impact from Malabar outfall is spreading southwards.

Specific objectives for each of the above aims, focusing on the relevant stressors (i.e. the sediment quality analytes) and the ecosystem receptors (i.e. sediment infaunal communities), are presented in Table 2-18.

Table 2-18 Aims and objectives for the offshore marine sediment quality and ecosystem health sub-program

Aims	Objectives
1. Assess the direct impacts of Sydney Water's deepwater ocean WRRF discharges on (a) sediment quality and (b) ecosystem health as measured by responses of sediment infauna.	**Surveillance years (annually in between assessment years)** *Stressors:* a. To summarise each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location sediment quality (grain size, TOC, metals, PAHs) for the current surveillance year. b. To compare sediment quality (TOC, metals, PAHs) for each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location with relevant sediment quality guidelines (where available) for the current surveillance year and the relevant historical record. c. To investigate the joint relationship between all sediment quality parameters to identify the most meaningful parameters impacting sediment quality for each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location and comparing the current surveillance year with the relevant historical record. d. To compare outfall (North Head, Bondi, Malabar) with control (Long Reef, Port Hacking, Marley) location sediment quality (grain size, TOC, metals, PAHs) for the current surveillance year and over the relevant historical record. e. To compare outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location mean effects range median quotients (MERMQs) for mixtures of contaminants to assess the potential risk of adverse biological effects for the current surveillance year and over the relevant historical record. *Ecosystem receptors:* f. To compare outfall (North Head, Bondi, Malabar) with control (Long Reef, Port Hacking, Marley) location infauna taxa richness and abundances with respect to numbers of taxa/individuals, polychaetes, crustaceans, molluscs, echinoderms, other worms and other phyla, community structure and composition for the current surveillance year and over the relevant historical record.
	Assessment years (aligned to IPART cycle) *Stressors:* a. To summarise each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location sediment quality (grain size, TOC, metals, PAHs) for the current assessment year. b. To compare sediment quality (TOC, metals, PAHs) for each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location with relevant sediment quality guidelines (where available) for the current assessment year and the relevant historical record. c. To investigate the joint relationship between all sediment quality parameters to identify the most meaningful parameters impacting sediment quality for each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location and comparing the current assessment year with the relevant historical record.

Aims	Objectives
	d. To compare outfall (North Head, Bondi, Malabar) with control (Long Reef, Port Hacking, Marley) location sediment quality (grain size, TOC, metals, PAHs) for the current assessment year and over the relevant historical record. e. To investigate the joint relationship between all sediment quality parameters to identify the most meaningful parameters impacting sediment quality for each outfall (North Head, Bondi, Malabar) and control (Long Reef, Port Hacking, Marley) location and comparing the current year with the relevant historical record.
	Ecosystem receptors: f. To compare outfall (North Head, Bondi, Malabar) with control (Long Reef, Port Hacking, Marley) location infauna taxa richness and abundances with respect to numbers of taxa/individuals, polychaetes, crustaceans, molluscs, echinoderms, other worms and other phyla, community structure and composition for the current assessment year and over the relevant historical record.
2. To investigate if any potential impact from Malabar outfall is spreading southwards.	**Surveillance years (annually in between assessment years)** *Ecosystem receptors (sediment infauna):* a. To summarise the infauna taxa richness and abundances with respect to numbers of taxa/individuals, polychaetes, crustaceans, molluscs, echinoderms, other worms and other phyla for the Malabar outfall (0 km) for the current surveillance year. b. To compare Malabar outfall (0km) infauna taxa richness, abundances, community structure and composition for the current year and over the relevant historical record c. Where TOC exceeds EPA set criteria for the Malabar outfall (0 km) location, or a trend in metal accumulation in sediment chemistry becomes apparent, and trends in infauna taxa richness, abundances or multivariate community analysis indicate a potential change that aligns with these sediment characteristics at Malabar outfall (0km) for the current surveillance year, further investigate the ecological response and potential drivers (e.g. by comparing with sediment quality data).
	Assessment years (aligned to IPART cycle) *Ecosystem receptors:* d. To summarise the infauna taxa richness and abundances with respect to numbers of taxa/individuals, polychaetes, crustaceans, molluscs, echinoderms, other worms and other phyla for the Malabar outfall (0 km) for the current assessment year. e. To compare Malabar outfall (0 km) with control and gradient (Long Reef, Malabar 3 km, 5 km, 7 km, Port Hacking, Marley) location infauna taxa richness, abundances, community structure and composition over the relevant historical record. f. To compare Malabar outfall (0km) with control and gradient (Malabar 3 km, 5 km, 7 km, Port Hacking, Marley) location taxonomic turnover over the relevant historical record.

Aims	Objectives
	g. To investigate the joint relationship between sediment quality (grain size, TOC, metals, PAHs) and benthic community structure at outfall (Malabar) and control/gradient (Long Reef, Malabar 3 km, 5 km, 7 km, Port Hacking, Marley) locations over the relevant historical record.

2.7.3. Monitoring approach

Design and sites

Aim 1 – assessment of direct impacts of WRRF discharges

The design focuses on comparisons of stressors from outfall and control sites in surveillance years and stressors and ecosystem receptors in assessment years to directly assess the impacts of the discharges. The study area covers the mid-shelf zone from Long Reef to Marley Beach. The three northern most study locations of Long Reef, North Head and Bondi, are in waters approximately 60 m deep. The remaining six study locations, at Malabar (0 km to 7 km), Port Hacking, and Marley Beach are in waters approximately 80 m deep. Two sites are sampled at each location and five sub-sites are sampled to yield 10 replicate samples from each study location on each sampling occasion. The gradient locations at Malabar (3 km, 5 km and 7 km) are only sampled in assessment years.

Aim 2 – investigation of potential impacts from Malabar outfall spreading southwards

The design focuses on assessment of stressors and ecosystem receptors only at the Malabar outfall in surveillance years and compares the Malabar outfall with Malabar gradient locations (3 km, 5 km, 7 km) and southern control locations (Port Hacking and Marley Beach) in assessment years.

In total there are nine locations, 18 sites and 90 sub-sites that address Aim 1 and an additional 30 sub-sites that address Aim 2 (Table 2-19, Figure 2-11). Sediment quality and benthic macroinvertebrates are sampled from the same grab so that representative sediment quality data are available for all ecosystem receptor indicator data.

Sub-site selection:

The method used for sub-site selection is consistent with the method outlined in EPA (1998). To select random sub-sites (five or ten as detailed in Table 2-19 for each site), a 250 m x 250 m spatial grid was constructed and centred on the sampling site whose grid coordinates are referred to in EPA (1998). The grid is subdivided into 50 m lengths along each axis, 50 m is equivalent to one length unit. Therefore, the grid consists of 50 m x 50 m cells and each point in the grid is allocated (x, y) co-ordinates ranging from 0 to 5 as illustrated Figure 2-12.

To establish the grid position of (0, 0) the sample positions are converted from latitude and longitude to easting and northing in Australian Map Grid (AGD 66, AMG zone 56). Prior to this, 125 m is subtracted from both the easting and northing of the original reference positions, which allows the grid to be centred on these positions.

The co-ordinates for the sub-sites are produced by randomly generating two sets of numbers (each representing either the x or y co-ordinates) ranging from 0 to 5. An example is shown in Figure 2-11 with the co-ordinates (3, 1). These co-ordinates are converted to easting and northing by adding the appropriate lengths that corresponded to the (x, y) co-ordinates. Since each cell is 50 m x 50 m, each co-ordinate ‘unit’ corresponds to a length of 50 m. The positions for each site are provided in Table 2-19.

Table 2-19 Receiving water monitoring sites and number of samples for the offshore marine sediment quality and ecosystem health sub-program

Category	Location	Site codes	Depth (m)	Stressors		Ecosystem receptor		Coordinates	
				Surveillance	Assessment	Surveillance	Assessment	Latitude	Longitude
Control	Long Reef	LR-1C	60	5	5		5	-33.72726872	151.3786946
		LR-2C	60	5	5		5	-33.74532758	151.3732145
Outfall	North Head	NH-1C	60	5	5		5	-33.80778469	151.3517427
		NH-2C	60	5	5		5	-33.82472204	151.3517036
Outfall	Bondi	B-1C	60	5	5		5	-33.89472367	151.3065893
		B-2C	60	5	5		5	-33.8716801	151.3136225
Outfall	Malabar 0km	M0-1C	80	5	5	5	5	-33.97810419	151.2983515
		M0-2C	80	5	5	5	5	-33.97677202	151.3055366
Control	Malabar 3km	M3-1C	80		5		5	-34.00006851	151.2824469
		M3-2C	80		5		5	-33.99914653	151.2847567
Control	Malabar 5km	M5-1C	80		5		5	-34.01688851	151.2740868
		M5-2C	80		5		5	-34.0183596	151.2769219
Control	Malabar 7km	M7-1C	80		5		5	-34.03102797	151.2617666
		M7-2C	80		5		5	-34.03386952	151.2602759
Control	Port Hacking	PH-1C	80	5	5		5	-34.07018599	151.2308685
		PH-2C	80	5	5		5	-34.07233234	151.2308238
Control	Marley Beach	MB-1C	80	5	5		5	-34.13519402	151.1741488
		MB-2C	80	5	5		5	-34.1368761	151.1749733

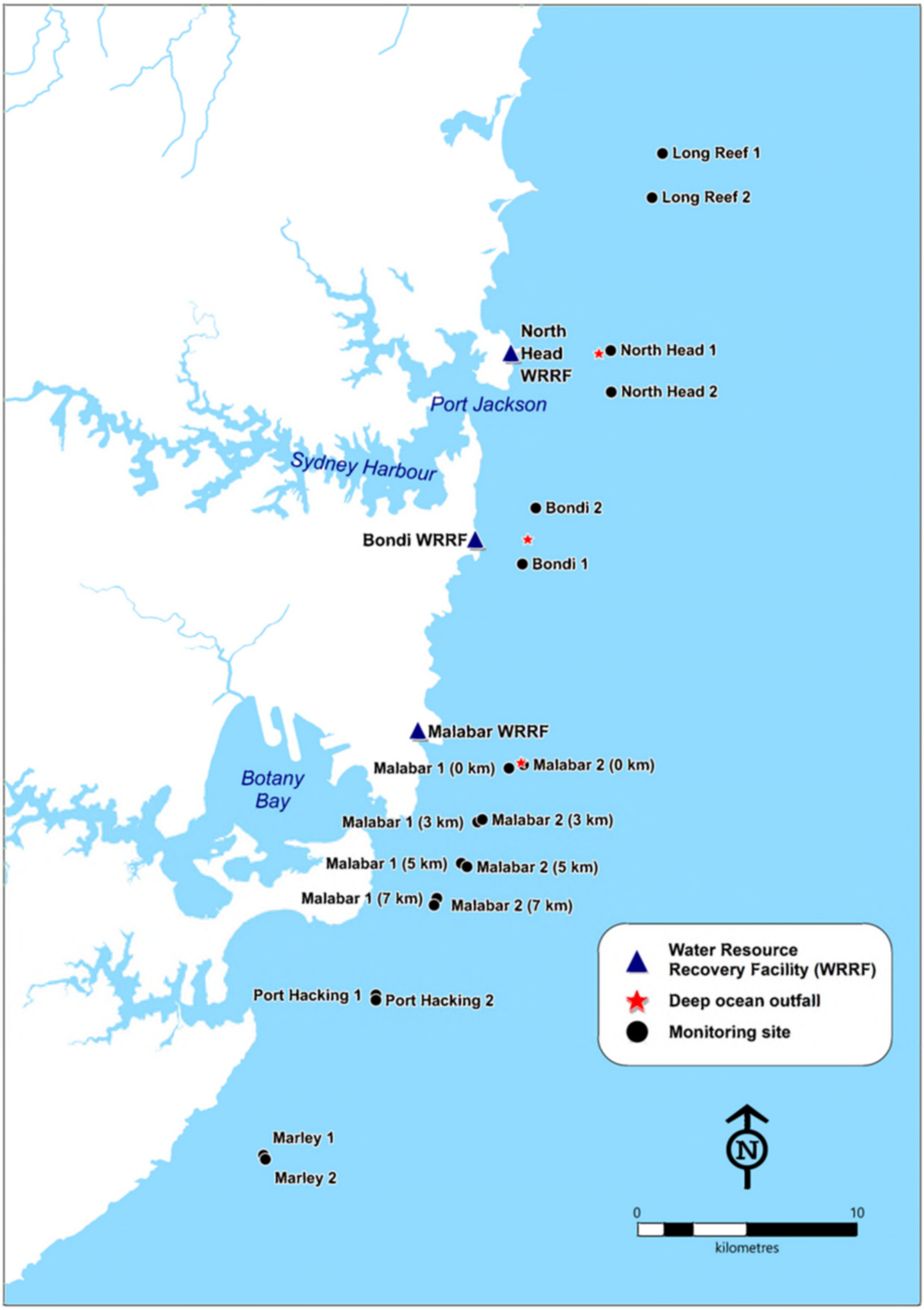


Figure 2-11 Site locations for offshore marine sediment quality and ecosystem health sub-program

A single sediment sample is collected from each subsite, for which there are five subsites for a site. This results in five samples being collected from each of two sites, with ten samples in total collected from each location (Table 2-19).

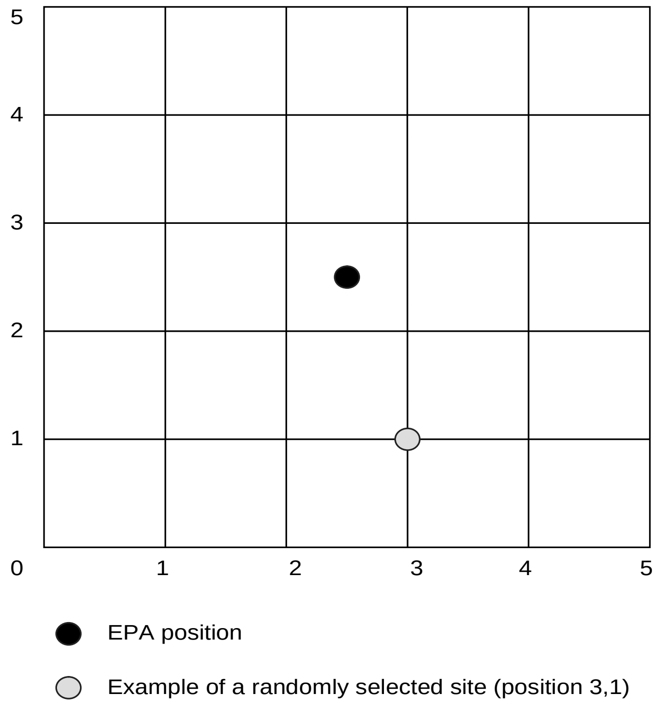


Figure 2-12 Grid used to randomly select sub-sites at each of the EPA (1998) sites

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 2-20.

Sampling of ocean sediments is to be conducted annually during February to allow comparability of data between years.

This year (2023-24) is a Surveillance year and altogether 60 sediment samples are collected for the physico-chemical analyses, and ten for the infaunal community analysis as per Table 2-19.

Table 2-20 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the offshore marine sediment quality and ecosystem health sub-program, for surveillance and assessment years[a]

PSER element	Line of evidence	Indicator	Analyte / parameter			
			Analyte	Practical quantitation limit (PQL)	Unit of measurements	Analyte method code / Reference
Stressor	Physico-chemical	General sediment quality	Total organic carbon (TOC)	0.01	%	XAL_TOC_S, External, ALS, APHA (2012) 5310C
			Grain size	-	mm	TM54WET, In house method derived from AS1289.C6.1 - 1997 for sizes >2mm, + TM71 For sizes <2mm, by Laser Diffraction inhouse method non NATA
			Moisture content	-	%	TM35GRIND, TM35MKG
	Chemical [b]	Nutrients*	Total Kjeldahl nitrogen (TKN)	20	mg/kg	NU72, APHA (2012) 4500- Norg/NO3 – I/J
			Total phosphorus	10	mg/kg	TM70MKG, USEPA 6010D
Stressor	Chemical [b]	Total acid extractable metals	Aluminium (Al)	2	mg/kg	TM70MKG, USEPA (2014) 6010D
			Arsenic (As)	0.02	mg/kg	TM66MKG, USEPA (2014) 6020B
			Cadmium (Cd)	0.01	mg/kg	as above
			Chromium (Cr)	0.02	mg/kg	as above
			Cobalt (Co)	0.01	mg/kg	as above
			Copper (Cu)	0.05	mg/kg	TM66MKG, USEPA (2014) 6020B
			Iron (Fe)	2	mg/kg	TM70MKG, USEPA (2014) 6010D

PSER element	Line of evidence	Indicator	Analyte / parameter			
			Analyte	Practical quantitation limit (PQL)	Unit of measurements	Analyte method code / Reference
			Lead (Pb)	0.01	mg/kg	TM66MKG, USEPA (2014) 6020B
			Mercury (Hg)	0.005	mg/kg	TM01MKG, APHA (2012) 3112B
			Nickel (Ni)	0.02	mg/kg	TM66MKG, USEPA (2014) 6020B
			Selenium (Se)	0.02	mg/kg	As Above
			Silver (Ag)	0.01	mg/kg	as Above
			Zinc (Zn)	0.1	mg/kg	as Above
Stressor	Chemical [b]	Organic compounds: (PAHs, pesticides and PCBs)*	PAHs (Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(a)pyrene TEQ, Benzo(b)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene TEQ, Benzo(ghi)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Perylene, Phenanthrene and Pyrene)	10	mg/kg	TC004SLL, In-house method based on USEPA 8270C; TC012SLL, In-house method based on USEPA 8260B
			Organochlorine pesticides: 4,4-DDD, 4,4-DDE, 4,4-DDT; Aldrin, Dieldrin, Endosulfan sulphate, Endrin, Heptachlor, Heptachlor Epoxide, Hexachlorobenzene Lindane (gamma-BHC); Methoxychlor, alpha-BHC, alpha-Chlordane, alpha-	5	mg/kg	TC001SLL, In-house method based on USEPA 8081B, APHA (2012) 6630 (modified)

PSER element	Line of evidence	Indicator	Analyte / parameter			
			Analyte	Practical quantitation limit (PQL)	Unit of measurements	Analyte method code / Reference
			Endosulfan, beta-BHC, beta-Endosulfan, delta-BHC, gamma-Chlordane)			
			Polychlorinated Biphenyls (PCB) total	25	mg/kg	TC003SLL, APHA (2012) 6630 (modified), based on USEPA 8082A
			Coronene	100	mg/kg	TC004COR, based on USEPA 8270C
			2-ChloroPhenol, M-Cresol, O-Cresol and P-Cresol	10	mg/kg	XAL_PHENOL, APHA (2012) 6420
Ecosystem receptor	Biodiversity	Sediment infaunal communities	Richness (total and families for main functional groups), Abundance (total and families for main functional groups), Community structure and composition	-	-	-

[a] *Refer to Table 2-19 for details of sites at which analytes/indicators should be measured in surveillance and assessment years*

[b] *The recommended suite of chemical analytes should be considered as interim, and needs to be more comprehensively determined through sampling studies for treated wastewater and receiving water and associated screening-level risk assessments*

** North Head and Malabar sites only*

2.8. Wastewater overflows and leakage

2.8.1. Wet weather overflows

Wastewater overflows under wet weather conditions occur when the hydraulic capacity of the sewers or WRRFs treatment capacities are exceeded due to excessive inflow and infiltration of stormwater into the wastewater system. The primary sources of stormwater in the wastewater system comes from incorrectly connected private stormwater and inflow into faulty Sydney Water assets. Saltwater ingress, particularly during large tidal events, is also known to affect assets located within the intertidal zone. Groundwater is similarly known to infiltrate the wastewater network.

Sydney Water estimates the volume of wet weather overflows via wastewater network hydraulic models under the established protocol 'Trunk Wastewater System Model Update, Re-calibration and Annual Reporting Procedure'. This model allows the performance of a system to be tracked through time independently of changes in performance from year-to-year due to climate (Sydney Water 2024b). Each year the model is updated when significant growth or changes in the geometry or operation of the system has occurred. The model is then validated and recalibrated using that year rainfall and sewer flow and level data (Sydney Water 2024b).

2.8.2. Dry weather overflows

Dry weather overflows predominantly occur due to blockages caused by tree roots. Inappropriate disposal of solids, such as 'wet wipes', sanitary products, oil and grease, and construction debris, exacerbate the blockages caused by tree roots. Pipe and structural faults are less common than blockages.

We calculate dry weather overflow volumes using the date and time when an incident is reported to Sydney Water, the date and time the leak/overflow ceases, the assumed flow rate and the number of properties upstream of the overflow. We record the total number of overflows and the overflow volume for each EPL and Sewer Catchment Area Management Plan (SCAMP) and report the portion that reaches the receiving waters via annual returns under EPL condition L7.4 for EPL, where applicable (Sydney Water 2024a).

2.8.3. Dry weather leakage detection monitoring program

Sydney Water has divided its wastewater network into 232 SCAMPs, each equivalent to about 100 km of sewer. Dry and wet weather overflows and dry weather wastewater leakage from these catchments can impact recreational water quality at designated swimming areas and biological communities in receiving waters. The information from this program is used to reduce the risk to public health and receiving water ecosystems by identifying dry weather leakage, enabling repairs to the system and providing an overall assessment of the condition of the sewers in each SCAMP. The dry weather component of this program aligns with the respective EPL conditions that require dry weather leakage monitoring, investigation and remedial actions.

The SCAMPs provide a basis for site selection under the dry weather wastewater leakage detection monitoring program. Typically, one sampling site has been identified for each SCAMP. These sites have been designed to best represent the stormwater quality draining the SCAMP and to enable the detection of wastewater leakage in the stormwater system. However, there are six SCAMPs where sites have not been allocated yet as they represent new systems where leaks are not expected, or all residents are not yet connected to the wastewater network. These areas are mostly located to the south of the city (Gerringong, Gerroa) or in underdeveloped areas (Douglas Park, Duffy's Forest, Luddenham, Wilton). With gaps in connection due to some residents still being on septic services, the stormwater quality may be impacted by contamination from these septic systems, which would yield misleading information if sampling was to be conducted. The current 226 dry weather leakage detection monitoring sites are identified in Table 2-22, Figure 2-13, Figure 2-14, Figure 2-15, Figure 2-16, Figure 2-17, Figure 2-18, Figure 2-19, Figure 2-20.

Dry weather leakage monitoring consists of three phases:

- Routine surveillance: All 226 SCAMP sites are sampled at least once every 12 months as per EPL requirements and the results are compared against the revised faecal coliform 10,000 cfu/100 mL threshold (the threshold was increased from 5,000 cfu/100 mL to 10,000 cfu/100 mL on 1 January 2015 following negotiations with the EPA). The annual sampling can be spread throughout the year to balance sampling workloads and is dependent on dry weather. When a routine sample exceeds the threshold, a resample is required to be collected.

  If a SCAMP's faecal coliform result exceeds the threshold value for three consecutive events, the sampling frequency transitions to a quarterly sampling regime. When three consecutive quarterly monitoring results are below the threshold, the SCAMP reverts to the standard annual routine surveillance.

- Resample: When a routine faecal coliform result exceeds 10,000 cfu/100 mL, a resample is required to be completed in dry weather at the routine monitoring site. Resamples help to determine if the exceedance is attributed to a recorded and/or rectified fault within the catchment and whether the leakage is persistent or intermittent. The timeframe for a resample is dictated by the associated risk to the receiving waterway. When the resample also exceeds the 10,000 cfu/100 mL threshold, a source detection investigation is initiated.
- Source detection investigation: A source detection investigation is initiated to investigate leaking infrastructure within the SCAMP. Source detection investigations may be instigated during a routine or resample monitoring event if there is evidence of the presence of wastewater but are mostly initiated following a resample exceedance.

The source detection process involves a 'catchment walk', taking a semi-instantaneous field-based ammonia test (HACH ammonia test strips) at the catchment outlet, then assessing the stormwater channel for any obvious signs of contamination at each stormwater junction. At key points (that is, branches in the line) composited grab samples are collected for faecal coliform analysis. These sampling points are geocoded and described for future reference to site locations. If the investigation determines that the leak is emanating from Sydney Water's reticulation system, remedial action is required. If the leak is associated with private services or infrastructure, the appropriate authorities are notified, and repairs are requested.

All sampling and the source detection process are done in dry weather conditions. The dry weather leakage program defines 'dry weather' as a period when less than 2 mm of rain has fallen in the previous 24 hours and has an Antecedent Wetness Index (AWI) of less than 5 mm. The AWI is calculated using the following equation:

$$AWI_{today} = 0.7 \times (Rain_{24hr} + AWI_{yesterday})$$

The AWI is based on the relaxation time from wet weather events in urban stormwater catchments and is specific to the Sydney region. In the above equation, the factor 0.7 is the remaining moisture fraction. The difference (1.0-0.7) is equivalent to assumed drainage yield/storage depletion factor/rate. The remaining moisture fraction (0.7) depends on the catchment run-off characteristics. The larger the remaining moisture fraction, the slower the catchment responds. Whereas lower remaining moisture fractions represent fast responding catchments.

Daily rainfall data is obtained for each SCAMP from the nearest available Sydney Water rain gauge. For all sites affected by tidal influence, samples are collected at low tide to ensure stormwater is representative of the catchment and not affected by tidal activity. If a site is dry or ponded because no flow is prevalent in the stormwater channel, then no sample is collected. Dry and ponded sites mean that no leaks are active within the SCAMP and thus represent a pass.

Table 2-21 contains the list of analytes monitored for the dry weather leakage detection monitoring program. The faecal coliform bacterial indicator is cost effective in detecting the presence of wastewater in SCAMPS and for leakage detection investigations.

Table 2-21 List of analytes, SCAMP Dry Weather Leakage Detection Program

Water quality analyte	Detection limit	Unit	Method/Reference	Place of measurement
Faecal coliforms	<1	cfu/100 mL	APHA (2017) 9222D	Laboratory
Ammonia Test Strip (Spot Test)	0.5	mg/L	In house test	Field
Conductivity	<7	µS/cm	APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
pH	-	pH unit	APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
Dissolved oxygen	-	mg/L and % sat	APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
Temperature	-	ºC	APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
Field observation and assessment of wastewater indicators	-	-	-	Field

Table 2-22 List of Dry Weather Leakage Detection Program monitoring sites

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
Blue Mountains	BHBLH1	Blackheath	1712	Popes Glen Creek	-33.62794	150.30136
	MVMVC1	Mount Victoria	1716	Fairy Dell Creek	-33.5814028	150.2552529
	PREMP1	Emu Plains	1409	Lapstone Creek	-33.738093	150.654999
	PRGLB1	Glenbrook	1409	Glenbrook Creek	-33.757347	150.627719
	PRGNP1	Glenmore Park	1409	School House Creek	-33.775443	150.665481
	PRJMT1	Jamisontown	1409	Peach Tree Creek	-33.759962	150.677740
	PRMPL1	Mount Pleasant	1409	Unnamed Creek	-33.713491	150.700428
	PRMRV1	Mount Riverview	1409	Unnamed Creek	-33.731120	150.651241
	PRPNR1	Penrith	1409	Peach Tree Creek	-33.749299	150.684740
	WGWAR1	Warragamba	12235	Megarritys Creek	-33.87447	150.611411
	WLWAL2	Wallacia	12235	Scotcheys Creek	-33.8973627	150.6234339
	WMHAZ1	Hazelbrook	1963	Hazelbrook Creek	-33.71272	150.45457
	WMMEB1	Medlow Bath	1963	Adams Creek	-33.670198	150.285413
	WMNKT2	North Katoomba	1963	Katoomba Creek	-33.70017	150.31216
	WMSKT1	South Katoomba	1963	Katoomba Cascades	-33.725121	150.306496
	WMWIN1	Winmalee	1963	Springwood Creek	-33.69720	150.55780
	WMWWF1	Wentworth Falls	1963	Valley of the Waters Creek	-33.71596	150.34734
Bondi Ocean Outfall Sewer (BOOS)	BNBNB1	Bondi Beach	1688	Bondi Beach Inflow	-33.8924119	151.2741713
	BNBNJ1	Bondi Junction	1688	Musgrave Pond	-33.9024078	151.2445898
	BNCMD1	Camperdown	1688	Johnstons Creek	-33.882605	151.176167
	BNEDG1	Edgecliff	1688	Rushcutters Bay	-33.875671	151.229774

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	BNROZ2	Rozelle	1688	Unnamed Creek	-33.865914	151.176522
	BNRSB1	Rose Bay	1688	Rose Bay Channel	-33.877040	151.263864
	BNSYE1	Sydney East	1688	Woolloomooloo Bay	-33.871290	151.219929
	BNSYW2	Sydney West	1688	Cockle Bay	-33.885858	151.206841
	BNVAU2	Vaucluse	1688	Unnamed Creek	-33.852357	151.278351
Cronulla Ocean Outfall Sewer (COOS)	CRBAG1	Bangor	1728	Still Creek	-34.0056477	151.0164489
	CRCRN2	Cronulla	1728	Unnamed Creek	-34.054445	151.145222
	CRCRS1	Caringbah South	1728	Unnamed Creek	-34.060757	151.127934
	CRENG1	Engadine	1728	Forbes Creek	-34.036713	151.036804
	CRGYM2	Gymea	1728	Coonong Creek	-34.048799	151.09109
	CRJAN1	Jannali	1728	Carina Creek	-34.008022	151.070687
	CRLOF1	Loftus	1728	Loftus Creek	-34.0388473	151.0400352
	CRMEN2	Menai	1728	Unnamed Creek	-33.987750	151.021697
	CRMIR1	Miranda	1728	Gwawley Creek	-34.0211773	151.1008282
	CRSUT1	Sutherland	1728	Unnamed Creek	-34.0190038	151.0756332
	CRWOL1	Woolooware	1728	Unnamed Creek	-34.042972	151.112255
Illawarra	BOJAM1	Jamberoo	2269	Unnamed Creek	-34.647549	150.780226
	BOKIA1	Kiama	2269	Unnamed Creek	-34.6773117	150.8532904
	SHALP2	Albion Park	211	Unnamed Creek	-34.565882	150.813662
	SHLIL1	Lake Illawarra	211	Bensons Creek	-34.5510703	150.8635116
	SHSLH1	Shellharbour	211	Oak Park Creek	-34.5601806	150.8300457

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	WOBSV1	Brownsville	218	Brookes Creek	-34.498069	150.806478
	WOBUL1	Bulli	218	Bellambi Creek	-34.3612061	150.9167495
	WOCOR1	Corrimal	218	Towradgi Creek	-34.3804334	150.8951622
	WODAP1	Dapto	218	Mullet Creek	-34.4797786	150.7978399
	WOFGT2	Figtree	218	American Creek	-34.444392	150.860962
	WOFMW1	Fairy Meadow	218	Cabbage Tree Creek	-34.398415	150.8957814
	WOGWY1	Gwynneville	218	Unnamed Creek	-34.4163954	150.8887018
	WOKGR1	Kembla Grange	218	Unnamed Creek	-34.470877	150.778892
	WOPKB1	Port Kembla	218	Minnegang Creek	-34.4916091	150.8735226
	WOTHI1	Thirroul	218	Hewitts Creek	-34.3223961	150.921729
	WOUNA1	Unanderra	218	Allans Creek	-34.4554794	150.8466842
	WOWOL1	Wollongong	218	Unnamed Creek	-34.4356715	150.8931144
Northern Suburbs Ocean Outfall Sewer (NSOOS)	NHAUB1	Auburn	378	Duck River	-33.863205	151.015178
	NHBAH1	Baulkham Hills	378	Toongabbie Creek	-33.758402	150.965363
	NHBCT1	Beecroft	378	Trib. Of Devlins Creek	-33.763509	151.064171
	NHBGH1	Balgowlah Heights	378	Unnamed Creek	-33.800450	151.265235
	NHBLR1	Belrose	378	French’s Creek	-33.734629	151.208696
	NHBLV1	Bella Vista	378	Lalor Creek	-33.770398	150.941269
	NHBRK1	Brookvale	378	Brookvale Creek	-33.770955	151.268276
	NHCCL1	Curl Curl	378	Greendale Creek	-33.765745	151.279202
	NHCHW1	Chatswood	378	Scotts Creek	-33.784651	151.198027

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	NHCLR1	Collaroy	378	Unnamed Creek	-33.745528	151.291260
	NHCMR1	Cromer	378	South Creek	-33.732287	151.276400
	NHCRM1	Cremorne	378	Unnamed Creek	-33.835094	151.233179
	NHCSH1	Castle Hill	378	Darling Mills Creek	-33.765096	151.008612
	NHDUN1	Dundas	378	Subiaco Creek	-33.807107	151.033551
	NHDVY1	Dundas Valley	378	Vineyard Creek	-33.803015	151.032199
	NHEAS1	Eastwood	378	Terrys Creek	-33.771247	151.093745
	NHEBL1	East Blacktown	378	Blacktown Creek	-33.773055	150.935750
	NHEPP1	Epping	378	Devlin Creek	-33.765392	151.082210
	NHFRV1	Forestville	378	Carroll Creek	-33.754194	151.207353
	NHGIW1	Girraween	378	Girraween Creek	-33.783487	150.952245
	NHGLF1	Guildford	378	Duck Creek	-33.835973	151.011882
	NHGRW1	Greenwich	378	Unnamed Creek	-33.826493	151.159794
	NHHOL1	Holroyd	378	A'Becketts Creek	-33.827284	151.010063
	NHHOR1	Hornsby	378	Cockle Creek	-33.706612	151.118154
	NHHUN1	Hunters Hill	378	Tarban Creek	-33.834908	151.135049
	NHKIL1	Killara	378	Rocky Creek	-33.751378	151.172093
	NHKLH1	Killarney Heights	378	Bates Creek	-33.769053	151.220064
	NHLID1	Lidcombe	378	Haslams Creek	-33.860417	151.041489
	NHLIN1	Lindfield	378	Gordon Creek	-33.768193	151.177673
	NHLNC2	Lane Cove	378	Swaines Creek	-33.798949	151.161888

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	NHMNY2	Manly Beach	378	Manly Beach	-33.7958739	151.2878308
	NHMOS1	Mosman	378	Unnamed Creek	-33.8268207	151.2515979
	NHMQP1	Macquarie Park	378	Shrimptons Creek	-33.774865	151.122591
	NHNEP1	North Epping	378	Unnamed Creek	-33.750955	151.084174
	NHNPR1	North Parramatta	378	Hunts Creek	-33.781766	151.024995
	NHNRB1	Naremburn	378	Unnamed Creek	-33.813078	151.199429
	NHNRD1	North Ryde	378	Unnamed Creek	-33.806494	151.137870
	NHNSY1	North Sydney	378	Unnamed Creek	-33.841224	151.198286
	NHPAR1	Parramatta	378	Parramatta River	-33.811823	151.007205
	NHPNH1	Pendle Hill	378	Pendle Creek	-33.784264	150.955375
	NHRSH2	Rosehill	378	Unnamed Creek	-33.820320	151.018746
	NHRSV1	Roseville	378	Moores Creek	-33.770158	151.195439
	NHRYD1	Ryde	378	Strangers Creek	-33.810789	151.129099
	NHRYL1	Rydalmere	378	Unnamed Creek	-33.817501	151.040676
	NHSEA1	Seaforth	378	Burnt Bridge Creek	-33.787393	151.266574
	NHSIL1	Silverwater	378	Unnamed Creek	-33.849943	151.052336
	NHSVH1	Seven Hills	378	Unnamed Creek	-33.778425	150.938318
	NHSWT1	South Wentworthville	378	Finlaysons Creek	-33.803429	150.978454
	NHTUR1	Turramurra	378	South Branch of Cowan Creek	-33.707437	151.155009
	NHWAH1	Wahroonga	378	Lovers Jump Creek	-33.707352	151.143270
	NHWIL1	Willoughby	378	Sugarloaf Creek	-33.798845	151.209808

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	NHWLI2	West Lindfield	378	Blue Gum Creek	-33.791787	151.161741
	NHWMN1	Westmead North	378	Quarry Branch Creek	-33.784183	150.989531
	NHWMS1	Westmead South	378	Domain Creek	-33.810932	150.991714
	NHWPH1	West Pennant Hills	378	Darling Mills Creek	-33.759626	151.017602
	NHWRY1	West Ryde	378	Charity Creek	-33.814465	151.089658
	NHWTH1	Winston Hills	378	Unnamed Creek	-33.783138	150.972779
	NHWTU1	West Turramurra	378	Unnamed Creek	-33.758311	151.118939
	NHWWA1	West Wahroonga	378	Coups Creek	-33.733100	151.092573
	NHWWV1	Wentworthville	378	Coopers Creek	-33.799083	150.974613
	NHYAG2	Yagoona	378	Duck River	-33.886724	151.016596
Southern and Western Suburbs Ocean Outfall Sewer (SWOOS)	MAACT1	Ashcroft	372	Cabramatta Creek	-33.923076	150.889642
	MAALX1	Alexandria	372	Unnamed Creek	-33.9074255	151.193935
	MAAPP1	Appin	372	Kennedy Creek	-34.200564	150.791276
	MAARN1	Arncliffe	372	Unnamed Creek	-33.932051	151.154151
	MAASF1	Ashfield	372	Iron Cove Creek	-33.874824	151.126494
	MAAVL1	Ambarvale	372	Mansfield Creek	-34.111745	150.80524
	MABEX1	Bexley	372	Muddy Creek	-33.960034	151.132282
	MABKH1	Blakehurst	372	Unnamed Creek	-33.983475	151.120173
	MABKN1	Bankstown	372	Salt Pan Creek	-33.932122	151.036489
	MABKS1	Banksia	372	Unnamed Creek	-33.945399	151.148868
	MABLM1	Belmore	372	Unnamed Creek	-33.903962	151.094790

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	MABLS1	Belmore South	372	Cup and Saucer Creek	-33.916499	151.119752
	MABOT1	Botany	372	Unnamed Creek	-33.946795	151.196261
	MABRG1	Bonnyrigg	372	Clear Paddock Creek	-33.876138	150.912765
	MABRT1	Brighton	372	Muddy Creek	-33.957246	151.143948
	MABSP1	Bossley Park	372	Orphan School Creek	-33.865449	150.9006112
	MABVH1	Beverly Hills	372	Wolli Creek	-33.9439818	151.0900862
	MACAB1	Cabramatta	372	Orphan School Creek	-33.885867	150.946204
	MACAS1	Casula	372	Brickmakers Creek	-33.910577	150.930115
	MACBT1	Campbelltown	372	Bow Bowing Creek	-34.057184	150.8198727
	MACDP1	Condell Park	372	Unnamed Creek	-33.93276	150.97659
	MACGE1	Coogee	372	Coogee Beach	-33.919310	151.259620
	MACHF2	Malabar beach	372	Malabar Beach	-33.960834	151.249372
	MACMP1	Campsie	372	Unnamed Creek	-33.9036447	151.0991055
	MACNE1	Concord East	372	Unnamed Creek	-33.856988	151.107213
	MACNW1	Concord West	372	Unnamed Creek	-33.840861	151.092278
	MACPN1	Chipping Norton	372	Drain to Amaroo Wetland	-33.908043	150.982269
	MACTB1	Canterbury	372	Unnamed Creek	-33.8991517	151.1046665
	MADRU2	Drummoyne	372	Unnamed Creek	-33.852161	151.135765
	MADUL1	Dulwich Hill	372	Unnamed Creek	-33.910280	151.138630
	MAEAR1	Earlwood	372	Unnamed Creek	-33.916518	151.132011
	MAEGV1	Eagle Vale	372	Thompson Creek	-34.021200	150.839360

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	MAFAR1	Fairfield	372	Unnamed Creek	-33.8785305	150.9538165
	MAFVD1	Five Dock	372	Unnamed Creek	-33.868308	151.118791
	MAGNF1	Glenfield	372	Macquarie Creek	-33.984768	150.895072
	MAGRA1	Greenacre	372	Cooks River	-33.8975866	151.0826365
	MAHOM1	Homebush	372	Unnamed Creek	-33.8574031	151.0776039
	MAHOX1	Hoxton Park	372	Maxwells Creek	-33.9267883	150.897793
	MAHUR1	Hurstville	372	Bardwell Creek	-33.9344583	151.1327922
	MAING1	Ingleburn	372	Redfern Creek	-33.983319	150.880929
	MAKEN1	Kensington	372	Unnamed Creek	-33.925091	151.221139
	MAKGB1	Kogarah Bay	372	Unnamed Creek	-33.990013	151.137847
	MAKOG1	Kogarah	372	Unnamed Creek	-33.976139	151.129820
	MAKSG1	Kingsgrove	372	Wolli Creek	-33.930684	151.125128
	MALAK1	Lakemba	372	Coxs Creek	-33.899443	151.078632
	MALCH1	Leichhardt	372	Whites Creek	-33.879021	151.168008
	MALEU1	Leumeah	372	Leumeah Creek	-34.055559	150.827367
	MALIV2	Liverpool	372	Unnamed Creek	-33.931867	150.924800
	MALNV1	Lansvale	372	Long Creek	-33.888413	150.957380
	MALUG1	Lugarno	372	Boggywell Creek	-33.979833	151.050782
	MAMAR1	Maroubra	372	Unnamed Creek	-33.958894	151.224938
	MAMAS1	Mascot	372	Unnamed Creek	-33.939132	151.196541
	MAMIN1	Minto	372	Bow Bowing Creek	-34.016924	150.847323

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	MAMOB1	Moorebank	372	Anzac Creek	-33.929324	150.941388
	MAMPR1	Mount Pritchard	372	Green Valley Creek	-33.877943	150.925146
	MAMRB2	Maroubra Beach	372	Unnamed Creek	-33.946403	151.258109
	MAMRV2	Marrickville	372	Unnamed Creek	-33.9193193	151.1540963
	MAPAD1	Padstow	372	Unnamed Creek	-33.933018	151.042154
	MAPAN1	Panania	372	Kelso Creek	-33.947767	150.995946
	MAPHS1	Penhurst	372	To Poulton Creek	-33.984288	151.096078
	MAPKH1	Peakhurst	372	Unnamed Creek	-33.975034	151.068208
	MARAN1	Randwick	372	Stormwater drain	-33.929330	151.223784
	MARBY1	Raby	372	Bunbury Curran Creek	-34.005847	150.837823
	MAREV1	Revesby	372	Little Salt Pan Creek	-33.955995	151.021674
	MARUS1	Ruse	372	Smiths Creek	-34.051287	150.831306
	MARVW1	Riverwood	372	Unnamed Creek	-33.938514	151.049724
	MASMF1	Smithfield	372	Prospect Creek	-33.860508	150.957804
	MASSY1	South Sydney	372	Alexandria Canal	-33.903999	151.199013
	MASTR1	Strathfield	372	Powells Creek	-33.862265	151.086357
	MASUM1	Summer Hill	372	Hawthorne Canal	-33.891806	151.144474
	MASYD2	Sydenham	372	Unnamed Creek	-33.921699	151.156777
	MAVIL2	Villawood	372	Unnamed Creek	-33.873420	150.966287
	MAWAK2	Wakeley	372	Orphan School Creek	-33.877456	150.928437
	MAWHO1	West Hoxton	372	Unnamed Creek	-33.910774	150.821057

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	MAWOD1	Woodbine	372	Bow Bowing Creek	-34.034790	150.831703
	MAWPK2	Wetherill Park	372	Prospect Creek	-33.849245	150.939151
	MAYEN2	Yennora	372	Orphan School Creek	-33.879362	150.960716
Warriewood	WWAVA2	Avalon	1784	Careel Creek	-33.630964	151.332970
	WWELH1	Elanora Heights	1784	Mullet Creek	-33.691922	151.282893
	WWNEW1	Newport	1784	McMahons Creek	-33.657814	151.315693
Brooklyn and Hornsby	BKBKL1	Brooklyn	12438	Hawkesbury River	-33.548675	151.228709
	HHCOW1	Cowan	750	Kimmerikong Creek	-33.585628	151.172362
	HHHHT1	Hornsby Heights	750	Walls Gully	-33.670957	151.102368
	WHCHB1	Cherrybrook	1695	Pyes Creek	-33.704180	151.053207
	WHTHO2	Thornleigh	1695	Waitara Creek	-33.702315	151.080528
West Camden and Picton	PIPIC1	Picton	10555	Redbank Creek	-34.189402	150.607521
	WCCMD1	Camden	1675	Unnamed Creek	-34.077803	150.702417
	WCMAN1	Mount Annan	1675	Kenny Creek	-34.039767	150.769537
	WCNRL1	Narellan	1675	Narellan Creek	-34.028048	150.736923
	WCOKD1	Oakdale	1675	Back Creek	-34.075328	150.537106
	WCSPF1	Spring Farm	1675	Unnamed Creek	-34.069462	150.720637
Western Sydney	CHCHS1	Castle Hill WTS	1725	Cattai Creek	-33.7122818	150.983797
	NRNRC1	North Richmond	190	Redbank Creek	-33.572819	150.730599
	QHBLT1	Blacktown	1724	Breakfast Creek	-33.751324	150.897256
	QHDON1	Doonside	1724	Eastern Creek	-33.754334	150.859422

Region	Site Code	SCAMP	EPL	Waterway	Latitude	Longitude
	QHOKH1	Oakhurst	1724	Bells Creek	-33.717219	150.846287
	QHQHL1	Quakers Hill	1724	Breakfast Creek	-33.742509	150.882700
	RHKEL1	Kellyville	4965	Smalls Creek	-33.687804	150.943774
	RHNKE1	North Kellyville	4965	Cattai Creek	-33.664706	150.938478
	RHRHL2	Rouse Hill	4965	Caddies Creek	-33.687840	150.928921
	RHTOP1	The Ponds	4965	Second Ponds Creek	-33.673249	150.915805
	RMFRE1	Freemans Reach	1726	Unnamed Creek	-33.554750	150.797018
	RMGLO1	Glossodia	1726	Unnamed Creek	-33.527410	150.769034
	RMHOB1	Hobartville	1726	Unnamed Creek	-33.604518	150.752005
	RMRIC2	Richmond	1726	Unnamed Creek	-33.596998	150.763076
	RMWLB1	Wilberforce	1726	Unnamed Creek	-33.559091	150.844748
	RSRVS1	Riverstone	1796	Unnamed Creek	-33.675420	150.857906
	SMBCT1	Blackett	1729	Little Creek	-33.722022	150.798306
	SMMDR1	Mount Druitt	1729	Ropes Creek	-33.740901	150.783919
	SMSMY1	St Marys	1729	Byrnes Creek	-33.769515	150.766633
	SMWER1	Werrington	1729	Werrington Creek	-33.749862	150.756716

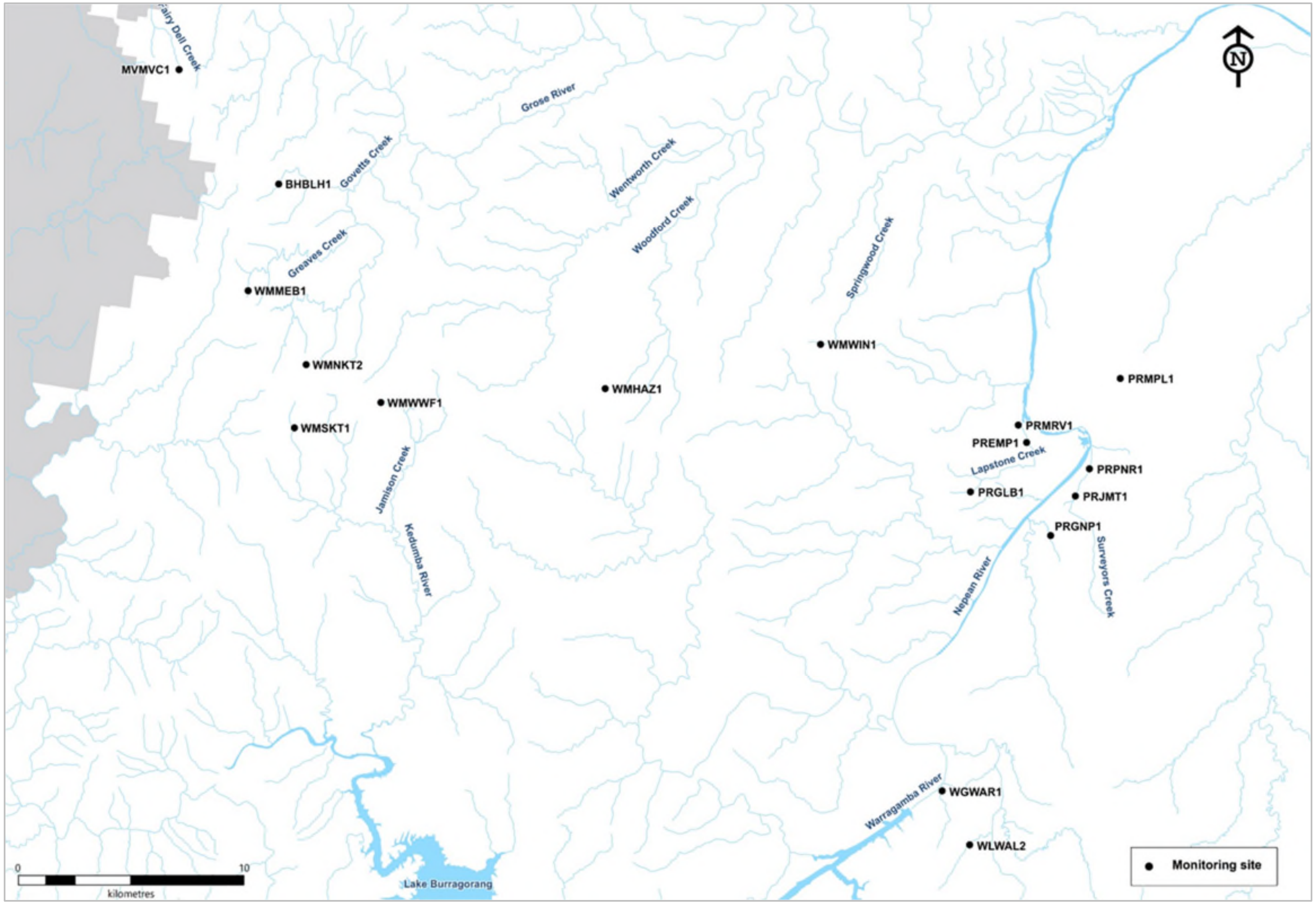


Figure 2-13 SCAMPs dry weather leakage detection monitoring sites: Blue Mountains

Figure 2-14 SCAMPs dry weather leakage detection monitoring sites: Bondi Ocean Outfall System and Cronulla Ocean Outfall System

Figure 2-15 SCAMPs dry weather leakage detection monitoring sites: Illawarra

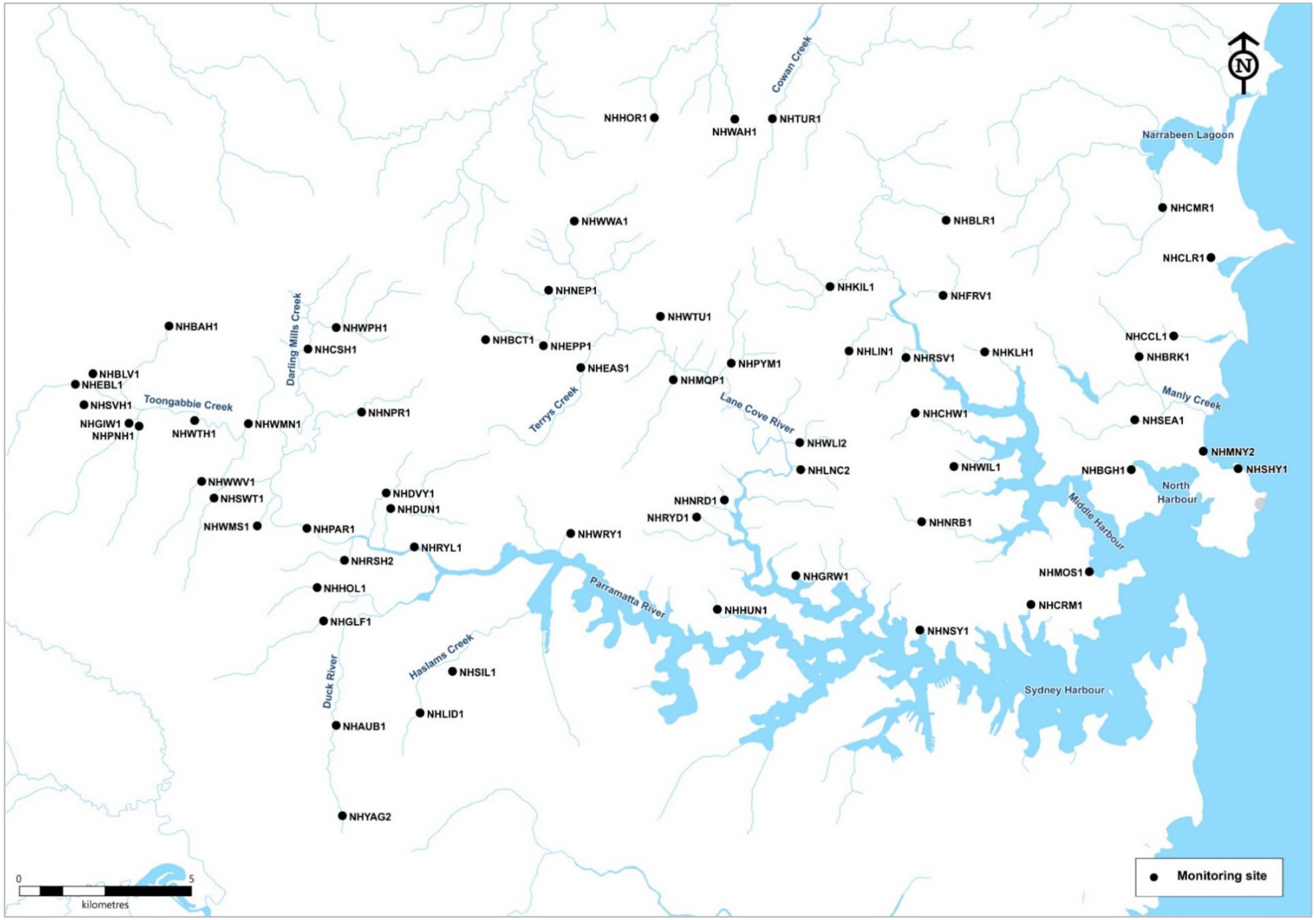


Figure 2-16 SCAMPs dry weather leakage detection monitoring sites: Northern Suburbs Ocean Outfall System

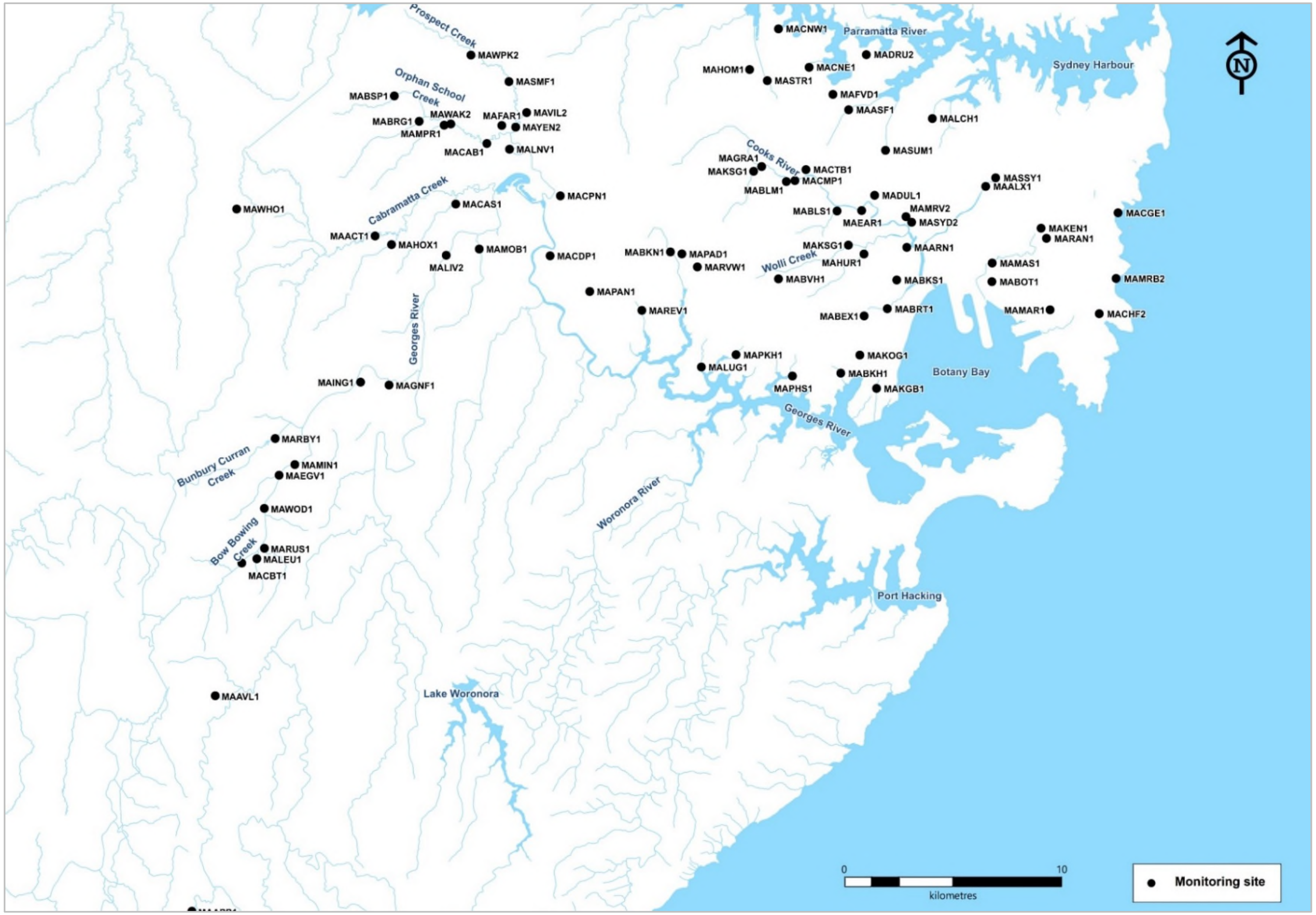


Figure 2-17 SCAMPs dry weather leakage detection monitoring sites: South Western Ocean Outfall System

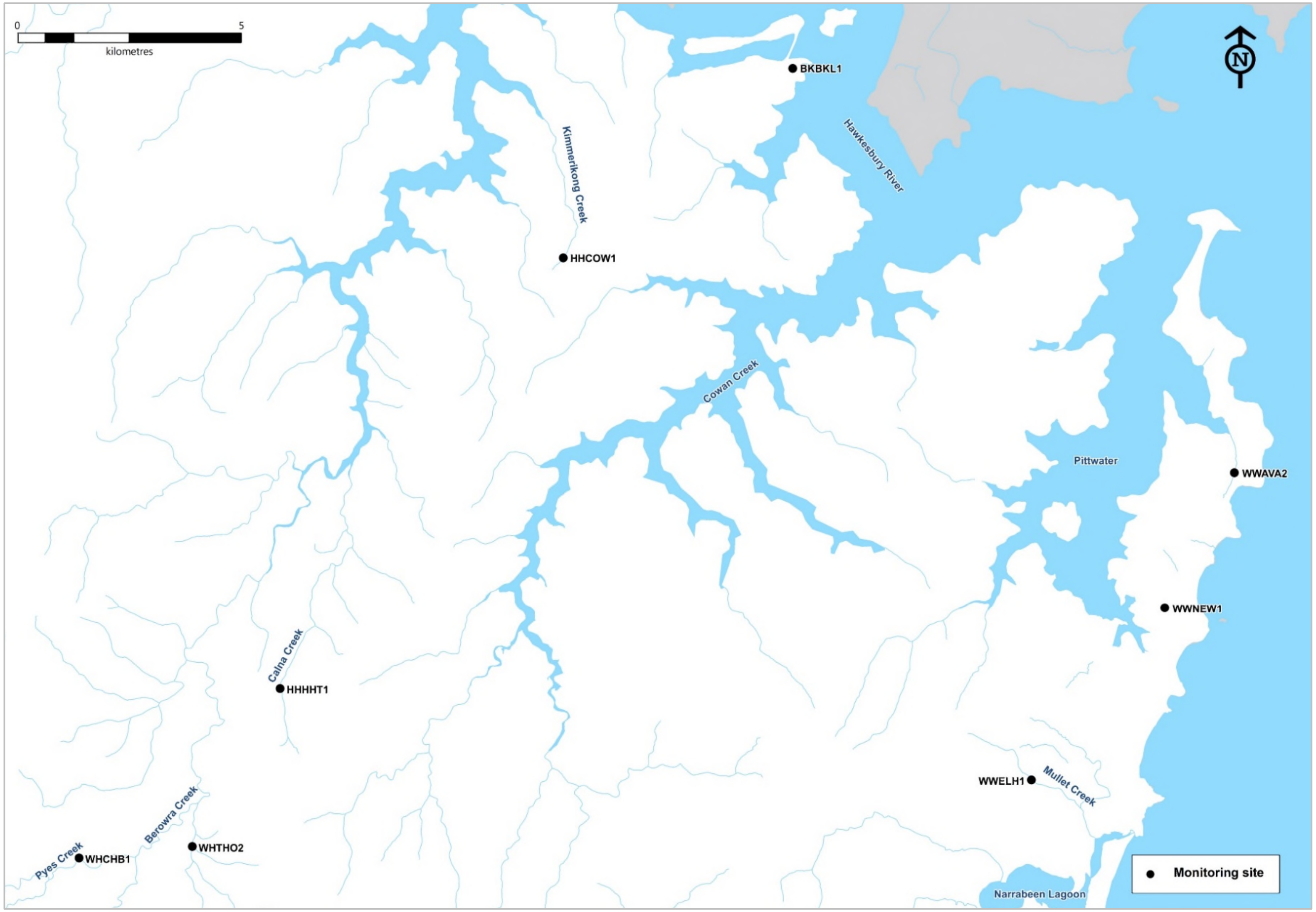


Figure 2-18 SCAMPs dry weather leakage detection monitoring sites: Warriewood and Brooklyn

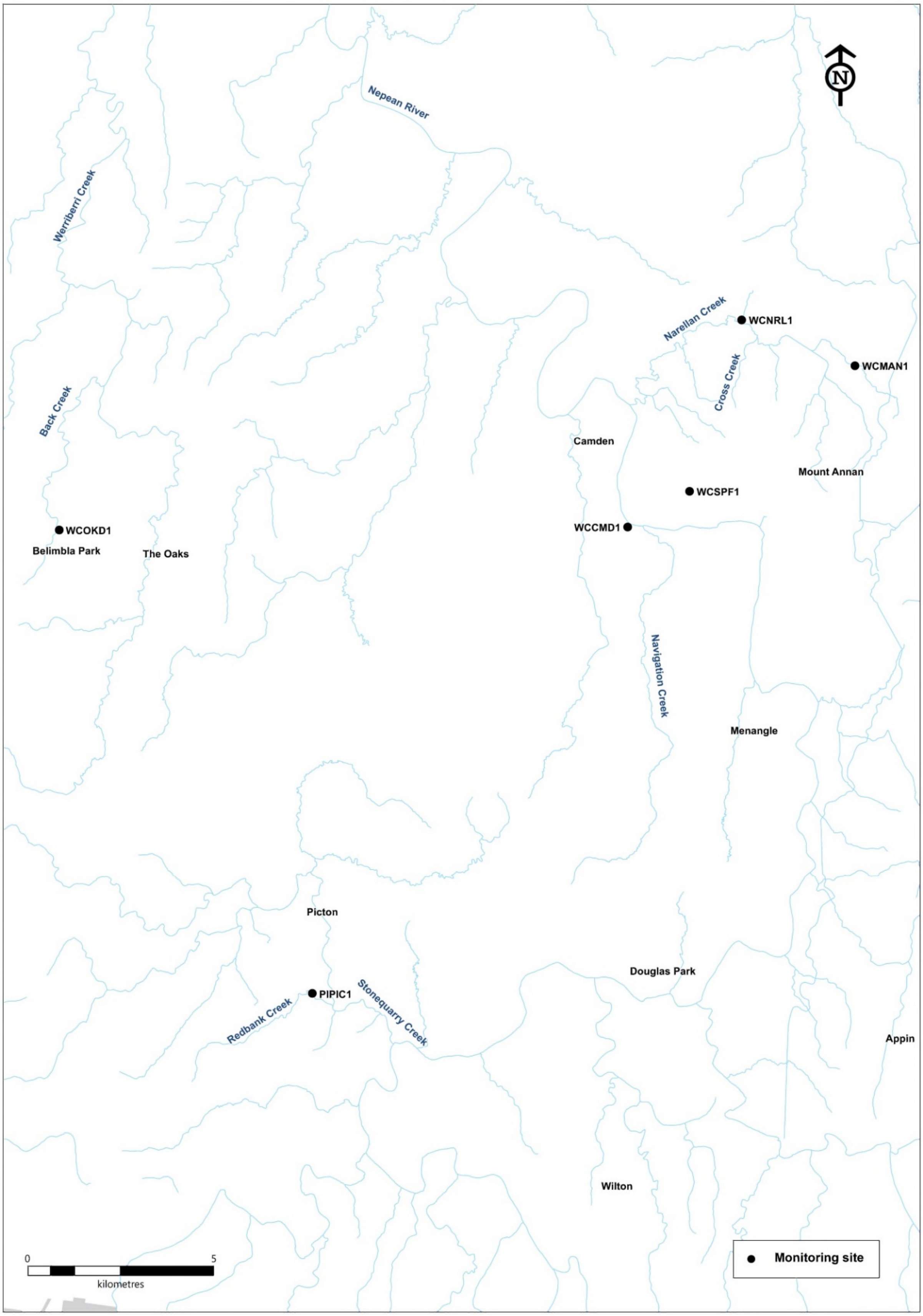


Figure 2-19 SCAMPs dry weather leakage detection monitoring sites: West Camden and Picton

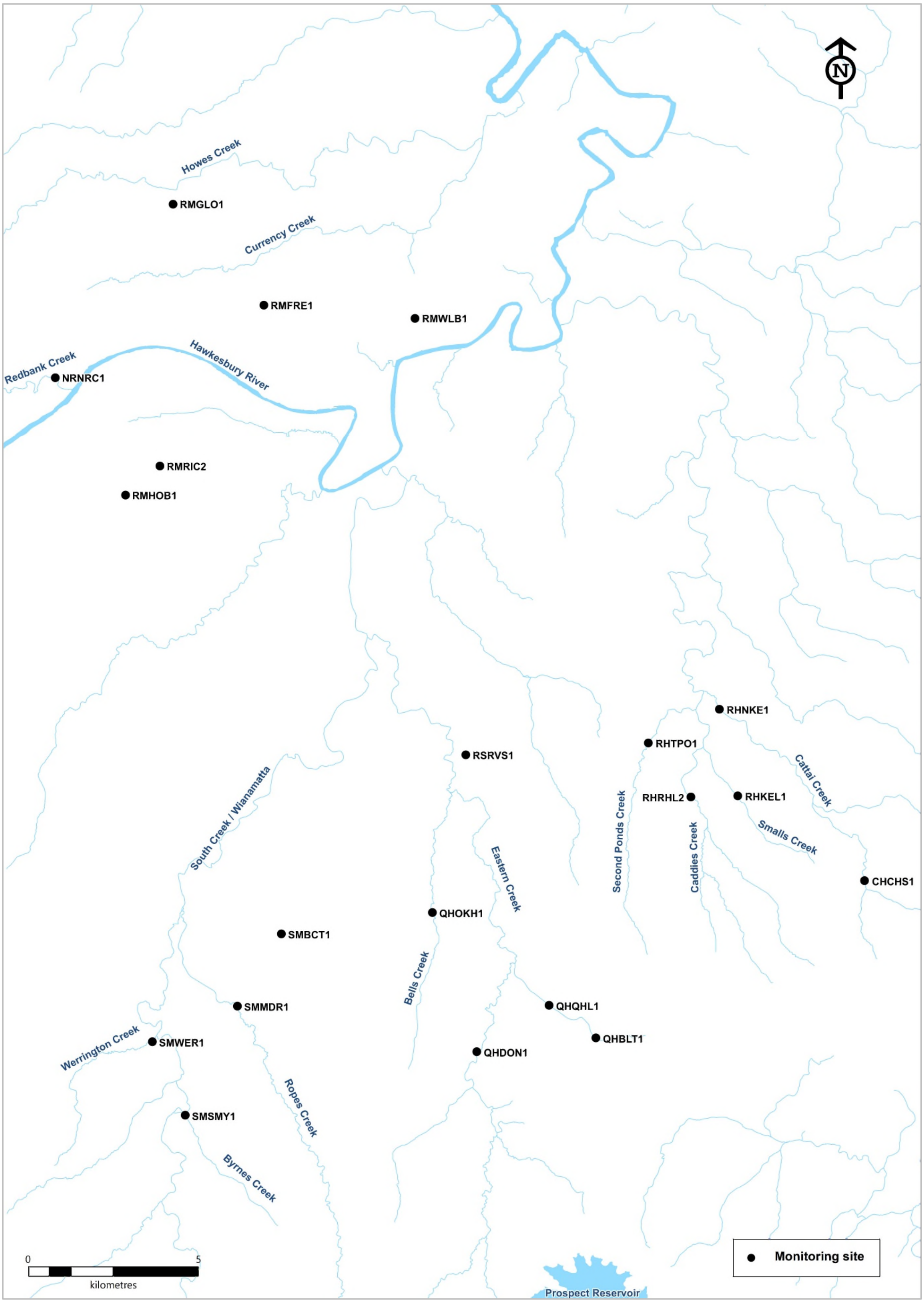


Figure 2-20 SCAMPs dry weather leakage detection monitoring sites: Western Sydney

2.9. Recreational water quality – Harbour and beaches

2.9.1. Rationale

Sydney Water contributes to Department of Climate Change, Energy, the Environment and Water (DCCEEW) Beachwatch Monitoring Program by collecting routine samples and undertaking conductivity and *Enterococci* testing for 18 beaches in the Illawarra region. DCCEEW shares Beachwatch data for 97 other beaches collected under DCCEEW's Beachwatch Monitoring Program. Results from DCCEEW's Beachwatch Monitoring Program are then analysed to understand potential impact of dry weather wastewater leakages on beach water quality.

2.9.2. Beachwatch monitoring program

Enterococci and conductivity data are collected predominantly by DCCEEW for the Beachwatch program. DCCEEW monitors 41 Sydney coastal beaches and 56 harbour beaches of Botany Bay, lower Georges River, Port Hacking, Port Jackson, Middle Harbour and Pittwater at locations listed in Table 2-23 and Table 2-24 as part of the Beachwatch Program. Location maps for these Beachwatch sites are provided in Figure 2-21, Figure 2-22, Figure 2-23 and Figure 2-24. Sydney Water monitors 18 Illawarra coastal beach monitoring sites on behalf of DCCEEW, although ten of these sites are also a requirement of our EPLs (Table 2-25, Figure 2-25).

Sydney and Illawarra coastal beach sites are monitored for *Enterococci* and conductivity (Table 2-26 Figure 2-25) at 6-day intervals throughout the year, except Austinmer, Thirroul and Kiama, which are only monitored from October to April. Harbour beaches are monitored for *Enterococci* and conductivity at 6-day intervals from October to April and monthly outside of this period.

Please see the Beachwatch website for more information on this program.

Table 2-23 List of Beachwatch coastal monitoring sites, monitored by DCCEEW

Northern Sydney	Central Sydney	Southern Sydney
Palm Beach	Bondi Beach	Boat Harbour
Whale Beach	Tamarama Beach	Greenhills Beach
Avalon Beach	Bronte Beach	Wanda Beach
Bilgola Beach	Clovelly Beach	Elouera Beach
Newport Beach	Gordons Bay	North Cronulla Beach
Bungan Beach	Coogee Beach	South Cronulla Beach
Mona Vale Beach	Maroubra Beach	Shelly Beach (Sutherland)
Warriewood Beach	South Maroubra Beach	Oak Park
Turimetta Beach	South Maroubra Rockpool	
Narrabeen Lagoon (Birdwood Park)	Malabar Beach	
North Narrabeen Beach	Little Bay	
Bilarong Reserve		
Collaroy Beach		

Northern Sydney	Central Sydney	Southern Sydney
Long Reef Beach		
Dee Why Beach		
North Curl Curl Beach		
South Curl Curl Beach		
Freshwater Beach		
Queenscliff beach		
North Steyne Beach		
South Steyne Beach		
Shelly Beach (Manly)		

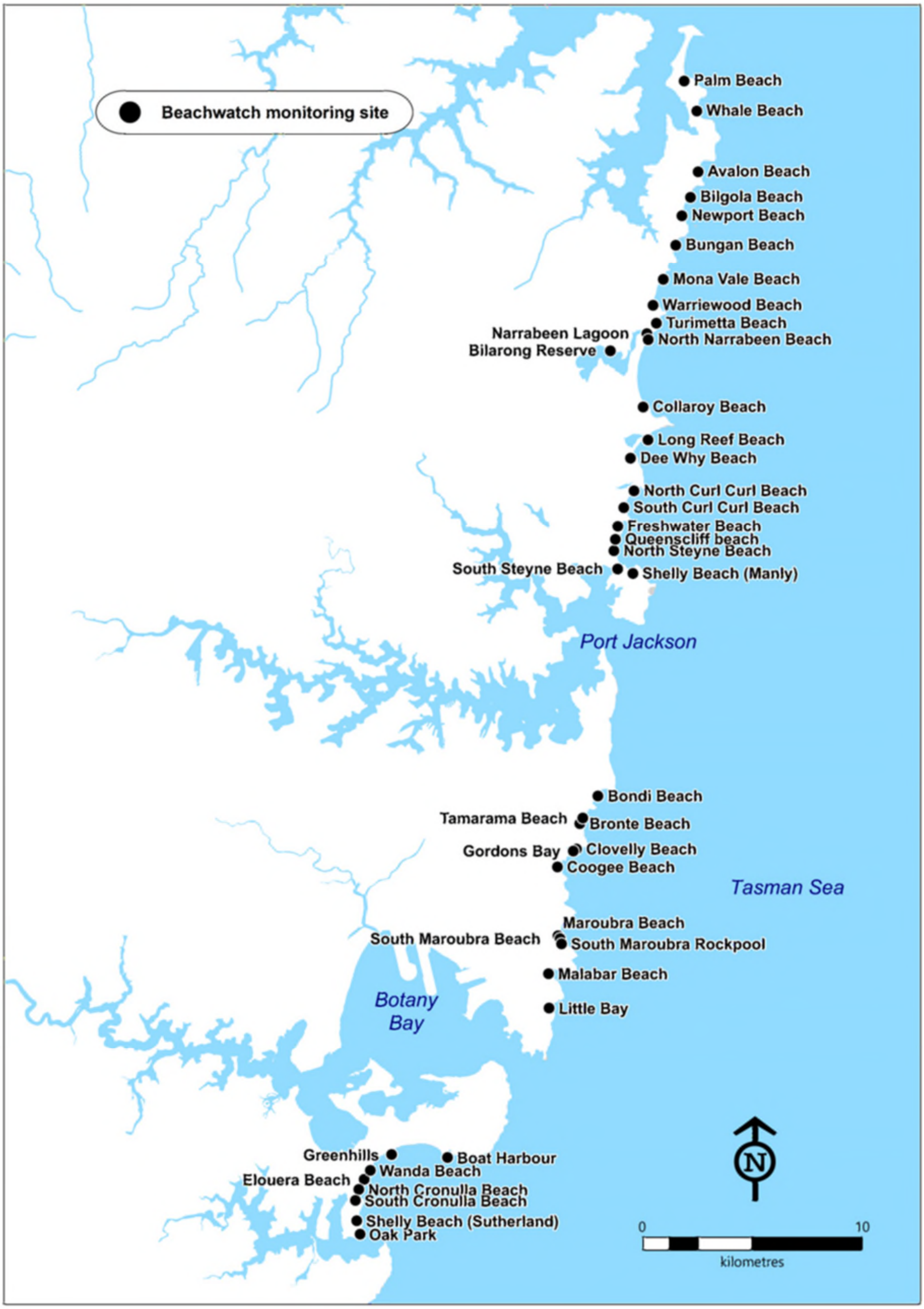


Figure 2-21 Beachwatch Sydney coastal monitoring sites

Table 2-24 List of Beachwatch harbour monitoring sites, monitored by DCCEEW

Botany Bay and Georges River	Port Hacking	Port Jackson	Middle Harbour	Pittwater
Silver Beach	Jibbon Beach	Watsons Bay	Balmoral Baths	Great Mackerel Beach
Como Baths	Hordens Beach	Parsley Bay	Edwards Beach	The Basin
Jew Fish Bay Baths	Lilli Pilli Baths	Nielsen Park	Chinamans Beach	Elvina Bay
Oatley Bay Baths	Gymea Bay Bath	Rose Bay Beach	Northbridge Baths	Bayview Baths
Carss Point Baths	Gunamatta Bay Baths	Murray Rose Pool (formerly Redleaf Pool)	Davidson Reserve	South Scotland Island
Sandringham Baths		Dawn Fraser Pool	Gurney Cr Baths	North Scotland Island
Dolls Point Bath		Chiswick Baths	Clontarf Pool	Taylors Point Baths
Ramsgate Bath		Cabarita Beach	Forty Baskets Pool	Clareville Beach
Monterey Baths		Woolwich Baths	Fairlight Beach	Paradise Beach Baths
Brighton Le Sands Bath		Tambourine Bay	Manly Cove	Barrenjoey Beach
Kyeemagh Baths		Woodford Bay	Little Manly Cove	
Foreshores Beach		Greenwich Baths		
Yarra Bay		Hayes St Beach		
Frenchmans Bay		Clifton Garden		
Congwong Bay		Camp Cove*		

** Monitored from 2015*

Figure 2-22 Beachwatch monitored harbour sites in Botany Bay, Georges River and Port Hacking

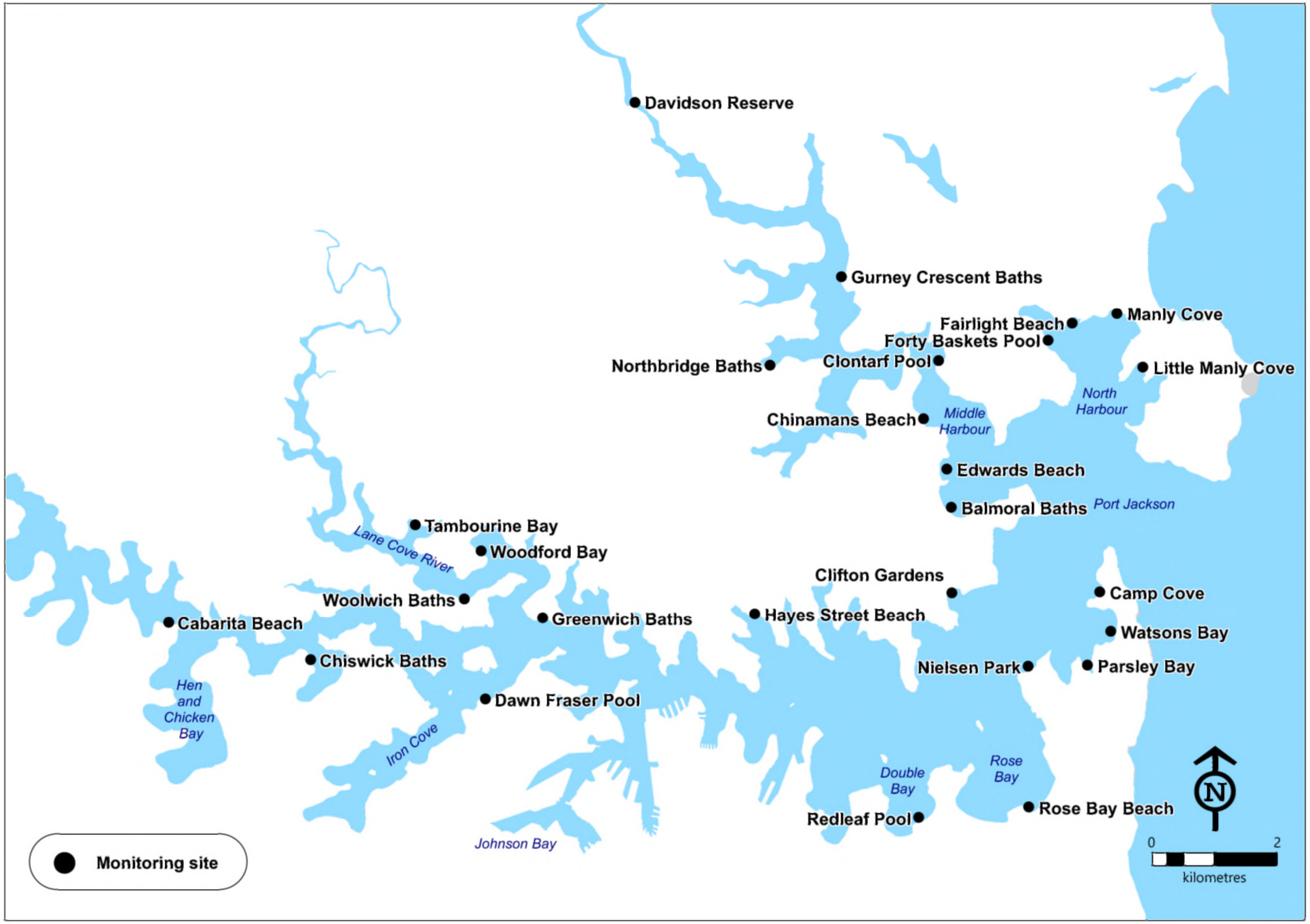


Figure 2-23 Beachwatch monitored harbour sites in Middle Harbour and Port Jackson

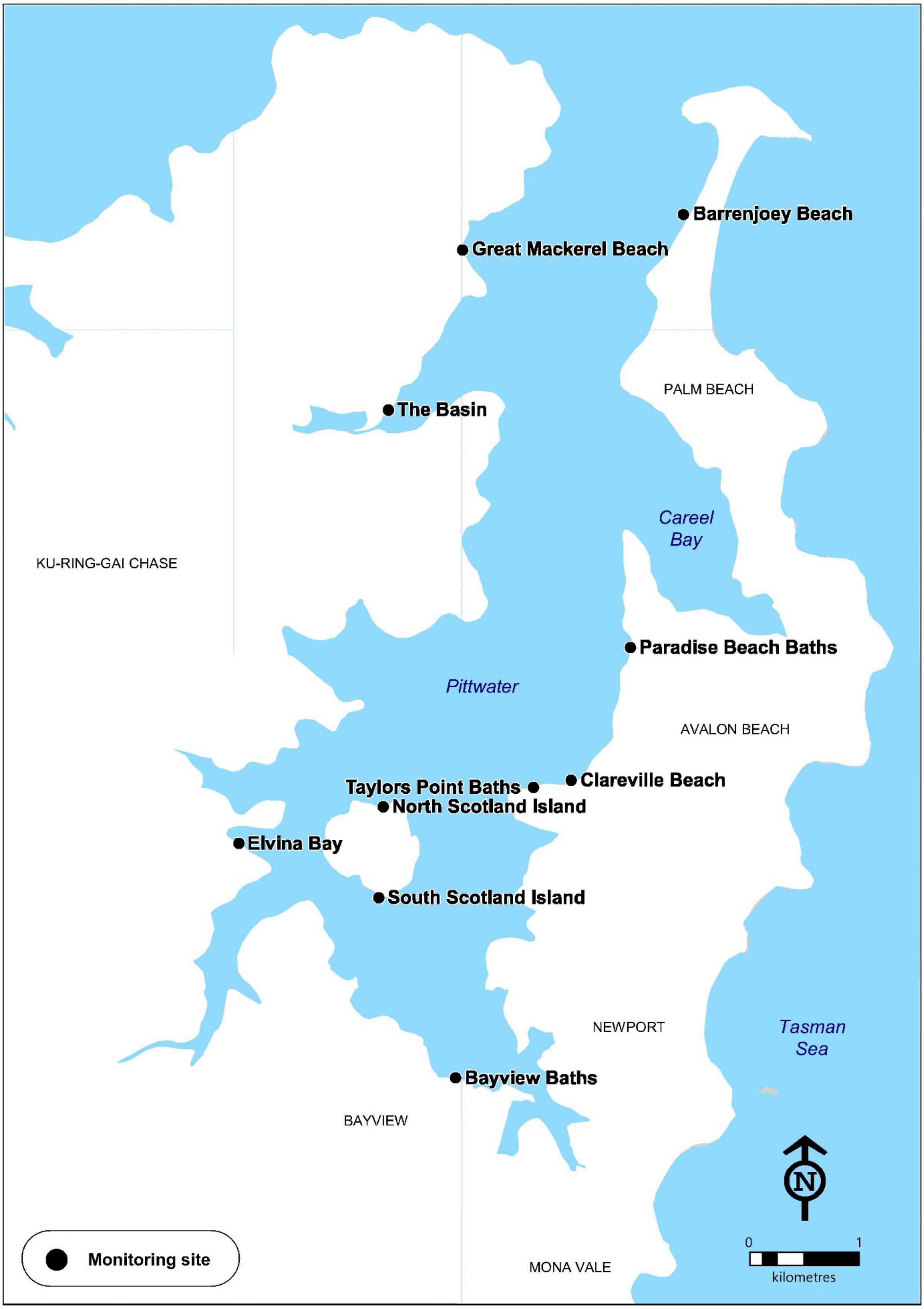


Figure 2-24 Beachwatch monitored harbour sites in Pittwater

Table 2-25 List of Beachwatch Illawarra beach sites, monitored by Sydney Water on behalf of DCCEEW

Wollongong	Shellharbour	Bombo
Austinmer Beach	Entrance Lagoon Beach	Boyd's Jones Beach*
Thirroul Beach	Warilla Beach*	Bombo Beach*
Bulli Beach*	Shellharbour Beach*	Kiama beach
Woonona Beach		Werri Beach
Bellambi Beach*		
Corrimal Beach		
North Wollongong Beach		
Wollongong Beach*		
Coniston Beach*		
Fisherman's Beach*		
Port Kembla Beach*		

** Monitoring required under Sydney Water's EPLs*

Table 2-26 List of analytes and methods for Beachwatch monitoring

Water quality analyte	Detection limit	Unit of measurement	Method/Reference	Place of measurement
Conductivity	7	µS/cm	APHA (2017) 2510 B, 4500-O G, 4500-H B	Field
Enterococci	<1	cfu/100mL	AS/NZS 4276.9 :2007	Laboratory

Figure 2-25 Beachwatch Illawarra coastal beach monitoring sites

2.10. Quality control and quality assurance

Sydney Water's Laboratory Services is accredited by NATA for technical competence to operate according to *ISO/IEC17025 for sampling and testing under the scope of accreditation No.63.*

2.10.1. Water quality sampling and quality control

The sampling quality control procedures routinely applied to field collection activities are:

- appropriate sample container type and pre-preparation
- field decontamination procedures
- field validation sample collection
- suitable sample preservation
- sample handling and storage procedures
- chain of custody procedures.

The following descriptions provide further detail for each of the above procedures.

Sample containers, pre-preparation and preservation

The container types required for each sample matrix were identified in work specifications. Containers are chosen to limit the potential for contamination. Sample containers, pre-preparation and preservation measures are consistent with Australian Standards, APHA or USEPA standards.

Field decontamination

Decontamination procedures are applied to all equipment used in the field that come into direct contact with any sample to be chemically analysed. The use of surfactants, acid and acetone is kept to a minimum. Sampling equipment is decontaminated after sampling and before sampling at the next site. Sampling equipment is rinsed three times with the water body. Sample containers are generally rinsed with the sample matrix (including filtered sample) at least once, with the exception of sample containers that contain a preservative.

Sample handling and storage

All sample handling and storage follows appropriate methods described in APHA and the USEPA guidelines. Contracted analytical laboratories generally commence analysis within 24 hours of sample collection. Where samples are not analysed within 24 hours, approved sample preservation method followed.

Chain of custody

Every sample collected in the field is labelled with a unique identifier code. At the completion of each sampling event, a chain of custody form is prepared to document the number, date, and type of samples collected. The chain of custody form accompanies the sample to document the handling and transfer of samples from the time they are collected to their receipt into the laboratory. These forms trace the possession and handling of samples by all parties. Chain of custody forms are signed, and copies retained by each party involved in sample transfer.

2.10.2. Analytical quality control

The analysis of samples is done by a NATA accredited laboratory, generally Sydney Water Laboratory Services or a suitably qualified external laboratory. Each laboratory is required to implement a range of quality control checks on laboratory procedures and subsequent sampling and handling procedures. The number, type and frequency of these checks vary depending on the size and range of analyses required.

The types of quality control samples used are described below:

Field duplicate

Field duplicates are collected by field sampling teams and analysed by the contracted laboratory to verify the precision of laboratory and/or sampling methodology. The samples are labelled so the laboratory cannot discern these quality control samples from environmental samples.

Field blank

To identify contamination introduced during field activities, field blanks are collected during field sampling operations. A field blank consists of ultra-pure water (17-18.4 megaohm resistivity) decanted into appropriate sample containers at a nominated sample collection site. The samples are labelled so the laboratory cannot discern these quality control samples from environmental samples.

Trip blank

Trip blanks are used to identify contamination that may occur during sample transportation or from the containers themselves. The trip blanks consist of a prepared water sampling container filled with ultra-pure water (17-18.4 megaohm resistivity) before commencement of field collection operations. These samples are transported together with all other sampling containers to the sampling site. The trip blanks remain unopened for the duration of the sampling event and are transported under the same conditions as environmental samples to the contracted laboratory for analysis. The samples are labelled so the laboratory cannot discern these quality control samples from environmental samples.

Method blank

Method blanks are used to detect laboratory contamination. Method blanks contain all reagents and undergo all procedural steps used for analysis. If the equipment used for sampling is dedicated equipment, that is not reused to obtain other samples, no method blank is necessary.

Laboratory duplicate

A laboratory duplicate is an environmental sample that is split into two separate samples by the contracted laboratory and analysed as separate samples. They are used to verify that the per cent difference between each separate result is within acceptable control limits. Per cent differences exceeding the specified limits signal the need for procedure evaluation, provided that the excessive difference between the samples is not matrix-related.

Certified reference material (CRM)

A material containing known quantities of target analytes in solution or in a homogeneous matrix. CRMs are used to document the bias of the analytical process. CRMs are reference standards with documented traceability back to core SI units.

Laboratory fortified matrix and duplicate

A matrix spike is an environmental sample to which known quantities of selected compounds have been added. Matrix spikes are processed as part of the analytical batch and used to verify method accuracy. Analysed in duplicate, matrix spikes verify both method accuracy and precision. If recovery values for the added compounds fall within specified limits, the analytical process is considered in control. Recovery values not within the specified limits, signal the need for procedure evaluation, provided that unacceptable recoveries are not related to the sample matrix.

Laboratory fortified blank

A blank spike is an aliquot of water or solid matrix to which selected compounds are added in known quantities. The blank spike is processed as part of the analytical batch and is used to determine method efficiency. If recovery values for the added compounds fall within specified limits, the analytical process is considered in control. Recovery values not within the specified limits signal the need for procedure evaluation.

Surrogate

Surrogate compounds are virtually identical to the analytes of interest but do not occur in nature and are added to samples prior to extraction in a known amount to document analytical performance.

Calibration

Calibration of analytical instruments followed the requirements specified by the appropriate method and NATA and/or Australian Standards. For all analyses, calibration is checked (or conducted) at the beginning of each analytical sequence or as necessary if the continuing calibration acceptance criteria are not met.

3. Data analysis and graphical presentation methods

3.1. Data collation

Generally, all SWAM (historically STSIMP), WRRF discharge compliance and wastewater network overflows monitoring data are used for presenting and assessing in this report. However, for the Hawkesbury-Nepean River sub-program, receiving water quality and freshwater macroinvertebrates data collected by other relevant monitoring programs are also used for assessing the impact of WRRF discharges (see sections 2.2.3 and 3.4.2).

In addition to presenting wastewater and environmental information, this report also uses *Enterococci* and conductivity data from 97 Sydney Beaches and Harbour sites provided by DCCEEW.

Rainfall data is also collated from catchment specific gauging stations run by Sydney Water or Bureau of Meteorology (BOM) (for details see 3.3).

Wastewater and water quality data collected between July 2023 and June 2024 was used to assess the current year's performance. Historical data collected over the nine previous years (where available) was also used to compare 2023-24 performance.

Assessment was also made on current year's data (July 2023 to June 2024) for the freshwater macroinvertebrates, ocean sediment characteristics and community data. Historical data going back up to more than 20 years was also used for comparison for some of the sites where available.

3.2. Gated analysis workflow

A formal gated analysis workflow has been included as part of the recommendations (van Dam et al. 2023). This allows a clear, efficient and consistent process of analysing and interpreting the results with the aim of identifying whether Sydney Water's operations have resulted in an impact and, if so, the nature, magnitude and including potential impact. As such, the gated analysis workflow has been adopted for the monitoring programs which measure the Pressure, Stressor and Ecosystem Receptor elements for the WRRFs (Table 3-1).

The unified analysis workflow comprises three formal Gates, as follows:

- Gate 1 – Undertake routine analyses of monitoring data
- Gate 2 – Assessment of results from Gate 1 analyses to determine the likelihood that any identified impacts were caused by Sydney Water
- Gate 3 – Where Sydney Water impacts are identified, undertake more detailed analyses to better establish the cause(s), nature and magnitude of impacts.

Table 3-1 Gated analysis workflow

Gate	Objective	Analyses
Gate 1	Identify water quality (pressure/stressors) and ecological (ecosystem receptor) changes possibly linked to Sydney Water activities and quantify their magnitude using routine analyses	Pressure: statistical analysis of pollutant concentration trends
		Stressor: statistical analysis comparing sites upstream and downstream of WRRFs
		Ecosystem Receptor: statistical analysis comparing chlorophyl-a and SIGNAL-SG scores upstream and downstream of WRRFs
Gate 2	Establish likelihood changes identified in Gate 1 are potentially caused by Sydney Water activities	A qualitative written synthesis of all Gate 1 pressure, stressor and ecosystem receptor outcomes, forming a screening step prior to more complex Gate 3 analyses.
Gate 3	Further investigate likely (or possible) Sydney Water impacts identified at Gate 2 to better establish cause and nature/magnitude of impact.	In data reports, this would include investigations to understand drivers (water quality) that may have led to ecosystem receptor changes. In 2023-24, a multivariate regression approach was trialled on West Camden WRRF.

Gate 2 determines the likelihood a Sydney Water impact has occurred. It uses existing Gate 1 analyses and does not require further work beyond a desktop review of existing results. If further analysis beyond that done in Gate 1 is required, this is done at Gate 3. For example, it determines if changes in ecosystem receptors identified at Gate 1, such as the SIGNAL-SG score for macroinvertebrates, can be linked to Sydney Water activities by overlaying the pressure and stressor analyses (i.e. discharge and receiving water quality analyses, respectively).

In 2023-24, the gated workflow was implemented in full for Gate 1 and Gate 2 for each WRRF, and a Gate 3 approach was trialled on West Camden WRRF. If the Gate 3 approach is accepted and endorsed, this analysis will be extended in the future to all WRRFs that have been determined to have a potential Sydney Water impact at the Gate 2 screening level.

3.2.1. Gate 2 synthesis

The Gate 2 step synthesises all outcomes from the Gate 1 tables and is a qualitative interpretation of results, to determine the likelihood of a Sydney Water impact on receiving waterways. Gate 2 is a summary of all Gate 1 outcomes, and no analysis steps are taken, rather, a written interpretation is provided and used as a screening step for possible progression to the Gate 3 step. In this year’s report, all Hawkesbury-Nepean and Georges River WRRFs will incorporate the full Gates 1 and 2 workflow and interpretation.

3.2.2. Gate 3 data analysis

The gate 3 analysis of West Camden WRRF waterway sites involved multivariate regression of both SIGNAL-SG and chlorophyll-a ecosystem receptor results against key water quality parameters, to understand linkages between stressors as potential drivers of waterway health. In future interpretive reports, further Gate 3 analysis on all Gate 2 results that indicate potential adverse ecological impact from Sydney Water's WRRF will be investigated and reported.

SIGNAL-SG

The multivariate regression 'Distance-based linear models' (DISTLM) routine (McArdle and Anderson, 2001) was used to assess SIGNAL-SG scores of the Nepean River sites situated upstream and downstream of the confluence with Matahil Creek to predictor variables in a multiple regression. Predictor variables comprised environmental physico-chemical (temperature, field dissolved oxygen, pH, temperature and turbidity), nitrogen (ammonia, oxidised nitrogen and total nitrogen), and phosphorus (total filterable phosphorus and total phosphorus) variables. This allows the test of the hypothesis there is no relationship between SIGNAL-SG scores and predictor variables. A second model run was conducted with data from Matahil Creek sites situated upstream and downstream of the West Camden WRRF discharge point.

A dissimilarity matrix based on Euclidean Distance was raised for each of the datasets with 9999 permutations for each model run. Prior to running models, draftsman plots were used to check for skewness and multi-collinearity. Inspection of draftsman plots of the values for each pair of metals before and after transformation visually confirmed natural log + 1 transformation choices ameliorated the effect of heavily skewness. To increase the sensitivity of the DISTLM analysis, strongly correlated variables ($r > 0.9$) among the nitrogen predictor variables either oxidised nitrogen and or total nitrogen were omitted to account for multi-collinearity under these model runs.

The step-wise selection procedure was employed using AICc selection criterion of the DISTLM routine to identify parsimonious models where the number of samples (n, 14) relative to predictor variables (q, 10) was small i.e. $n/q < 40$ (Burnham and Anderson, 2002). Modelled output of DISTLM was displayed in a constrained dbRDA ordination plot. To assess the adequacy of the plot, both fitted variation and total variation were inspected. If fitted variation exceeded 70%, the plot was likely to capture most of the salient pattern in the fitted DISTLM model (Anderson et al., 2008). But if the model itself only explains a paltry amount of total variation in the first place, then the dbRDA axis may be of little relevance by not capturing a lot of residual variation in the original data matrix (Anderson et al., 2008).

Draftsman plots and the statistical analysis routine of DISTLM were run with the PRIMER version 7.0.23 (Clarke et al., 2014) and add on PERMANOVA+ module (Anderson et al., 2008).

Chlorophyll-a

The multivariate regression 'Distance-based linear models' (DISTLM) routine (McArdle and Anderson, 2001) was used to assess chlorophyll-a concentrations of the Nepean River sites situated upstream and downstream of the confluence with Matahil Creek to predictor variables in a multiple regression. Predictor variables comprised environmental physico-chemical (temperature, field dissolved oxygen, pH, temperature and turbidity), nitrogen (ammonia NH3-N, oxidised nitrogen and total nitrogen), and phosphorus (total filterable phosphorus and total phosphorus) variables. This allows the test of the hypothesis there is no relationship between chlorophyll-a concentrations and predictor variables. A second model run was conducted with data from Matahil Creek sites situated upstream and downstream of the West Camden WRRF discharge point.

A dissimilarity matrix based on Euclidean Distance was raised for each of the datasets with 9999 permutations for each model run. Prior to running models, draftsman plots were used to check for skewness and multi-collinearity. Inspection of draftsman plots of the values for each pair of metals before and after transformation visually confirmed natural log + 1 transformation choices ameliorated the effect of heavily skewness. To increase the sensitivity of the DISTLM analysis, strongly correlated variables (r>0.9) among the nitrogen predictor variables oxidised nitrogen was omitted to account for multi-collinearity under these model runs.

The step-wise selection procedure was employed using AICc selection criterion of the DISTLM routine to identify parsimonious models where the number of samples (n, 150) relative to predictor variables (q, 10) was small i.e. n/q < 40 (Burnham and Anderson, 2002). Modelled output of DISTLM was displayed in a constrained dbRDA ordination plot. To assess the adequacy of the plot, both fitted variation and total variation were inspected. If fitted variation exceeded 70%, the plot was likely to capture most of the salient pattern in the fitted DISTLM model (Anderson et al., 2008). But if the model itself only explains a paltry amount of total variation in the first place, then the dbRDA axis may be of little relevance by not capturing a lot of residual variation in the original data matrix (Anderson et al., 2008).

Draftsman plots and the statistical analysis routine of DISTLM were run with the PRIMER version 7.0.23 (Clarke et al., 2014) and add on PERMANOVA+ module (Anderson et al., 2008).

3.3. Wastewater quantity, quality, toxicity and pollutant loads

Wastewater quantity and quality data sets were used to determine the performance of each WRRF during 2023-24 with respect to the EPLs. To understand how 2023-24 compared to recent years (previous nine years) all wastewater pollutant analytes were tested statistically for any significant differences under an Analysis of Variance (ANOVA) with a single fixed factor ‘period’, with two levels. These levels were represented by data from ‘the current 2023-24 year’ compared against the ‘previous nine years of data (2014-15 to 2022-23)’ when applicable.

Each model took the following form:

$$Y_i = PERIOD_i$$

Where

Y is the continuous outcome measure of interest (i.e. analyte concentration)

i = 1 to n, the number of periods assessed (i.e. two periods – ‘current’ and ‘past’)

Statistical analysis was performed in R, using packages stats and car. The trend was considered significantly increasing or decreasing when the p-value was <0.05 and the estimated ‘period’ co-efficient was positive or negative, respectively.

Sydney Water commenced biochemical oxygen demand (BOD) monitoring from September 2020. Historically Sydney Water monitored carbonaceous biochemical oxygen demand (CBOD) in WRRF discharges. Therefore, 2023-24 data for BOD could only be compared against the previous three years (2020-23).

Method detection limits for nine other analytes were higher after July 2016 (hydrogen sulphide, copper, iron, zinc, arsenic, nickel, chromium, manganese and molybdenum), following an in-house shift to more standard detection limits. Statistical tests for these analytes were based on 2023-24 data with the previous seven years (2016-23). Statistical tests were performed for all analytes with licence concentration limits. The results are shown on the plots. Statistical tests for some of the analytes were not performed when 90% or more results were less than the detection limits (for example, diazinon, hydrogen sulphide).

The wastewater quality data are presented as box plots by each WRRF to show the trends and comparisons over the years (Figure 3-1). The lower and upper hinges correspond to the 25th and 75th percentiles. The median/50th percentile is presented as dot within the box and connected by a line. The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR (Interquartile Range) from the hinge. The lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge. (1.5 x IQR is the default setting for the whiskers). Black dots outside of whiskers are outliers.

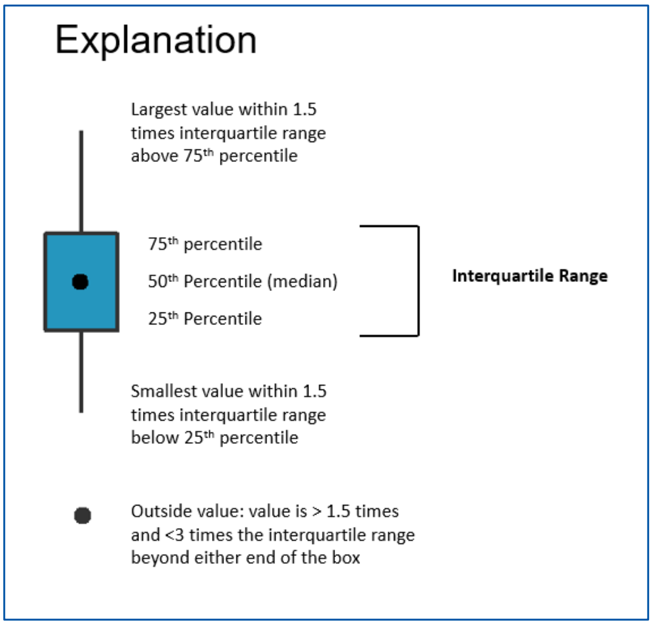


Figure 3-1 Example box plot for presenting the wastewater data

Where the recorded measurement was below the method detection limit, half the detection limit value was used for calculations and graphics. The exception to this is load calculations where zero is substituted if more than half reported values are below the detection limit. These box plots also include other important information, such as the detection limit of that particular analyte, WRRF specific EPL limits and statistical outcomes.

All box plots on wastewater quality are presented in Volume 2: Appendix A, B, D, and E. Only box plots with a significant statistical outcome are presented in Volume 1, Chapter 4.

If the 2023-24 data was significantly different from the previous nine years, then these were identified as an exception and presented in the main body of this report (Volume 1).

The load of key pollutants (oil and grease, total suspended solids, biochemical oxygen demand, nitrogen and phosphorus, as applicable to each EPL) were determined following the Load

Calculation Protocol, where the total wastewater discharge volume was multiplied by the flow-weighted mean concentration of the pollutant (DECC 2009).

Raw data and summary statistics on wastewater discharge volume, characteristics load data by WRRFs (all analytes) and year are provided as electronic appendices (H-1 and H-3).

Daily average rainfall data from 35 gauging stations are used to generate WRRF catchment specific trends in rainfall in comparison to wastewater inflows and discharges (Table 3-2 and Figure 3-2). These data are provided as an electronic appendix (Appendix H-1).

Figure 3-2 Rainfall gauging stations used for assessing the wastewater data

Table 3-2 List of wastewater catchment specific rainfall station and WRRF zones

Catchments	Rainfall station (Hydstra code and site name/ description)	Latitude	Longitude	Owner	WRRF
Upper Nepean	568053 Picton WRRF	-34.2029	150.6148	Sydney Water	Picton and West Camden WRRFs
	568130 West Camden WRRF (composite)	-34.0590	150.6809	Sydney Water	
Mid Nepean	567163 Regent Ville Rural Fire Service	-33.7745	150.6716	BOM	Penrith, St Marys, Glenbrook*, Warragamba* and Wallacia WRRFs
	567087 St Marys WRRF	-33.7342	150.7692	Sydney Water	
	568044 Warragamba Water Filtration Plant	-33.8915	150.5983	Sydney Water	
Lower Nepean	567084 Quakers Hill WRRF	-33.7365	150.8783	Sydney Water	Quakers Hill, Richmond, North Richmond, Winmalee and Riverstone WRRFs
	567085 Richmond WRRF	-33.6080	150.7671	Sydney Water	
	563069 North Richmond WRRF	-33.5748	150.7156	Sydney Water	
	563146 Winmalee WRRF	-33.6767	150.6250	Sydney Water	
	567100 Riverstone WRRF	-33.6562	150.8477	Sydney Water	
Lower Hawkesbury	567076 Castle Hill WRRF	-33.7111	150.9842	Sydney Water	Castle Hill and Rouse Hill WRRFs
	567102 Dural (WPS14)	-33.6969	151.0277	Sydney Water	
Berowra	567120 Brooklyn WRRF	-33.5513	151.1959	Sydney Water	Brooklyn, West Hornsby and Hornsby Heights WRRFs
	566055 Hornsby Bowling Club*	-33.7067	151.1070	BOM	
	566073 Pymble Bowling Club	-33.7408	151.1394	BOM	
	566053 Hornsby Heights WRRF	-33.6672	151.1047	Sydney Water	
South West Sydney	567077 Fairfield WRRF	-33.8807	150.9504	Sydney Water	Fairfield, Glenfield and Liverpool WRRFs
	567078 Glenfield WRRF	-33.9827	150.9071	Sydney Water	
	566049 Liverpool WRRF	-33.9218	150.9386	Sydney Water	
Cronulla	566078 South Cronulla	-34.0700	151.1517	Sydney Water	Cronulla WRRF

Catchments	Rainfall station (Hydstra code and site name/ description)	Latitude	Longitude	Owner	WRRF
	566018 Cronulla WRRF	-34.0307	151.1635	Sydney Water	
Illawarra	568162 Balgownie Reservoir	-34.3928	150.8703	BOM	Bellambi, Port Kembla, Shellharbour, Wollongong and Bombo WRRFs
	568173 Berkeley (Berkeley Sports and Social Club)	-34.4830	150.8473	BOM	
	568171 Albion Park Bowling Club	-34.5703	150.7684	Sydney Water	
	568181 Figtree Bowling Club	-34.4363	150.8646	BOM	
	568188 Kiama Water Tank	-34.6735	150.8434	BOM	
North Sydney Coast	566089 Manly Croquet Club (formerly Manly Golf Course)*	-33.7906	151.2758	Sydney Water	North Head and Warriewood WRRFs
	566100 North Head WRRF	-33.8080	151.3019	Sydney Water	
	566051 Warriewood WRRF (Composite)	-33.6912	151.2993	Sydney Water	
Malabar	566026 Marrickville Bowling Club	-33.9099	151.1641	BOM	Malabar WRRF
	567077 Fairfield WRRF	-33.8807	150.9504	Sydney Water	
	567078 Glenfield WRRF	-33.9827	150.9071	Sydney Water	
	566049 Liverpool WRRF	-33.9218	150.9386	Sydney Water	
Bondi	566032 Paddington (Composite)	-33.8870	151.2253	BOM	Bondi WRRF
	566038 Vaucluse Bowling club	-33.8578	151.2788	BOM	

**Not monitored after 2016*

3.4. Hawkesbury-Nepean River water quality and ecosystem health

3.4.1. Data availability and data selection – Water quality

During last year (2023-24), all scheduled routine sampling events were completed at most sampling sites (44 of 51). The following exceptions occurred where routine samples at seven sites were unable to be collected:

- No samples were collected from the Matahil creek upstream of West Camden WRRF (N7824A) due to dry or ponded conditions on four out of 17 sampling occasions. Downstream flowing water quality will not be comparable with the upstream ponded data due to altered water quality dynamics.
- Site N642A was not accessible for sampling throughout the 2023-24 reporting year. This site was last sampled on 14-Feb-2023 by boat. After that boat sampling at this site was permanently stopped due to safety concerns on sampling by boat. An alternative road path or site is still not determined. As such, for the purposes of analysis, a nearby state of environment (SoE) site, N67, was used as an 'upstream proxy' site in lieu of N642A.
- Samples were unable to be collected at three other sites on two different dates, as access was limited due to a lock change or unavailability of the property owner (N48A 27-Oct-23; NS082 and NS081 23-May-24).
- Hawkesbury River site Off Cattai SRA (N3001) was not sampled on 14-Jun-24 due to construction activity closures.
- Extreme preceding wet weather and unsafe roads or site conditions interrupted water quality sample collection at two monitoring sites (NC516 on 15-Jan-24; N42 on 11-Apr-24 and 14-Jun-24).

Monitoring at two sites of an unnamed creek of South Creek (NS242 and NS241) only commenced from November 2023. These site data will be presented visually and via summary statistics in 2023-24, due to insufficient data to conduct statistical analysis.

A maximum of 10 years water quality data was considered for the analysis or presentation. Receiving water quality data for the routine monitoring sites were generally complete for the previous nine years with the exception of a few site-specific extreme conditions, similar to the 2023-24 year as described above. Data availability periods for all other sites that were considered for water quality assessment varied between one to nine years (Table 3-4). Data for some these sites were collected by multiple projects with different monitoring protocols (e.g. high monitoring frequency, monitoring tailored to special discharge events or other WRRF-specific operational activities). Data was only included in this data report for sites sampled at a comparable frequency to the routine SWAM monitoring (i.e. every 17 to 25 days). The full historical data period was considered for the macroinvertebrate graphical summaries to demonstrate the long-term ecological trend. Statistical analysis was conducted on the current year data (2023-24).

3.4.2. Data categorisation

Receiving water quality data for two selective zones in the Hawkesbury-Nepean River were categorised based on the intervention dates i.e. WRRF upgrades that might have significantly influenced the data sets:

1. West Camden WRRF zone: Nitrogen treatment process upgrade,
   - Cutoff/ completion date: 28 February 2015
   - Matahil Creek and Nepean River sites: N7824A, N7824, N78 and N75
   - Analytes: total ammonia nitrogen, oxidised nitrogen, total nitrogen and chlorophyll-a
2. Riverstone WRRF zone: Nitrogen treatment process upgrade
   - Cutoff/ completion date: 22 January 2019
   - Eastern Creek sites: NS082 and NS081
   - Analytes: total ammonia nitrogen, oxidised nitrogen, total nitrogen and chlorophyll-a
3. Riverstone WRRF zone: Phosphorus treatment process upgrade,
   - Cutoff/ completion date: 5 March 2019
   - Eastern Creek sites: NS082 and NS081
   - Analytes: filterable total phosphorus, total phosphorus, soluble reactive phosphorus

Data collected prior to an intervention date was retained for all data summaries (i.e. visualisations and summary statistics) but was excluded from statistical analyses.

3.4.3. Data preparation

Where the recorded measurement was below the method detection limit (MDL), half the MDL value was used for calculations and graphics. The replicate water quality results for each monitoring site and date were averaged first to use in subsequent data analysis and plots.

All water quality analytes except dissolved oxygen saturation and pH were log10-transformed prior to analysis to make the data distribution more Gaussian or symmetric in shape. This allows the data to better meet the assumption of normality and constant variance required for the linear modelling approach taken for the statistical analysis.

Results from the statistical analysis were back transformed to the original scale for interpretation. For example, the mean on the log scale became the geometric mean on the original scale, the absolute difference between two means on the log scale became the relative difference on the original scale.

3.4.4. Data analysis and presentation – Water quality

Water quality data collected from 53 sites were analysed under the following sub-groups in line with the underlying three key objectives of the monitoring program:

- Assessing the impact of each WRRF by comparing the upstream and downstream sites (20 paired sites)

- Assessing the SoE at ten other sites
- Assessing the SoE in terms of phytoplankton biovolume, counts and species succession at ten selective long-term monitoring sites.

Assessing the WRRF impact – upstream vs downstream

The statistical and graphical presentation methods for assessing the WRRF impact in line with the underlying objectives of the monitoring sites are stated in Table 3-3.

Altogether 40 monitoring sites were assessed in 20 site pairs for the 14 WRRFs (Table 3-4). For Picton, West Camden, Penrith, Winmalee and North Richmond WRRF zones, upstream downstream sites are compared both in the respective tributary and mainstream river. For St Marys WRRF, paired sites are compared both in unnamed tributary where it discharges and in South Creek.

Table 3-3 Monitoring program objectives and respective data analysis and graphical presentation methods for water quality, for assessing the WRRF impact

Objectives/ Hypothesis	Data analysis and graphical presentation methods
• To compare for each WRRF downstream/upstream site pair with relevant water quality objectives (where available) for the current year	• A needle plot of all sample observations for the current year for the downstream/upstream site pair overlaid with a reference line for the relevant water quality objectives • Summary statistics tables on current years data (minimum, maximum, median, mean etc.) including the number of observations above the respective guideline/trigger limits or below method detection
• To compare downstream with upstream site physico-chemical water quality, nutrients, toxicants and metals for each downstream/upstream site pair for the current year and over the relevant historical record	• A figure consisting of the series of annual boxplots (maximum of ten years including current year) over the relevant record for the downstream/upstream site pair overlaid with a reference line for the relevant water quality objective • Summary statistics tables (minimum, maximum, median, mean etc.) by each financial year and sites including the number of observations above the respective guideline/trigger limits or below method detection limit • Tables containing outcomes from generalised linear models (continuous outcome measure with categorical explanatory measures – year and site). Pre-planned hypothesis tests using post-hoc comparison procedures (contrasts) based on the following three hypotheses: – Is the downstream site different to the upstream site for the current year? – Is the current year different to the previous historical record at the upstream site? – Is the current year different to the previous historical record at the downstream site?

The temporal trend for each upstream and downstream pair for water quality analyte (nutrients, toxicants, other physico-chemical analytes, phytoplankton as chlorophyll-a) was explored by plotting both historical annual boxplots and needle plots for the current year. Each water quality analyte is plotted for the 20 paired sites (upstream and downstream) to understand the generalised trends and differences between upstream and downstream sites for each WRRF and catchment (tributary/river).

An example plot for these paired sites is shown in Figure 3-3. The boxplots graphed the 25th percentile value, median/50th percentile and 75th percentile values. The lower and upper hinges correspond to the 25th and 75th percentiles. The upper whisker extends from the hinge to the largest value no further than 1.5 x IQR (interquartile range) from the hinge. The lower whisker extends from the hinge to the smallest value at most 1.5 x IQR of the hinge. Black dots outside of whiskers are outliers.

Needle plots contain the raw or unsummarised data for each sampling event across the current financial year, for both downstream and upstream sites.

Both the needle and boxplots also contain annotated guidelines/ trigger values as horizontal lines for comparison when available (Table 3-6).

For all paired box and needle plots, the upstream site is depicted in blue, and the downstream site is depicted in orange.

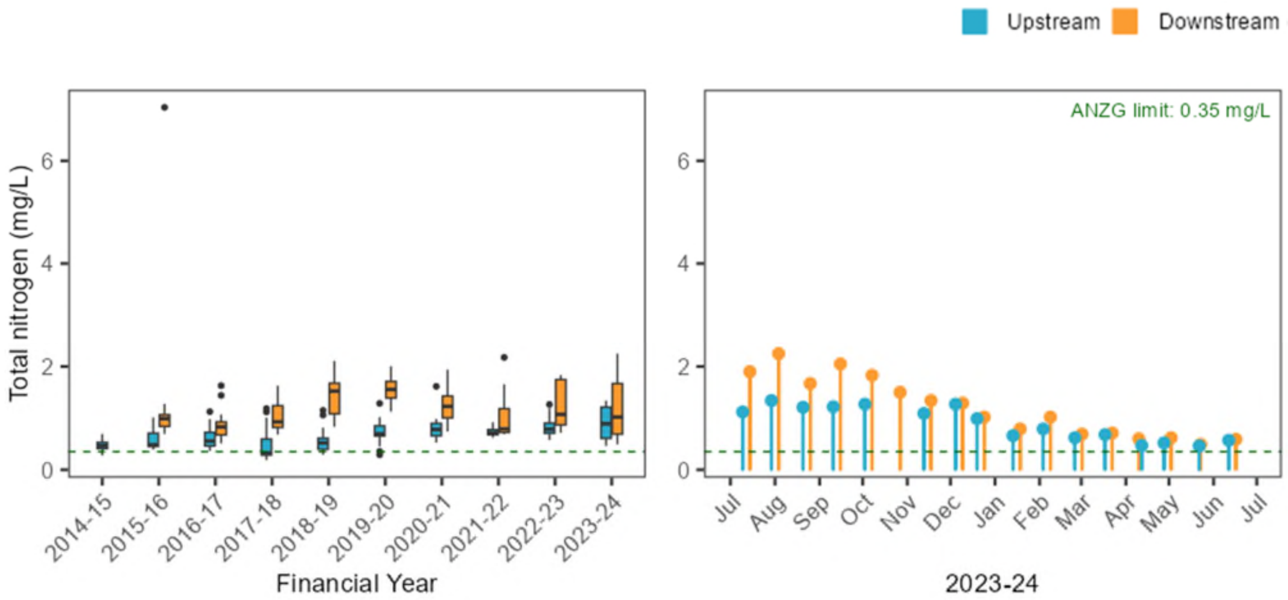


Figure 3-3 Example total nitrogen combined box and needle plot for presenting water quality at upstream downstream site pairs

Table 3-4 Monitoring sites, data period and statistical design for assessing the impact of each WRRF

WRRF	Waterway	Site Code	Water quality		Macroinvertebrates	
			Period	Site pair	Period	Site pair
Picton	Tributary	N911B	2021-2024	N911B vs N911	2015-2024	N911B vs N911
		N911			2013-2024	
	River	N92	2014-2024	N92 vs N91	-	-
		N92A	NC		1995-2024	N92A vs N91
		N91	2015-2024			
West Camden	Tributary	N7824A	2017-2024	N7824A vs N7824	2003-2024	N7824A vs 7824
		N7824				

WRRF	Waterway	Site Code	Water quality		Macroinvertebrates	
			Period	Site pair	Period	Site pair
	River	N78	2017-2024	N78 vs N75	1995-2024	N78 vs N75
		N75	2014-2024			
Wallacia	River	N67*	2014-2024	N67* vs N641	1994-2024	N67* vs N641
		N642A	2019-2023		1997-2022	
		N641	2019-2024		1994-2024	
Penrith	Tributary	N542	2018-2024	N542 vs N541	2003-2024	N542 vs N541
		N541				
	River	N57	2014-2024	N57 vs N53	-	-
		N57A	NC		1995-2024	N57A vs N53
		N53	2017-2024			
Winmalee	Tributary	N461	2016-2024	N461 vs N462	2004-2024	N461 vs N462
		N462	2023-2024		1995-2024	
	River	N48A/N48	2014-2024	N48A vs N464	1995-2024	N48 vs N44
		N464	2015-2024		2023-2024	
		N44	NC		1995-2024	
North Richmond	Tributary	N412	2018-2024	N412 vs N411	2004-2024	N412 vs N411
		N411				
	River	N42	2014-2024	N42 vs N39	1995-2024	N42 vs N39
		N39				
Richmond	Tributary	N389	2021-2024	N389 vs N388	2022-2024	N389 vs N388
		N388				
St Marys	Tributary	NS242	2023-2024	NS242 vs NS241	2023-2024	NS242 vs NS241
		NS241				
	Tributary	NS26	2018-2024	NS26 vs NS23A	1995-2024	NS26 vs NS23A
		NS23A				
Riverstone	Tributary	NS082	2016-2024	NS082 vs NS081	1995-2024	NS082 vs NS081
		NS081				
Quakers Hill	Tributary	NS090	2017-2023	NS090 vs NS087	1995-2024	NS090 vs NS087
		NS087				

<table>
<tr><th rowspan="2">WRRF</th><th rowspan="2">Waterway</th><th rowspan="2">Site Code</th><th colspan="2">Water quality</th><th colspan="2">Macroinvertebrates</th></tr>
<tr><th>Period</th><th>Site pair</th><th>Period</th><th>Site pair</th></tr>
<tr><td rowspan="3">Rouse Hill</td><td rowspan="3">Tributary</td><td>NC53</td><td>2017-2023</td><td rowspan="3">NC53 vs NC516</td><td>1995-2024</td><td rowspan="3">NC53 vs NC515</td></tr>
<tr><td>NC516</td><td>2017-2023</td><td>-</td></tr>
<tr><td>NC515</td><td>-</td><td>1995-2024</td></tr>
<tr><td rowspan="2">Castle Hill</td><td rowspan="2">Tributary</td><td>NC8</td><td rowspan="2">2017-2024</td><td rowspan="2">NC8 vs NC75</td><td rowspan="2">1995-2024</td><td rowspan="2">NC8 vs NC75</td></tr>
<tr><td>NC75</td></tr>
<tr><td rowspan="2">West Hornsby</td><td rowspan="2">Tributary</td><td>NB83</td><td rowspan="2">2017-2024</td><td rowspan="2">NB83 vs NB825</td><td rowspan="2">1996-2024</td><td rowspan="2">NB83 vs NB825</td></tr>
<tr><td>NB825</td></tr>
<tr><td rowspan="2">Hornsby Heights</td><td rowspan="2">Tributary</td><td>NB43</td><td rowspan="2">2017-2024</td><td rowspan="2">NB43 vs NB42</td><td rowspan="2">1996-2024</td><td rowspan="2">NB43 vs NB42</td></tr>
<tr><td>NB42</td></tr>
</table>

** Data from N67 was used as an interim measure for comparison with the downstream Warragamba River site (N641) as the upstream Warragamba River site (N642A) was unable to be monitored due to safety reasons. N67 is an SoE site located on the Nepean River*

NC No comparison was made, will be assessed as SoE site when data become available

'-' Not applicable

ANZG 2018 guidelines recommend developing site-specific guidelines. As these have not been developed for the Hawkesbury-Nepean River, default trigger values for NSW lowland river or estuaries or NSW/VIC east flowing coastal river were used for some of the water quality analytes (ANZG 2018). For the toxicants (ammonia and metals) default low reliability to high reliability trigger/guideline values for 95% species protection are used (Table 3-6).

Data summaries or descriptive statistics (number of total observations, number of observations above the respective guideline, number of observations below the method detection limit minimum, 10^{th} percentile, 20^{th} percentile, median/ 50^{th} percentile, average, standard deviation, 80^{th} percentile and maximum) were produced for each site and financial years. All these outputs are included in Appendix A (Volume 2) or respective Electronic Appendices.

To understand differences for all analytes between upstream/downstream site pair for the current year and over the relevant historical record, generalised linear models were used, with each model taking the following form:

$$Y_{ij} = YEAR_i + SITE_j + YEAR_i \times SITE_j$$

Where

Y is the continuous outcome measure of interest and may be transformed prior to analysis (see section 3.4.3 Data preparation)

i = 1 to n, the number of years in the relevant record;

j = site ID.

ANOVA tables were generated to capture the experimental design structure and residual plots generated to assess the goodness of fit of each model (see Electronic Appendices).

The estimated marginal mean for each year at each site along with its 95% confidence interval was obtained from each model. The means were grouped into two levels of period (‘current’ and ‘past’) so that pre-planned comparisons could be made based on hypotheses of interest.

ANOVA tables, as well as estimated means and confidence intervals are provided in the Electronic Appendices sent to EPA.

The hypotheses tested in 2023-24 using pre-specified post-hoc comparison methods were:

1. Is the downstream site different to the upstream site for the current year?
2. Is the current year different to the previous historical record at the upstream site?
3. Is the current year different to the previous historical record at the downstream site?

Hypotheses were tested by evaluating the estimated marginal mean or “adjusted geometric mean” (R package “emmeans”) calculated from the generalised linear models. The magnitudes of impact of discharge were estimated by “contrasting”, i.e. obtaining the difference of the estimated means of each group. For analytes that were log10 transformed, back-transforming the difference provided the estimated ratio of the two groups (e.g. A vs B), as shown below:

$$\log A - \log B = x \quad \text{Equation 1-1}$$

$$\log \frac{A}{B} = x \quad \text{Equation 1-2}$$

$$\frac{A}{B} = 10^{x} \quad \text{Equation 1-3}$$

Ratios equal to one (1) imply complete similarity. The lower and upper 95% confidence levels were also calculated to determine the range of plausible ratios.

Analytes that were not log10 transformed (i.e. pH and DO saturation) have their contrast estimates expressed as absolute differences rather than ratios, therefore estimates of zero (0) imply complete similarity.

To screen for significant differences, a significance level cut-off (alpha) of $p < 0.05$ was used. Adjustment of the significance level due to multiple comparisons was not undertaken at this step as a conservative approach, allowing more results to be identified as significant and enabling further screening in Gate 2 (see van Dam et al. 2023 for further justification).

Outcomes from pre-planned contrasts are presented as a summary Volume 1 Gate 1 tables, as well as in full in Volume 2, Appendix A. An example paired site contrast table is included below (Table 3-5). As stated above, pH and DO saturation have their estimates presented as an absolute difference between the two site means, e.g.:

- a pH estimate below zero means that the downstream site is on average 0.02 pH units lower than the upstream, however this difference is not significant ($p>0.05$)
- a DO saturation estimate of 2.49 means that the downstream site on average is 2.49% higher in DO saturation than the upstream site, however this difference is not significant ($p>0.05$)

Conversely, all other analytes have their differences back transformed from the log10 scale, therefore are presented as a ratio, e.g.:

- a total ammonia nitrogen ratio of 1.21 suggests the downstream site is 21% higher in total ammonia relative to the upstream site, however this difference is not significant (p>0.05)
- an oxidised nitrogen ratio of 2.5 suggests the downstream site is 2.5 times higher on average relative to the upstream site, and this magnitude of difference is highly significant (p<0.001).

The p values from the hypothesis tests are also presented on a weight of evidence neoFisherian scale to demonstrate the margin of significance, rather than a simple binary significant/non-significant approach (van Dam et al., 2023).

Table 3-5 Example paired comparison contrast table for volume 2

Site(s)	Analyte	Estimate	SE	DF	T ratio	P value
DS vs US	Total ammonia nitrogen	1.21	0.21	291	1.30	0.689
DS vs US	Oxidised nitrogen	2.50	0.57	291	4.00	<0.001
DS vs US	Dissolved oxygen saturation	2.49	2.07	290	1.20	0.625
DS vs US	pH	-0.02	0.09	291	-0.20	0.997

not significant (p>0.05) | p <0.05 and >=0.01 | p <0.01 and >=0.001 | p <0.001

Limitations

Analysis outcomes for some of these sites and analytes should be considered with caution due to some limitations in the data sets:

Data screened for inclusion in the models were:

- Financial years with >10 data points. This sample size threshold was determined to be appropriate to represent a full year of environmental variation
- Only complete models, those with both levels of period (i.e. both 'current' and 'past') were deemed appropriate to run. This ensures model consistency as well as comparative interpretation between SWAM reports. As such, new site pairings or new analytes with <2 financial years of data are represented visually (box and needle plots) and descriptively (summary statistics) for the first year of monitoring.
- Only years following an intervention at a WRRF are included in a model, due to step-changes in treatment quality and subsequent changes in receiving waterways. In 2023-24, interventions at West Camden and Riverstone WRRFs were considered (see Section 3.4.1).

All box plots and needle plots for the paired sites and analytes are presented in Appendix A (Volume 2). If the 2023-24 data for either upstream or downstream monitoring site were significantly different from the previous one to nine years or exceeded the guideline/trigger limits, then these were identified as exceptions and presented in the main body of this report (Volume 1, Chapter 4.1).

Table 3-6 Water quality and phytoplankton guidelines used in box plots and summary statistics calculation and interpretation

Analytes	Type/Class	Guideline or trigger value	Notes	References/ links
Stressors: Nutrients and toxicants				
Total ammonia nitrogen (mg N/L)	Freshwater	<0.79	default very high reliability trigger values for 95% species protection at 7 (median pH was 7.4 for the freshwater SWAM sites, 2023-24 data)	ANZG 2023
	Marine	<2.49	default marine trigger values for 95% species protection at 7.4 (median pH was 7.4 for the estuarine SWAM sites, 2023-24 data)	ANZG 2018
Oxidised nitrogen (mg/L)	Freshwater	<0.040	default trigger value for lowland river	ANZG 2018
	Estuarine	<0.015	default trigger values for estuaries	
Total nitrogen (mg/L)	Freshwater	<0.35	default trigger values for NSW and VIC east flowing coastal river	ANZG 2018
	Estuarine	<0.30	default trigger values for estuaries	ANZG 2018
Total phosphorus (mg/L)	Freshwater	<0.025	default trigger values for NSW and VIC east flowing coastal river	ANZG 2018
	Estuarine	<0.030	default trigger values for estuaries	
Stressors: Physico-chemical analytes				
Conductivity (mS/cm)	Freshwater	125 to 2200	default trigger value for lowland river	ANZG 2018
	Estuarine	NA	no guideline applied	
Dissolved oxygen saturation (%)	Freshwater	>85 and <110	default trigger value for lowland river	ANZG 2018
	Estuarine	>80 and <110	default trigger values for estuaries	
pH	Freshwater	>6.5 and <8.5	default trigger values for NSW lowland river	ANZG 2018
	Estuarine	>7 and <8.5	default trigger values for estuaries	
Turbidity (NTU)	Freshwater and estuarine	6 to 50	default trigger value for lowland river	ANZG 2018
Stressors: Trace metals as toxicants				
Aluminium (mg/L)	Freshwater	55	moderate reliability trigger value at pH >6.5 for 95% species protection, moderate to disturbed ecosystem	ANZG 2018
	Marine	0.5	low reliability trigger value for 95% species protection	
Cobalt (mg/L)	Freshwater	2.8	low reliability trigger value for 95% species protection	ANZG 2018

Analytes	Type/Class	Guideline or trigger value	Notes	References/ links
	Marine	1	high reliability trigger value for 95% species protection	
Copper (mg/L)	Freshwater	1.4	high reliability trigger value for 95% species protection	ANZG 2018
		0.47	Default guideline value for dissolved copper	ANZG 2023a
	Marine	1.3	high reliability trigger value for 95% species protection	ANZG 2018
		0.72	(draft) High reliability default guideline value; for dissolved copper	ANZG 2023b
Nickel (mg/L)	Freshwater	2	(draft) default guideline value, 95% species protection; for dissolved nickel	ANZG 2024a
	Freshwater	11	High reliability trigger value for 95% species protection	ANZG 2018
	Marine	70		
Zinc (mg/L)	Freshwater	4.1	(draft) high reliability trigger value at pH 6.5 to 8.1 for 95% species protection	ANZG 2024b
	Marine	8	default trigger value for 95% species protection	ANZG 2018
Ecosystem Receptor: Chlorophyll-a and phytoplankton				
Chlorophyll-a (mg/L)	Freshwater	<3.0[b]	default trigger values for NSW and VIC east flowing coastal river	ANZG 2018
	Estuarine	<4.0[c]	default trigger values for estuaries	
Blue-green biovolume (mm^3/L)	Green alert	0.04	combined total blue-greens	Blue-greens alert levels for recreational water (NHMRC 2008)
	Amber alert	≥0.4	combined total blue-greens	
	Red alert	≥10	combined total blue-greens	
	Red alert	≥4	combined total blue-greens where a known toxin producer is dominant	
Toxic blue-green counts (cells/mL)	Green alert	>500	toxic blue-green counts eg Microcystis	Blue-greens alert levels for recreational water (NHMRC 2008)
	Amber alert	≥5,000		
	Red alert	≥50,000		

Assessing the SoE at other long-term sites

The statistical and graphical presentation methods for the ten SoE sites and the underlying objectives of the monitoring program are stated in Table 3-7. Data are available for the entire ten years (2014-2024) for the ten long-term monitoring sites (Table 3-8). For two macroinvertebrate monitoring sites (N92A and N57A), water quality data commenced from July 2023-24 (i.e. only one year of data is available).

Table 3-7 Monitoring program objectives and respective data analysis and graphical presentation methods for assessing SoE at ten sites

Objectives	Data analysis and graphical presentation methods
To compare physico-chemical water quality, including nutrients metals and phytoplankton as chlorophyll-a with the water quality objectives (where available), for the current year	• A needle plot of all sample observations for the current overlaid with a reference line for the relevant water quality objectives • Summary statistics tables on current years data (minimum, maximum, median, mean etc.) by each financial year and sites including the number of observations above the respective guideline/trigger limits or below method detection limit
To compare physico-chemical water quality, including nutrients, metals and phytoplankton as chlorophyll-a for the current year and over the relevant historical record	• A figure consisting of the series of annual boxplots (maximum of ten years including current year) over the relevant record for the downstream/upstream site pair overlaid with a reference line for the relevant water quality objective • Summary statistics tables (minimum, maximum, median, mean etc.) by each financial year and sites including the number of observations above the respective guideline/trigger limits or below method detection limit • Tables containing outcomes from generalised linear models (continuous outcome measure with explanatory measure ‘year’). Pre-planned hypothesis test using post-hoc comparison procedures (contrasts) based on the following hypothesis: – Is the current year different to the previous historical record at the site?

Table 3-8 List of sites for assessing the SoE

Site code	Description
N44	Nepean River at Yarramundi Bridge, downstream of Winmalee WRRF
NS04A	Lower South Creek at Fitzroy pedestrian bridge, Windsor
N35	Hawkesbury River at Wilberforce, Butterfly farm, downstream of South Creek
NC11A	Lower Cattai Creek at Cattai Road Bridge, 100m downstream of bridge
N3001	Hawkesbury River Off Cattai State Recreation Area (SRA), downstream of Cattai Creek
N26	Hawkesbury River at Sackville Ferry, downstream of Cattai Creek
N2202	Lower Colo River at Putty Road Bridge, Reference site
N18	Hawkesbury River at Leets Vale, opposite Leets Vale Caravan Park, downstream of Colo River
NB13	Berowra Creek at Calabash Bay (Cunio Point)
NB11	Berowra Creek, Off Square Bay (Oaky Point)

Similar to the WRRF plots, all receiving water quality data (nutrient, toxicants, metals, physico-chemical analytes, phytoplankton as chlorophyll-a) for the SoE sites were presented as single box plots for the historical and current record, and needle plots for the current year (Figure 3-4). These box and needle plots also contain annotated guidelines (Table 3-6) as horizontal lines for comparison when available.

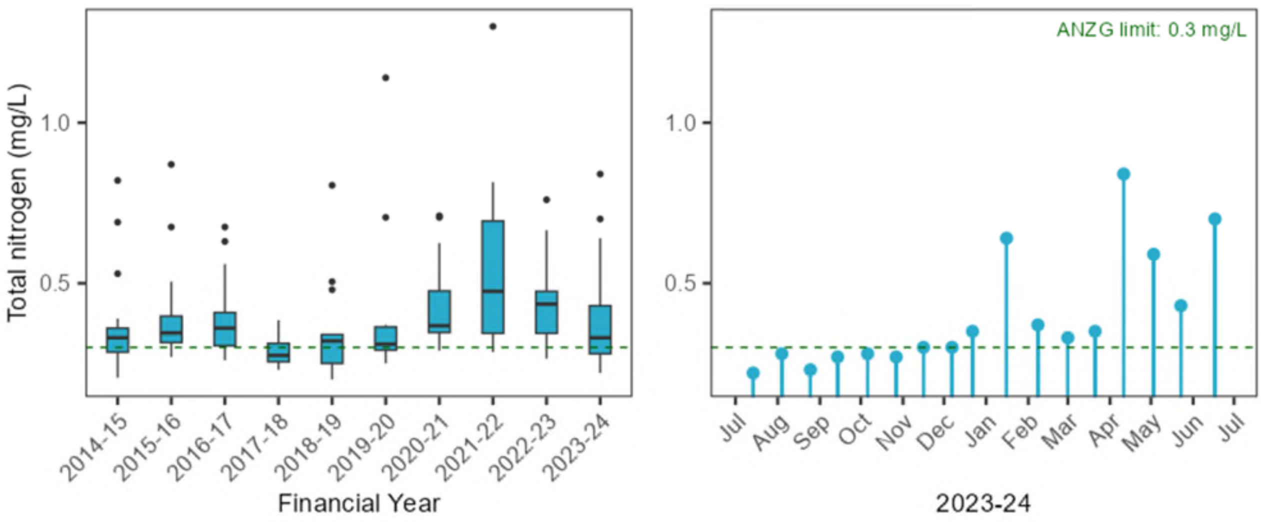


Figure 3-4 Example box and needle plot for the single site water quality for total nitrogen

To understand differences for all analytes between the current year and previous nine years for the single sites, the generalised linear models took the following form:

$$Y_i = YEAR_i$$

Where

Y is the continuous outcome measure of interest and may be transformed prior to analysis (see section 3.4.3 Data preparation)

i = 1 to n, the number of years in the relevant record.

ANOVA tables were generated to capture the experimental design structure and residual plots generated to assess the goodness of fit of each model (see Electronic Appendices).

The estimated marginal mean for each year for each site along with its 95% confidence interval was obtained from each model. The means were grouped into two levels of period (‘current’ and ‘past’) so that pre-planned comparisons could be made based on hypotheses of interest.

ANOVA tables, as well as estimated means and confidence intervals are provided in the Electronic Appendices sent to EPA.

The hypotheses tested for single sites using pre-specified post-hoc comparison methods were:

Is the current year different to the previous nine years at the site?

If the 2023-24 data was significantly different from the previous nine years or exceeded guideline/alert limits, then these were identified as exceptions and presented in the main body of this report (Volume 1, Chapter 4.3.1). These exceptions could either denote improvement or deterioration in water quality. All plots and statistical outcomes for these single sites are included in

Appendix C (Volume 2). Statistical outcomes (contrast tables) are interpreted in a similar manner to the paired comparison table example provided above (see Table 3-5).

Assessing the SoE as phytoplankton biovolume, counts and species succession

The statistical and graphical presentation methods for phytoplankton at the SoE sites and the underlying objectives of the monitoring program are stated in Table 3-9.

Ten selective and representative long-term sites on the Hawkesbury-Nepean River and tributaries were monitored for phytoplankton biovolume and counts throughout the year during 2023-24 (Table 3-10). Prior to 2023-24 phytoplankton was only counted if chlorophyll-a was >7 mg/L. As such the data cannot be accurately compared with the historical records.

Statistical analysis comparing the current year's data over historical records will be conducted from 2024-25, when these sites have both 'current' and 'past' periods with a unified approach of monitoring (i.e. not chlorophyll-a dependent monitoring).

Three selected analytes (total phytoplankton biovolume, blue-green biovolume and toxic blue-green counts) are presented as needle plots in Chapter 4.3.2 for the current years data (2023-24). These needle plots also contain annotated NHMRC 2008 alerts on blue-green biovolume or counts (Table 3-6) as horizontal lines for comparison. Area plots on five key taxonomic group of significance for the current year (2023-24) are also included. Further details about the key phytoplankton taxonomic group are included in Table 3-10.

Table 3-9 Monitoring program objectives and respective data analysis and graphical presentation methods for assessing SoE at 10 phytoplankton monitoring sites

Objectives	Data analysis and graphical presentation methods
• To compare three key phytoplankton analytes (total phytoplankton biovolume, blue-green biovolume and toxic blue-green counts) for the current year	• A needle plot of all sample observations for the current year for each site pair overlaid with a reference line for the relevant water quality objectives (when available) • Summary statistics tables on current years data (minimum, maximum, median, mean etc.) including the number of observations above the respective guideline/trigger limits or below method detection/ nil presence
• To compare three key phytoplankton analytes (total phytoplankton biovolume, blue-green biovolume and toxic blue-green counts) for the current year and over the relevant historical record.	• Not explored in this report (2023-24)
• To compare phytoplankton succession or seasonality for the current year	• Area plots on phytoplankton biovolume by five key taxonomic groups of significance (see notes below)

Table 3-10 Key taxonomic groups of phytoplankton

Phytoplankton group	Description
Diatoms (Bacillariophyta)	The abundance and distribution of the diatoms is largely governed by silicate availability, which in turn is regulated by flow. Diatoms are highly abundant throughout the Hawkesbury Nepean River sites.
Greens (Chlorophyta)	This group generally flourish in the middle of a typical seasonal phytoplankton succession in eutrophic waters (Reynolds 1984). These are also highly abundant in and often co-dominant with other groups of phytoplankton
Blue-greens or Cyanobacteria (Cyanophyta)	This is an important taxonomic group as some species are able to form toxins. Blue-green algal toxin can cause stock death and contact by human can cause skin, eye or respiratory irritation and ingestion can cause hepato-enteritis and pneumonia. In addition to toxins, these blooms can pose problems for water treatment and contact recreation, can also reduce the aesthetic amenity of the river causing unsightly scums, odours and fish kills. The most abundant blue-green algae in the river are Microcystis and Anabaena. Their distribution is associated with maximum water temperature and they co-occur in the river. They persist at high cell densities for long periods because they sequester nutrients like phosphorus in the rapid growth phase and are adapted to resist predation when the bloom is established. Anabaena is differentiated from Microcystis because of the presence of heterocysts which confer a capacity to fix atmospheric nitrogen. Nitrogen fixation has been invoked as a reason for Anabaena blooms in Australian inland waters, which are susceptible to nitrogen limitation because of typically low nitrogen exports from Australian catchments (Harris 1996).
Flagellated monads (Chloromonadophyta, Cryptophyta and Euglenophyta)	typically dominate the phytoplankton population following high flow event or wet weather importing excessive nutrients from diffuse sources by stormwater runoff. This motile flagellated group of phytoplankton are very efficient in scavenging nutrients from highly turbid water rich in suspended organic particles. These blooms are generally short-lived or transitory in nature and disappear or are succeeded by other groups once the high influx of nutrient depletes over time. This group is generally harmless as these co-occur in highly turbid or dirty water
Others:	Combining all other taxonomic groups, notably Dinoflagellates are a special group of algae which are usually unicellular and have paired flagella. In estuarine or marine sites population explosion of toxic dinoflagellates are also called 'red tides' especially in marine or estuarine environments.

Table 3-11 List of sites for assessing SoE as phytoplankton biovolume, species counts

Site code	Site description
N92	Nepean River immediately upstream of Maldon Weir, upstream of all Sydney Water WRRFs, Reference site
N75	Nepean River at Sharpes Weir, downstream of Matahil Creek and West Camden WRRF
N57	Nepean River at Penrith Rowing Club ramp, upstream of Penrith Weir and Penrith WRRF
N48A	Nepean River at Smith Road, Princes farm, upstream of Winmalee WRRF
N42	Hawkesbury River upstream of North Richmond WRRF, downstream of Grose River
NS04A	Lower South Creek at Fitzroy pedestrian bridge, Windsor
N35	Hawkesbury River at Wilberforce, Butterfly farm, downstream of South Creek
NC11A	Lower Cattai Creek at Cattai Road Bridge, 100m downstream of bridge

Site code	Site description
N26	Hawkesbury River at Sackville Ferry, downstream of Cattai Creek
NB11	Berowra Creek, Off Square Bay (Oaky Point)

3.4.5. Data analysis and presentation – Macroinvertebrates

Assessment of freshwater macroinvertebrate data for each inland WRRF was based on scores from the SIGNAL-SG biotic index. These scores were calculated as described by Besley and Chessman (2008). In brief, a SIGNAL-SG biotic index pollution sensitivity score is calculated as follows:

- The first step was to apply predetermined sensitivity grade numbers (from 1, tolerant to 10, highly sensitive) to genera counts that occur within a sample.
- Then multiply the square root transformed count of each genus by the sensitivity grade number for that genus, summing the products, and dividing by the total square root transformed number of individuals in all graded genera.
- Genera that were present in the samples but with no grade numbers available (relatively few) were removed from the calculation of the SIGNAL-SG score for the sample.
- These steps were repeated for each habitat sampled.

Analysis of SIGNAL-SG scores from different habitats at the same site and time have shown pool edges are on average 0.1 units higher than riffles or pool rocks. This habitat adjustment value (Besley and Chessman, 2008) was therefore applied to habitats other than pool edges, when collected, to provide a location specific average score and a measure of variation (one standard deviation of the average) through time as recommended by ANZECC (2000) for ecosystem health comparisons.

In other words, a SIGNAL-SG score can simplistically be thought of as an average of the pollution sensitivity grades of the macroinvertebrate types present that also incorporates a measure of the animal counts (abundance).

Average SIGNAL-SG scores and standard deviations are calculated so that a comparison between sites can be made. Typically, Sydney Water's monitoring of the WRRF point source discharges is conducted upstream-downstream of the WRRF discharge point to determine if any impact has occurred from operation of these facilities. Upstream downstream (paired site) comparisons in this manner allows for separation of WRRF discharge impacts on ecosystem health from upstream catchment influences on ecosystem health.

SIGNAL-SG is a region-specific version of SIGNAL (Chessman, 1995) which was raised in response to suggestions that region specific models are more suitable than those derived for the broad scale as was the case for the original version of SIGNAL (Bunn 1995, Bunn and Davies 2000). The Sydney region specific version of SIGNAL-SG (Chessman et al. 2007) has benefited from development and testing since the original version (Chessman, 1995). This testing included the response of SIGNAL to natural and human influenced (anthropogenic) environmental factors (Growns et al. 1995), variations in sampling and sample processing methods (Growns et al. 1997;

Metzeling et al. 2003) and most importantly setting sensitivity grades of the taxa objectively (Chessman et al. 1997; Chessman 2003).

An interpretation of organic pollution impacts with this tool was demonstrated in Besley and Chessman (2008). They presented univariate analysis of paired (upstream downstream) sites for five decommissioned Blue Mountains WRRFs using the tolerance based SIGNAL-SG statistical analysis tool. The analysis was based on temporal replication (each six months as per national protocol) and within time replication (from collection of multiple habitats at each visit). Within time replication was made possible by applying habitat correction factors to SIGNAL-SG scores of habitats other than pool edge waters.

Primary assessment of scores calculated from the SIGNAL-SG biotic index was done visually using plots along the lines of a process control chart for ecological monitoring presented by Burgman et al. (2012) to display information in a simple, practical and scientifically credible way. This style of control chart illustrates temporal trends and allows interpretation of data against background natural disturbance and variation of the respective streams. In these control chart plots, the range of each site period has the mean plotted together with error bars of ± one standard deviation of the mean, as recommended by ANZECC (2000) for basing ecological decisions. These ± one standard deviation of the mean formed ranges of stream health for period displayed. These charts were plotted on a financial year basis. Calculating a site-specific guideline value such as this range is valid as ANZECC (2000) indicates this can be done, provided at least three years of baseline data have been gathered. This has been done for all upstream sites of the program. In each year’s report, this range is recalculated including the last years upstream data to keep refining each upstream site-specific range.

In the control chart plots, the mean stream health for the 2023-24 for the downstream site was assessed against the range of stream health recorded for all previous financial years (e.g. 1995-23) for the upstream site. Downstream mean stream health for 2023-24 was also compared against the range of stream health collected from the upstream site for 2023-24. These comparisons had three possible outcomes:

- Mean downstream stream health was within the range recorded for the upstream site over the longer overall monitoring period
- Mean downstream stream health was within the range recorded for 2023-24 at the upstream site
- Mean downstream stream health lay outside these two upstream stream health ranges listed above.

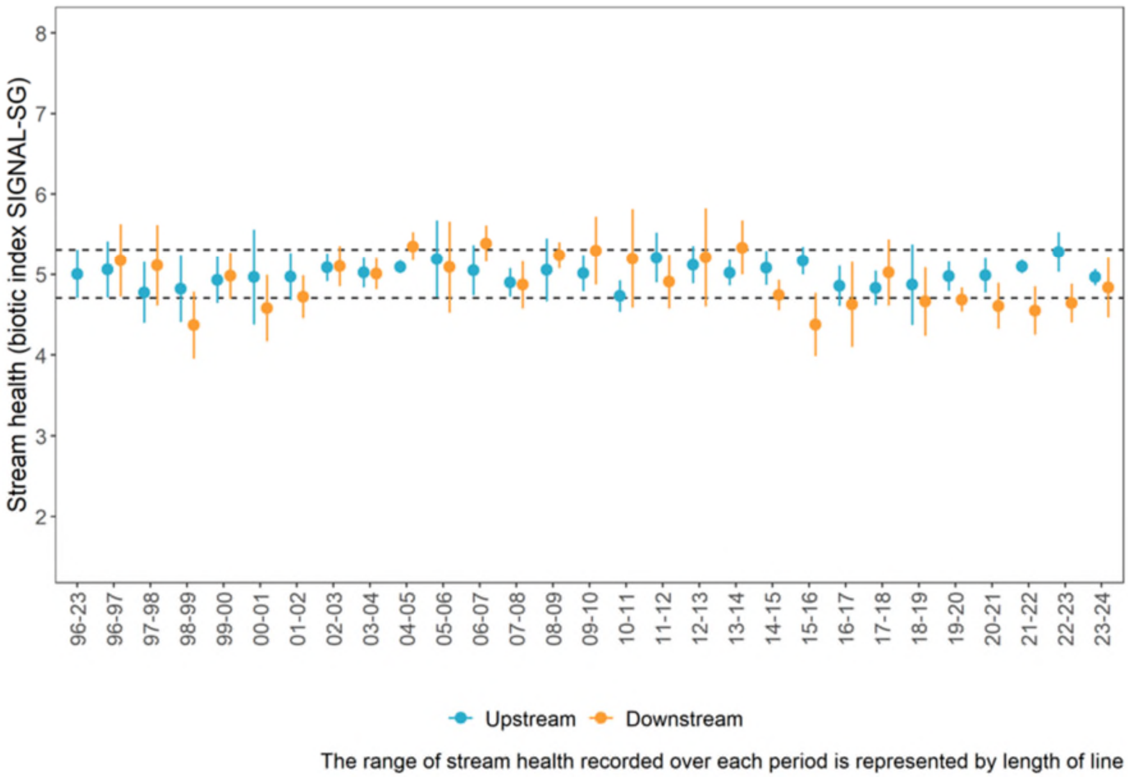


Figure 3-5 Example SIGNAL-SG control chart for an upstream-downstream pair

Univariate t-tests were also conducted on the 2023-24 SIGNAL scores between upstream and downstream paired sites. Previous STSIMP reports adopted a two-stage process involving an equality of variance test prior to a Pooled or Satterthwaite t-test. As advised in the STSIMP Recommendations Report, the two-stage method may lead to poorer results due to low power from small sample sizes (van Dam et al, 2023). Conversely, the Welch t-test performs well in terms of Type I error and has similar power. Therefore, the Welch t-test method was adopted this year as recommended (van Dam et al, 2023).

3.5. Georges water quality and ecosystem health

During 2023-24, all scheduled water quality sampling events for the three Georges River sites were completed.

The objectives of this monitoring program, and respective statistical and graphical presentation methods for assessing the Glenfield WRRF impact is similar to those described for the paired upstream and downstream site of the Hawkesbury-Nepean River WRRF (see section 3.4.3 to 3.4.5).

Two site pairs were considered for the analysis (Table 3-12).

Sampling for these three sites commenced in 2023-24 hence no previous year's water quality data was available. Therefore, analysis was limited to current year's box plots, needle plots, summary statistics table. Statistical analysis will be conducted from 2024-25, when these sites have both 'current' and 'past' periods, so that the hypotheses listed in section 3.4.4 can be tested.

All box plots and needle plots for the paired sites and analytes are presented in Appendix B (Volume 2). If the 2023-24 data for either upstream or downstream monitoring site were exceeded the guideline/trigger limits, then these were identified as exceptions and presented in the main body of this report (Volume 1, Chapter 4.2).

Table 3-12 Monitoring sites, data period and statistical design for assessing the impact of Glenfield WRRF

Waterway	Site code	Period	Site pair
Tributary	GR231A	2023-2024	GR231A vs GR23
River	GR23		
River	GR23B	2023-2024	GR23B vs GR23
	GR23		

3.6. Freshwater reference sites water quality and ecosystem health

A number of reference sites around greater Sydney were monitored to define the level of natural variation of macroinvertebrate communities in streams of bushland areas without urban or rural influences on water quality. This information was and continues to be used to calibrate the stream health SIGNAL-SG biotic index assessment tool (Chessman et al. 2007). The range of scores for natural water quality status and pollution categories is shown below. The control sites include Lynch's Creek (N451) a tributary of Hawkesbury-Nepean River, Hacking River at McKell Avenue in Royal National Park (PH22), the upper Georges River system at O'Hares Creek (GE510) and Georges River at Ingleburn Reserve (GR24). Three sites are reference sites used for calibration of SIGNAL-SG – an unnamed tributary of Devlin's Creek (LC2421), McCarrs Creek (NP001) and Bedford Creek (N628).

Sites were visually assessed against criteria in Table 3-13, SIGNAL-SG scores back to 1995 were plotted by financial year (Appendix C-2).

Table 3-13 SIGNAL-SG inferred pollution categories

Impairment rating	Criteria
Natural water quality	SIGNAL-SG score > 6.5
Mild water pollution	SIGNAL-SG score < 6.5 to 5.1
Moderate water pollution	SIGNAL-SG score < 5.1

3.7. Nearshore marine water quality and ecosystem health

Results from the shoreline outfall program for the Shellharbour WRRF are presented in Appendix D.

The Bray-Curtis resemblance measure is focused on compositional changes in taxa identities (Anderson and Walsh 2013). This is an appropriate choice since we understand the former measurable impact from nearshore wastewater discharge at Shellharbour caused a change in the composition of the intertidal rock platform community.

Multivariate data analyses were performed using statistical routines of the PRIMER Version 7.0.13 software package (Clarke et al. 2014) and the add-on module PERMANOVA+ (Anderson et al. 2008).

The PERMANOVA routine is designed to test whether it is reasonable to consider the existence of pre-defined groups given overall variability (Anderson et al. 2008).

An asymmetrical permutational analysis of variance test (PERMANOVA) was conducted with 'Control' and 'Impact' locations treated as a fixed factor. Sites were nested within 'Control' and 'Impact' and treated as a random factor. The outfall site was the only site under the 'Impact' location and the other 2 sites formed the 'Control' locations. A quadratic root transformation was applied to the data before a Bray-Curtis dissimilarity matrix was constructed. This matrix was the basis for PERMANOVA testing with 9999 permutations run under a reduced model, with conservative Type III sums of squares inspected to base hypothesis decisions upon.

To further explore site differences, hypothesis testing was conducted with PERMANOVA of a single fixed factor 'Site'.

SIMPER analysis reflected a community structure dominated by invertebrates with a lesser contribution of macroalgae at all three locations including the outfall location.

Inclusion of yearly replicate samples from 2008-09 to 2022-23 allowed the factor 'Time' to be included in the above PERMANOVA. Time was comprised of 2008-09, 2009-10, 2010-11, 2011-12, 2012-13, 2013-14, 2014-15, 2015-16, 2016-17, 2017-18, 2018-19, 2019-20, 2020-21, 21-22, 2022-23 and 2023-24 surveys, which were conducted at varying times through late winter to late spring each year.

Ordination plots were raised to visualise data patterns. The non-metric multidimensional scaling (nMDS) ordination routine of PRIMER was used to produce 2- and 3-dimensional ordination plots. In these plots, the relative distance between samples is proportional to the relative similarity in taxonomic composition and abundance – the closer the points on the graph the more similar the community (Clarke 1993). That is, site samples with similar taxa lay closer together and site samples with a differing taxon composition lie farther apart. An unconstrained ordination procedure such as nMDS inevitably introduces distortion when trying to simultaneously represent the similarities between large numbers of samples in a few dimensions. The success of the procedure is measured by a stress value, which indicates the degree of distortion imposed. In the PRIMER software package, a stress value of below 0.2 indicates an acceptable representation of the original data, although lower values are desirable. Where stress values are just above 0.2, the patterns displayed should be confirmed with other techniques such as PERMANOVA.

To understand the context of 2023-24 site data to that from previous years (2008-09 to 2022-23), site sample data were colour coded.

Under the nMDS routine, due to rank ordering of dissimilarities, some detail can be hidden. This detail may be seen using a Principal Coordinates Analysis (PCO) routine as PCO is based upon original dissimilarities being projected onto axes in the space of the chosen resemblance measure (Anderson et al. 2008). As a check for any additional dimensionality in the multivariate data cloud a

PCO ordination plot was produced based on a quadratic transformation of the data and a Bray-Curtis resemblance measure.

A Canonical Analysis of Principal Coordinates (CAP) ordination plot was also produced. The CAP routine is designed to ascertain if axes exist in the multivariate space that separate groups. CAP is designed to purposely seek out and find groups even if differences occur in obscure directions and may not have been apparent from nMDS or PCO plots that provide views of the multivariate data cloud as a whole (Anderson et al. 2008).

3.8. Ocean receiving water quality

Data from the effluent monitoring point of the three major ocean outfall WRRFs (North Head, Bondi and Malabar) were collated and averaged for the 2023-24 monitoring year. Modelled dilution factors from the PLOOM3 modelling outcomes are then applied to the average effluent concentration data, at 98% and 10% probability of exceedance thresholds. These results are then compared with known ANZG (2018) guideline values for 95% protection of marine species. Results from the ocean receiving water quality program are presented in Appendix E-5.

3.9. Ocean sediment quality and ecosystem health

In surveillance years, grain size and total organic carbon (TOC) analyses are conducted for the two sites of each of the three deepwater outfall locations. While benthic community samples are only collected and analysed for the Malabar 0 km location.

Particle size analyses were done with results for sediment fractions obtained for three categories: < 0.063 mm (%); > 0.063 mm (%); and > 2.0 mm (%). A table of mean and standard deviations of the mean were raised for each of the six sites. Mean particle size for the three size classes was also plotted by year over the period 2000 to 2024 to look for signs of build-up in fines size class (< 0.063 mm).

Results from the analysis of TOC obtained from Malabar 0 km (Site 1) were compared with the 99th percentile value of 1.2% specified in EPA (1998). No set trigger values were defined for Bondi or North Head outfall locations. A table was also presented of TOC samples with values equal to or greater than 1.2% TOC content across the nine locations of the broader study program from 2001 to 2024 to look for increasing trends of TOC.

The higher taxonomic level composition of benthic community samples collected from the Malabar 0 km location was plotted at the Polychaeta, Crustacea, Mollusca and Echinodermata taxonomic levels for both the number of taxa and number of individuals of each these four broader taxonomic groups.

In addition to the above check of the higher taxonomic structure, a finer comparison of the taxonomic structure at the Malabar 0 km location to assessment years was performed at the family taxonomic level as a check that taxonomic structure was typical of that seen in these past interpretive years. This was done by placing the 2023-24 sample results from the Malabar outfall location onto the canonical axes of a Canonical Analysis of Principal coordinates (CAP) model of assessment year data (2002, 2005, 2008, 2011, 2014, 2016, 2020) with the outputted sample allocations inspected for fit of the 2023-24 samples to historical samples.

The most recent scheduled assessment year was 2020. For 2020, we analysed all assessment year data extensively (2002, 2005, 2008, 2011, 2014, 2016 and 2020). Under STSIMP 2020 reporting, a separate report (*Ocean Sediment Program 2020 Assessment Year Report*) contains these outcomes (Sydney Water 2020a).

3.10. Wastewater overflows

Wastewater overflows can occur under dry or wet weather conditions. Each year wastewater overflows are reported extensively to the EPA in two separate reports:

- Sydney Water, 2024a*. Annual Sewage Treatment System Performance Report - Environment Protection Licences Condition R5.5 b) and c) Reticulation System Dry Weather Overflows and Cronulla EPL U3.6, North Head EPL U9.6, 2023-24.* Sydney Water, September 2024*.*
- Sydney Water, 2024b*. Sewage Treatment System Licence, Annual Sewage Treatment System Performance Report - Wet Weather Overflow, 2023–24,* Sydney Water, September 2024.

This SWAM Data Report is mainly based upon these two reports and provides a condensed summary of wastewater overflows over the last 10 years.

3.10.1. Dry weather leakage detection program

The wastewater network has been divided into 232 SCAMPs, with 226 SCAMPs requiring routine monitoring. When monitoring results from a SCAMP exceed the EPA set trigger threshold value, that SCAMP is investigated to determine the source of the faecal contamination. Investigations may result in multiple sampling events and exceedances for that SCAMP, as these investigations remain open until a source is identified, rectified and verification samples are below the threshold. If a resample (of the routine sample) returns a value below the threshold, the investigation is closed, as the leak is not persistent. The findings and rectification work from these investigations are recorded and documented for the current financial year.

The dry weather wastewater leakage data presented in this report is based on faecal coliform concentrations recorded over the last 10 years (2014 to 2024). Exceedances were compared against the EPA's >10,000 cfu/100 mL trigger threshold. Dry sites and sites without flowing water at the time of sampling are considered to have passed, as a dry site or no flow indicates no possibility of wastewater contamination.

Historically, two replicate grab samples collected 5 minutes apart were analysed for faecal coliforms up to and including the first quarter of the 2015-16 year (July to September 2015). From October 2015, the sample methodology changed with analysis completed on a composited sample, made up of two equally portioned grab samples collected 5 minutes apart. For consistency, only the highest recorded faecal coliform concentration from the paired duplicate samples (pre-October 2015) was used to generate the exceedance data represented in the Dry Weather Wastewater Leakage results.

The repeat visits outlined above can result in multiple sampling events and exceedances. For consistency, all information presented in the exceedance chart was based on the site exhibiting at least one exceedance within the corresponding financial period. The percentage of exceedance and pass values for the project were derived by dividing by the number of SCAMPS measured each year.

Alternately, exceedance percentage data presented in the 3-year and 10-year SCAMP performance is derived from the total number of exceedances / number of times the site was sampled. These percentages were overlaid on the existing SCAMP catchment map and categorised into percentage exceedance ranges to highlight problematic SCAMPs with respect to temporal variation.

3.11. Recreational water quality – harbour and beaches

The Beachwatch data analysis and assessment for this report focused on dry weather *Enterococci* data. Overflows or leakage reaching the waterways during dry weather conditions pose a greater risk to public health. The wet weather public health risk for recreational activities in waterways (harbour and beaches) are a known fact and people are generally aware of this.

3.11.1. Trends in *Enterococci*: Bubble plots

The temporal trends in health of Sydney beaches, harbours and estuaries were first explored by plotting *Enterococci* results for each site with the respective conductivity (Volume 2: Appendix G). These bubble plots highlighted the dry weather elevated *Enterococci* densities (as shown by larger bubbles). Assumptions behind these plots were:

- *Enterococci* results without a respective conductivity value were excluded.
- Only dry weather results were included in these plots. *Enterococci* results collected when conductivity was below 30,000 µS/cm were considered extreme wet weather and not included in these plots.
- Data labels: Maximum *Enterococci* values for each financial year were labelled where Enterococci values ≥ 230 cfu/100mL, which is the secondary contact recreation guideline (ANZG 2018).

Dry weather overflows or leakage would be represented by higher value bubbles that corresponded to the upper conductivity level. Sites identified by this assessment might inform catchments in which to undertake non-routine investigations under the dry weather leakage program.

3.11.2. Site-specific investigations

Site-specific investigations were carried out on all Beachwatch data with *Enterococci* values higher than the primary contact recreational guideline (35 cfu/100 mL, ANZG 2018) during 2023-24. Firstly, these exceptions were merged with the site-specific rainfall data (BOM). Any *Enterococci* data collected following 2 mm or more rainfall in the previous 72 hours of sampling time were excluded considering wet weather conditions and other catchments impacts (Volume 2: Appendix G, Table G-1).

These short-listed extreme dry weather *Enterococci* exceptions were cross-checked against wastewater network overflow records and relevant environmental response data to determine if the elevated levels were potentially associated with known surcharges. Sites that could not be explained by known network issues represented unexplained dry weather events. If those unexplained events are persistent, there is an opportunity to complete non-routine catchment investigations under the Dry Weather Leakage Detection Program to locate the potential source.

4. Results and Discussion – WRRF Discharges

4.1. Hawkesbury-Nepean River

This chapter presents the monitoring results for the Hawkesbury-Nepean River catchment that are directly linked with the assessment of WRRF impact. WRRFs discharging into this catchment are ordered from upstream (Picton) to downstream (Brooklyn). Under each WRRF, results are presented following the **Pressure**, **Stressor** and **Ecosystem Receptor** (**P-S-ER**) causal pathway elements.

The volume of treated wastewater discharged from the Hawkesbury-Nepean River WRRFs in 2023-24 and the population serviced by these WRRFs is shown in Table 4-1.

This section contains a summary of exceptions for each of the Hawkesbury-Nepean River discharging WRRFs.

Trend plots of measured discharge volume and catchment specific rainfall are presented first, then reuse volume where applicable. This is followed by load limit plots where there was an exceedance of an annual EPL limit during the 2023-24 monitoring period.

Trend plots showing the concentration of analytes in the discharge are only presented where they exceeded the respective EPL limit for a WRRF during the 2023-24 monitoring period, or where there was a significant analyte concentration increase/decrease in 2023-24 in comparison to the previous nine years.

Trend plots of nutrients, toxicants, physico-chemical water quality and phytoplankton as chlorophyll-a for the upstream/downstream sites are presented when:

– there was a significant difference in 2023-24 analyte concentration/level between upstream and downstream site

– there was a significant increase or decrease in 2023-24 analyte concentration/level compared to earlier years

– 2023-24 median analyte concentrations/level exceeded the respective ANZG or NHMRC guideline/trigger limit.

All trend plots on macroinvertebrate biotic index SIGNAL-SG are presented in Volume 1. Univariate statistical analysis outcomes on 2023-24 macroinvertebrate data are included in Volume 2 (Appendix A-1 to A-14, Ecosystem receptor – macroinvertebrate sections). Raw data of macroinvertebrate taxa and counts are also included in the electronic appendices provided to the EPA (December 2024).

All trend plots showing the analyte concentration and load data for Hawkesbury-Nepean River WRRFs, including applicable EPL limits, can be found in Volume 2 (Appendix A-1 to A-15)

All trend plots on nutrients, toxicants, physico-chemical water quality, trace metals and phytoplankton as chlorophyll-a of the Hawkesbury-Nepean River are also included in Volume 2 (Appendix A-1 to A-14).

Multiple electronic appendix files on raw data and summary of results for all Hawkesbury-Nepean River WRRFs, receiving water quality by year has also been provided to the EPA (December 2024).

Table 4-1 Hawkesbury-Nepean River WRRFs operated by Sydney Water

WRRFs	Treatment level	Discharge 2023-24 (ML/year)[a]	Projected population 2023-24 [b]	Discharge location
Picton	Tertiary and disinfection	1,094	20,673	Re-used for on-site agricultural irrigation with wet-weather discharge to Stonequarry Creek
West Camden	Tertiary and disinfection	8,093	130,311	Matahil Creek to the Hawkesbury-Nepean River
Wallacia	Tertiary and disinfection	430	6,892	Warragamba River to the Hawkesbury-Nepean River
Penrith	Tertiary and disinfection	5,766	118,001	Boundary Creek to the Hawkesbury-Nepean River
Winmalee	Tertiary and disinfection	7,355	59,680	Unnamed creek to the Hawkesbury-Nepean River
North Richmond	Tertiary and disinfection	447	7,707	Redbank Creek to the Hawkesbury River
Richmond	Tertiary and disinfection	627	16,858	Re-used for irrigation at the University of Western Sydney Richmond campus and Richmond Golf Club; excess discharged to an unnamed creek that flows to Rickabys Creek
St Marys	Tertiary and disinfection	12,536	177,670	Unnamed creek to South Creek
Quakers Hill	Tertiary and disinfection	15,666	174,626	Breakfast Creek to Eastern Creek
Riverstone	Tertiary and disinfection	5,954	94,727	Eastern Creek to South Creek
Rouse Hill	Tertiary and disinfection	8,245	132,997	Second Ponds Creek to Cattai Creek; also re-used for local recycling scheme
Castle Hill	Tertiary and disinfection	2,570	33,109	Cattai Creek
West Hornsby	Tertiary and disinfection	5,415	59,736	Waitara Creek to Berowra Creek
Hornsby Heights	Tertiary and disinfection	2,670	33,477	Calna Creek to Berowra Creek
Brooklyn	Tertiary and disinfection	99	1,510	Hawkesbury River at 14 m depth on the second pylon of the old road bridge adjacent to Kangaroo Point

[a] *Discharge volume excludes onsite and offsite reuse.*
[b] *Projected populations (at 30 June 2023) are based on forecasts by the Australian Bureau of Statistics and the DCCEEW.*

4.1.1. Picton WRRF

- Total nitrogen and total suspended solids in the precautionary discharge from Picton WRRF exceeded EPL annual load limits in 2023-24. All other discharge parameters were within EPL limits. There was a significantly increasing trend in ammonia nitrogen concentration in the treated discharge, while total phosphorus concentrations in the WRRF discharge, Eastern and Western irrigation storage Dams showed decreasing trends compared to the previous nine years.
- Nutrient concentrations remained stable at all four receiving water sites in 2023-24 for Stonequarry Creek and Nepean River in comparison to the previous years.
- Total ammonia nitrogen, oxidised nitrogen and total nitrogen concentration were significantly higher at the downstream Stonequarry Creek site in comparison to the upstream site. Ammonia nitrogen concentrations were also significantly higher at the downstream Nepean River site, suggesting a nitrogen impact from Picton WRRF, extending to the Nepean River.
- Total and filterable phosphorus concentrations were significantly higher at the downstream Nepean River site compared to upstream. This could not be linked with an increase in phosphorus concentrations in WRRF treated discharges.
- Chlorophyll-a remained stable in 2023-24 compared to the previous two to nine years, and no significant difference was found between upstream and downstream sites. This indicates that the elevated nutrient concentrations at the downstream receiving water site had no influence on phytoplankton as chlorophyll-a.
- Ecosystem health in terms of macroinvertebrates suggest localised adverse ecological impact in Stonequarry Creek downstream of Picton WRRF. There was no evidence these impacts extended to the Nepean River to which this creek flows. Further investigation of likely localised impacts will be conducted in 2024-25 interpretive report.

Pressure – Wastewater discharge

Table 4-2 Gate 1 Analysis outcome summary – Picton WRRF

Analytes / Picton WRRF	Nutrients			Conventional analytes				
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	pH	Total suspended solids
Concentration EPL ID 1 (Precautionary discharge)	↗	→	↘	→	→	(not required)	(not required)	→
Load EPL ID 1 (Precautionary discharge)	(not required)	(EPL limit exceedance)	(within EPL limit)	(within EPL limit)	(not required)	(within EPL limit)	(not required)	(EPL limit exceedance)
Concentration EPL ID 11 (Eastern Dam to Irrigation Farm)	→	→	↘	→	→	(not required)	→	→
Concentration EPL ID 13 (Western Dam to Irrigation Farm	→	→	↘	→	→	(not required)	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

The annual EPL load limits for total nitrogen and total suspended solids were exceeded in the precautionary discharge from Picton WRRF (EPA ID 1, PI0001) during the 2023-24 reporting period. All other concentration and load levels in the precautionary discharge and irrigation storage dams were within EPL limits.

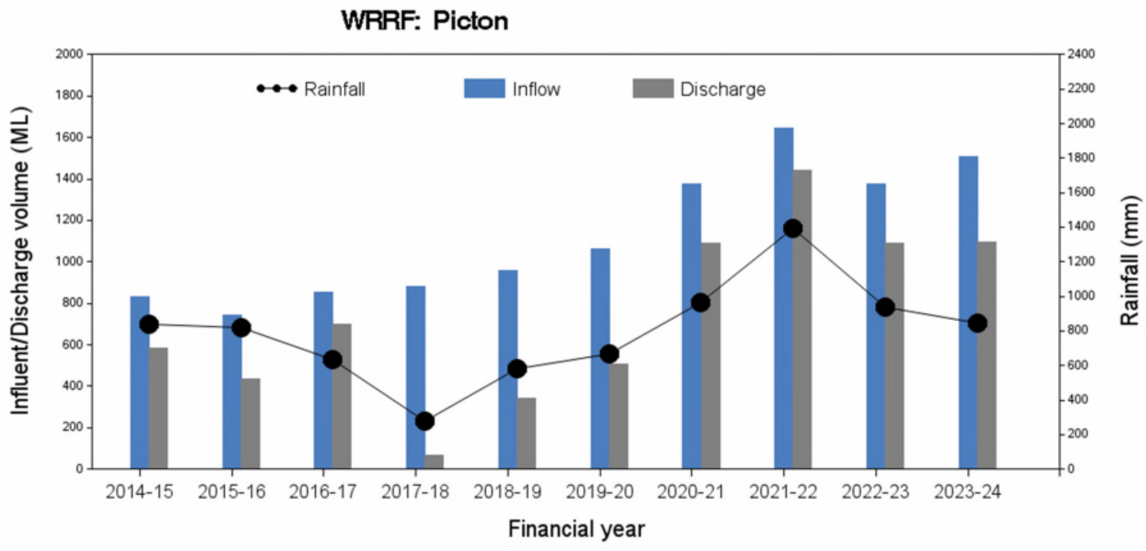
Statistical analysis identified a significant increasing trend in ammonia nitrogen concentrations within the precautionary discharge from Picton WRRF in 2023-24 compared to the previous nine years. A significant decreasing trend was observed in total phosphorus concentrations in the precautionary discharge, Western irrigation dam (EPA ID 13) and Eastern irrigation dam (EPA ID 11).

The annual EPL load limits for total nitrogen and total suspended solids were exceeded in the 2023-24 reporting period due high rainfall in the second half of the reporting period which:

- increased inflow and reduced opportunities for irrigation.
- increased the transfer of partially treated effluent to Western Dam to minimise uncontrolled discharge from the Eastern Dam.

Despite increased transfer to the Western Dam, high volumes of treated effluent were discharged to the environment through the Emergency Operating Protocol resulting in annual load limits being exceeded.

The increasing trend in ammonia nitrogen can also be linked to the wet weather events in the second half of 2023-24 and the subsequent transferring of secondary treated effluent from the Eastern to Western Dam to reduce dam overflow risk.



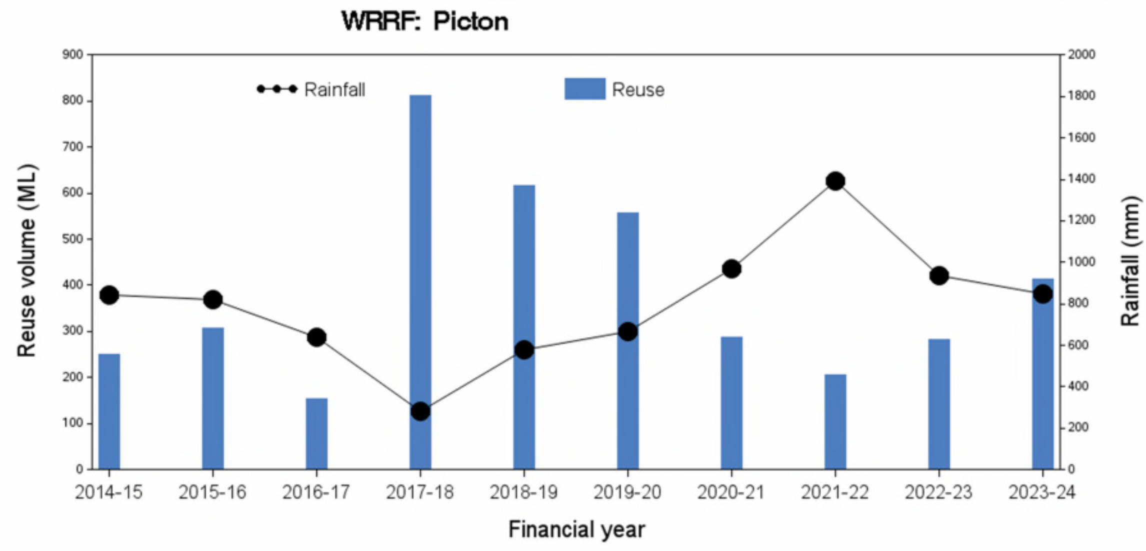
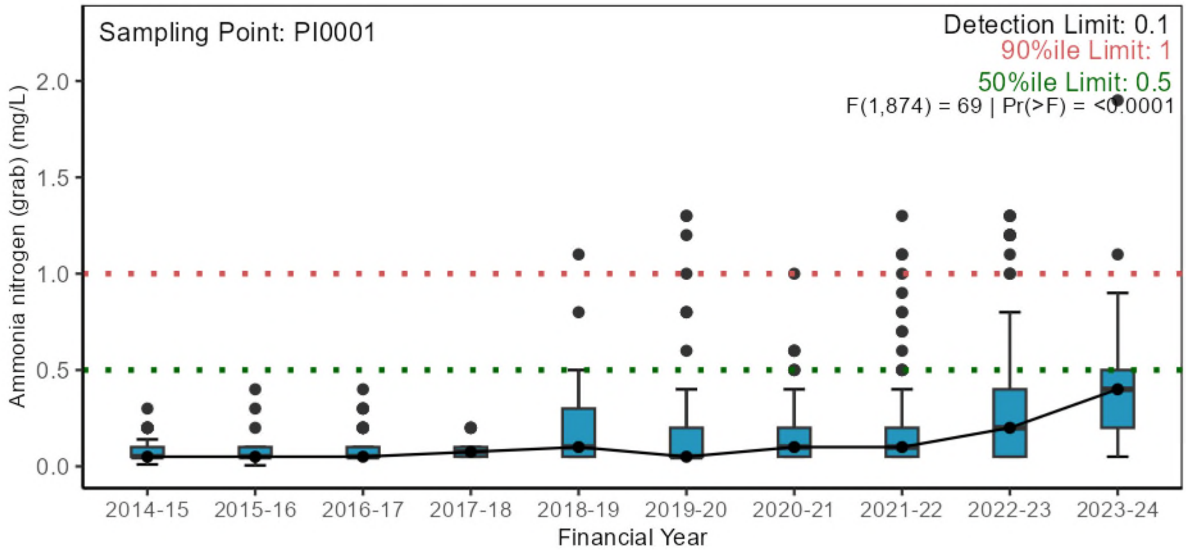
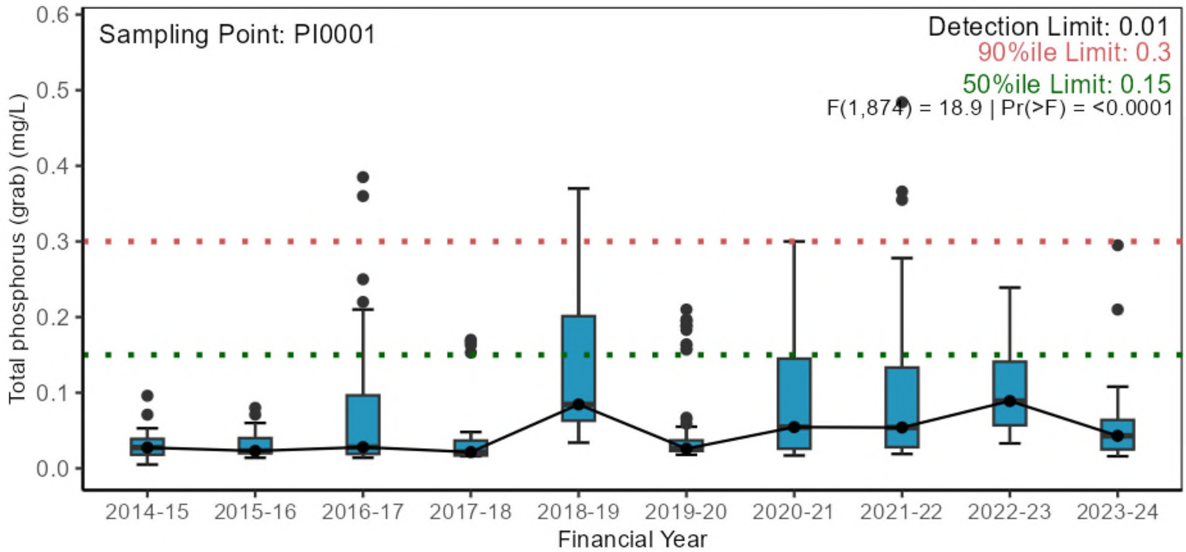


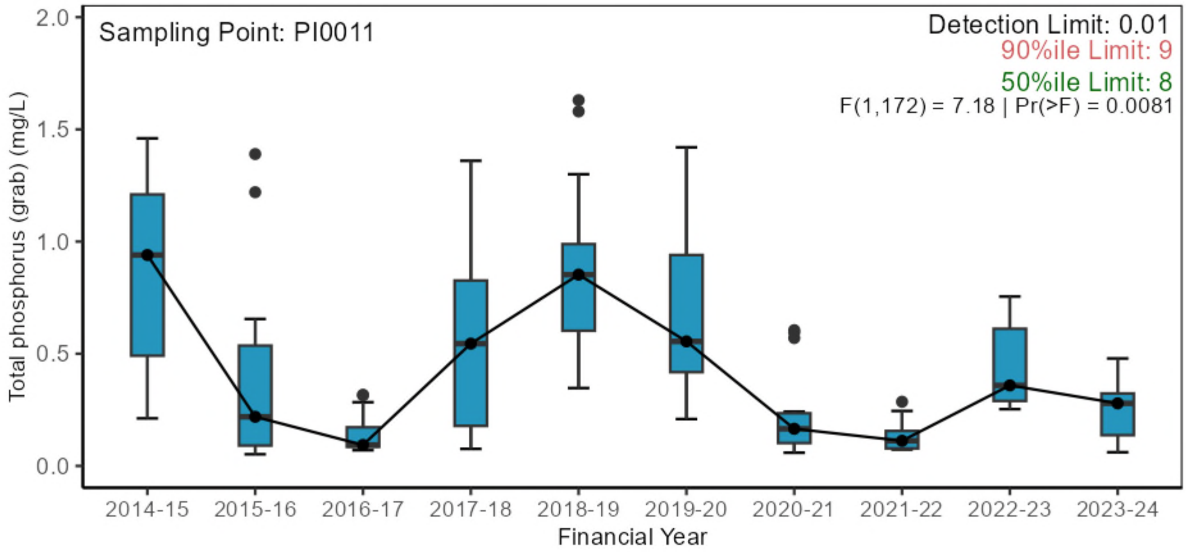
Figure 4-1 Picton WRRF inflow, discharge and reuse volume with catchment rainfall

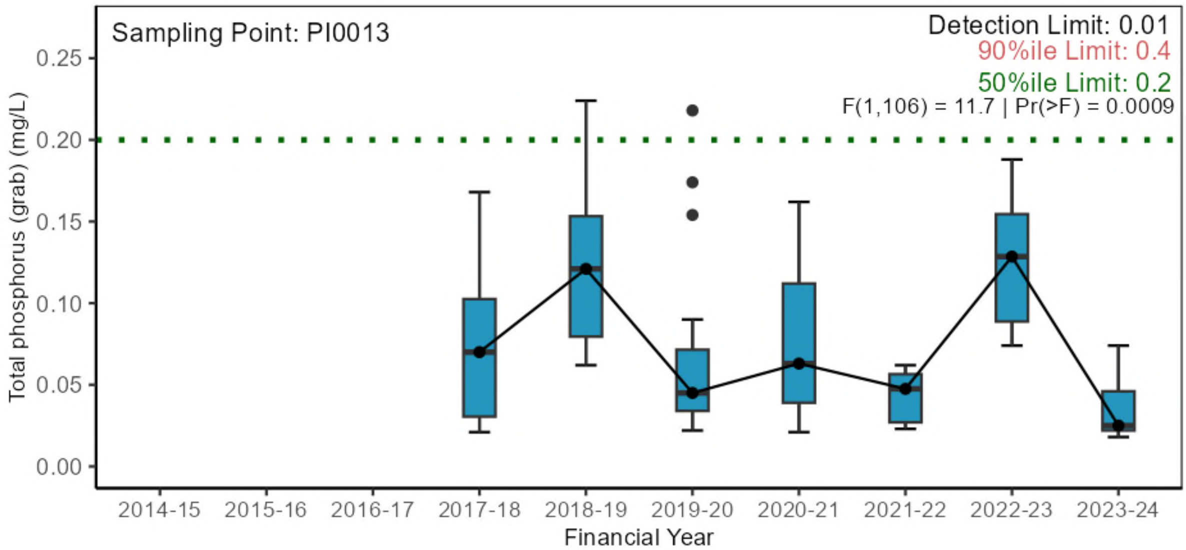


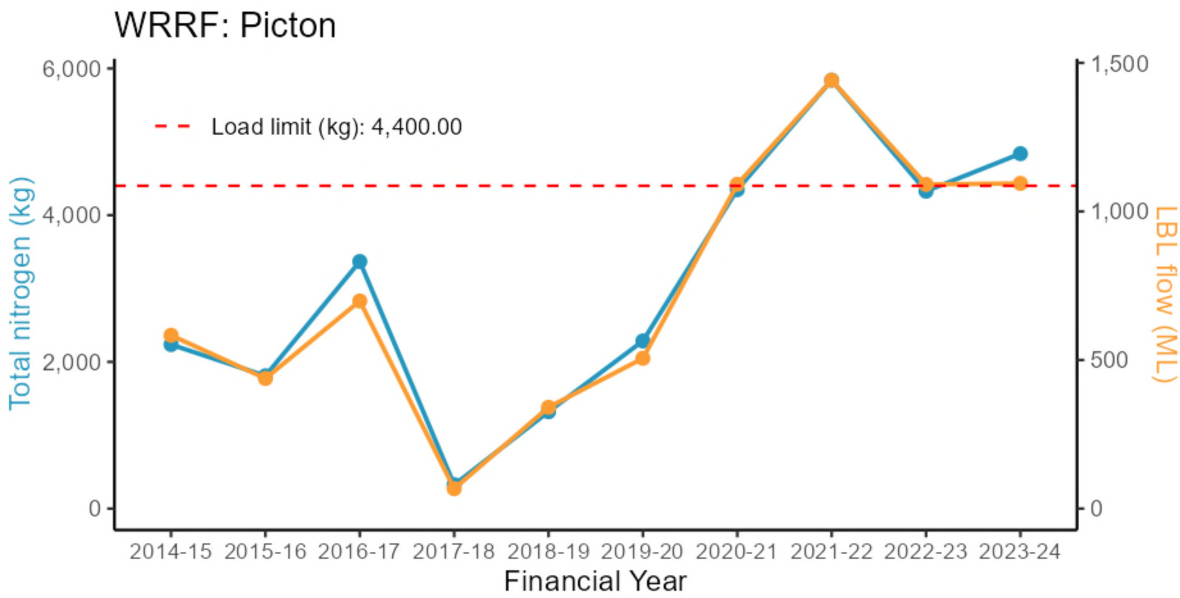
Sampling Point: PI0001
Detection Limit: 0.1
90%ile Limit: 1
50%ile Limit: 0.5
F(1,874) = 69 | Pr(>F) = <0.0001
Ammonia nitrogen (grab) (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24



Sampling Point: PI0001
Detection Limit: 0.01
90%ile Limit: 0.3
50%ile Limit: 0.15
F(1,874) = 18.9 | Pr(>F) = <0.0001
Total phosphorus (grab) (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24


Sampling Point: PI0011
Detection Limit: 0.01
90%ile Limit: 9
50%ile Limit: 8
F(1,172) = 7.18 | Pr(>F) = 0.0081
Total phosphorus (grab) (mg/L)
2.0
1.5
1.0
0.5
0.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: PI0013
Detection Limit: 0.01
90%ile Limit: 0.4
50%ile Limit: 0.2
F(1,106) = 11.7 | Pr(>F) = 0.0009
Total phosphorus (grab) (mg/L)
0.25
0.20
0.15
0.10
0.05
0.00
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



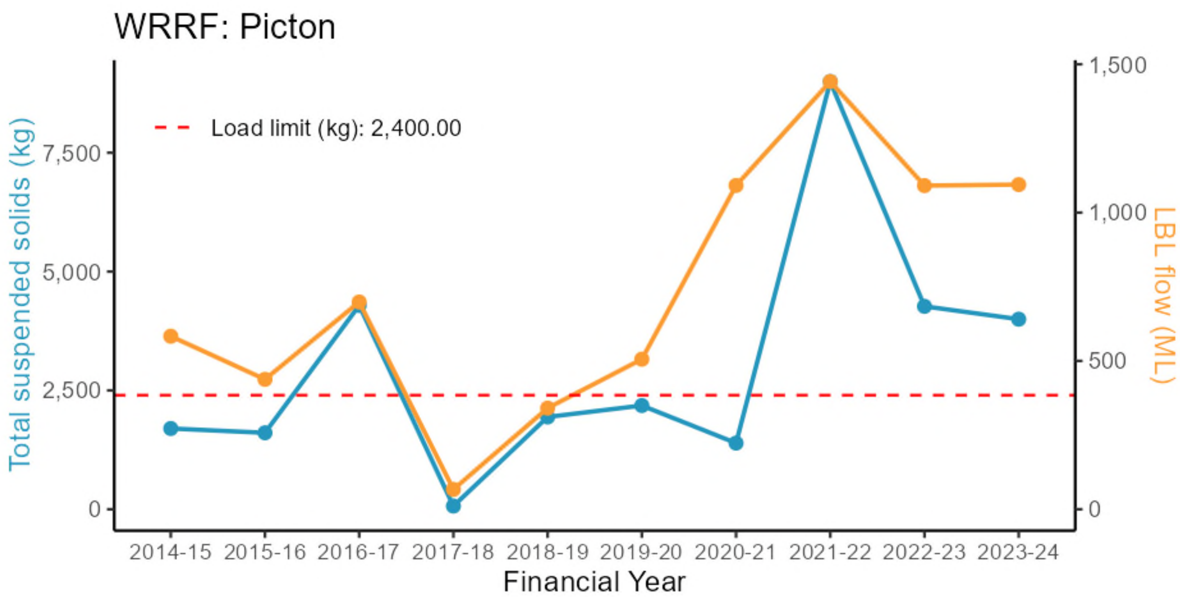


Figure 4-2 Picton WRRF treated discharge and reuse quality exceptions

Stressor – Water quality

Table 4-3 Gate 1 Analysis outcome summary – water quality upstream and downstream of Picton WRRF treated discharge

Picton WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (N911B)	→	→ (yellow)	→	→	→	→	→	→	→	→	→
	Downstream tributary (N911)	→	→ (yellow)	→ (yellow)	→	→	→	→	→	→	→	→
River	Upstream river (N92)	→	→ (yellow)	→ (yellow)	→	→	→	→	↗	→	→	→ (yellow)
	Downstream river (N91)	→	→ (yellow)	→ (yellow)	→	→	→	→	→	→	→	→ (yellow)

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
(yellow)	Median value outside the guideline limit in 2023-24				

Picton WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (N911B vs N911)	D	D	D	-	-	-	-	-	-	-	-
River	Upstream vs downstream current year (N92 vs N91)	D	-	-	D	D	-	-	-	-	-	-

D	Downstream higher ($p<0.05$)	U	Upstream higher ($p<0.05$)	-	No difference ($p>0.05$)

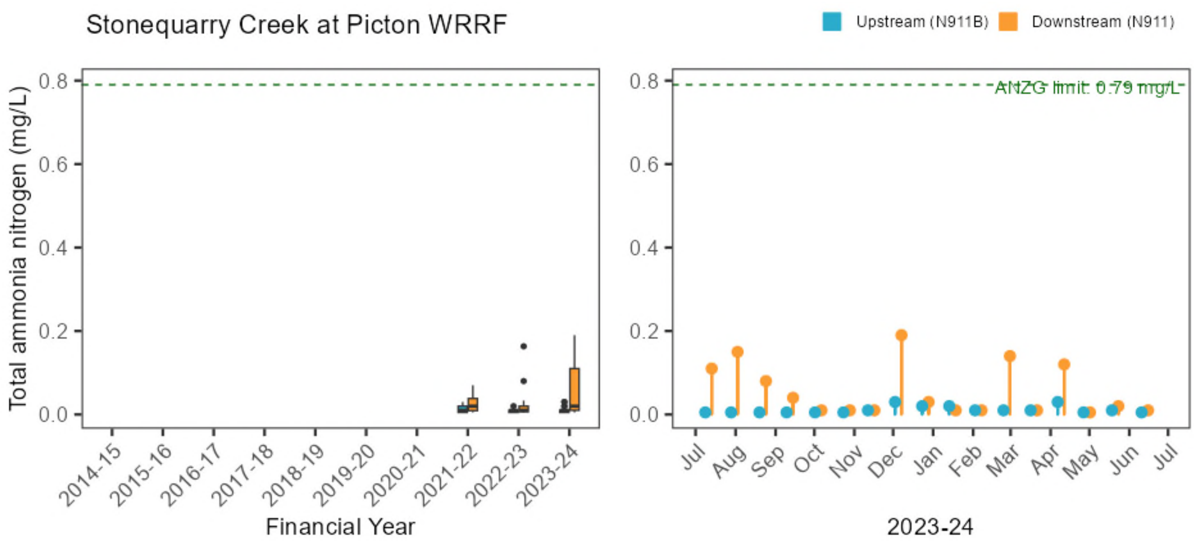
Picton WRRF discharges into Stonequarry Creek which flows into the Nepean River downstream of Maldon Weir. The control site for Stonequarry Creek is located immediately upstream of the Picton WRRF discharge point at Picton Farm (N911B). The water quality of this site is also influenced by upstream catchment run-off with mixed land uses, including low density rural residential areas and township of Picton and Thirlmere (partly). For the Nepean River, N92 is the control site at Maldon Weir upstream of Stonequarry Creek. The water quality at Maldon Weir is influenced by upstream rural catchment factors, Tahmoor colliery and environmental flows released from upstream water storage dams (Nepean, Avon and Cordeaux).

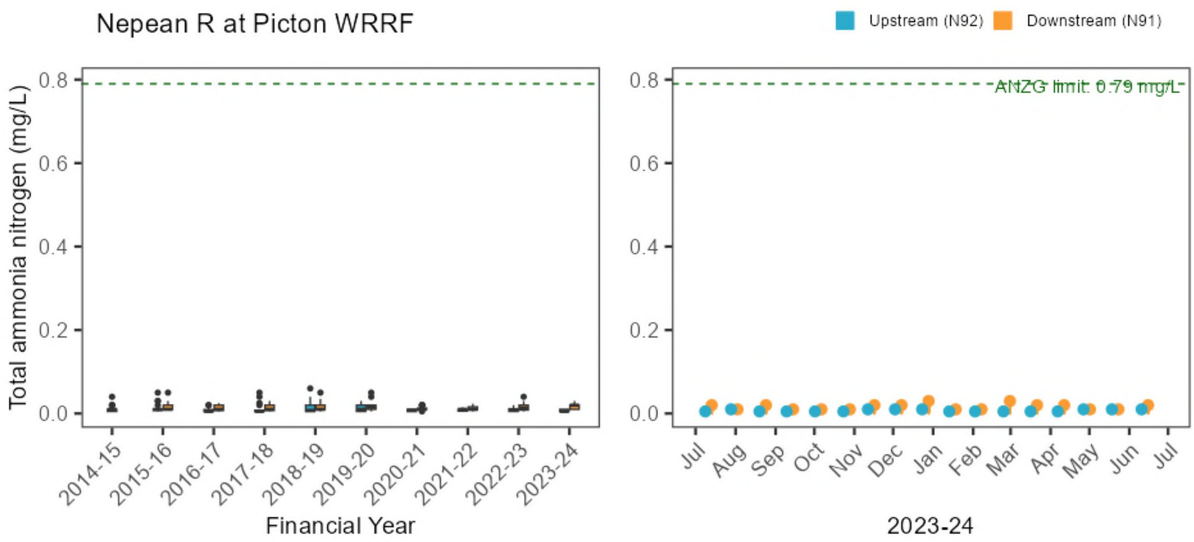
Statistical analysis confirmed that nutrient and other physico-chemical analyte concentrations were mostly steady in 2023-24 compared to the previous years at all four monitoring sites in Stonequarry Creek and the Nepean River. The only exception was dissolved oxygen saturation at the upstream Nepean River site (N92), which increased significantly in the 2023-24 period compared to the previous nine years.

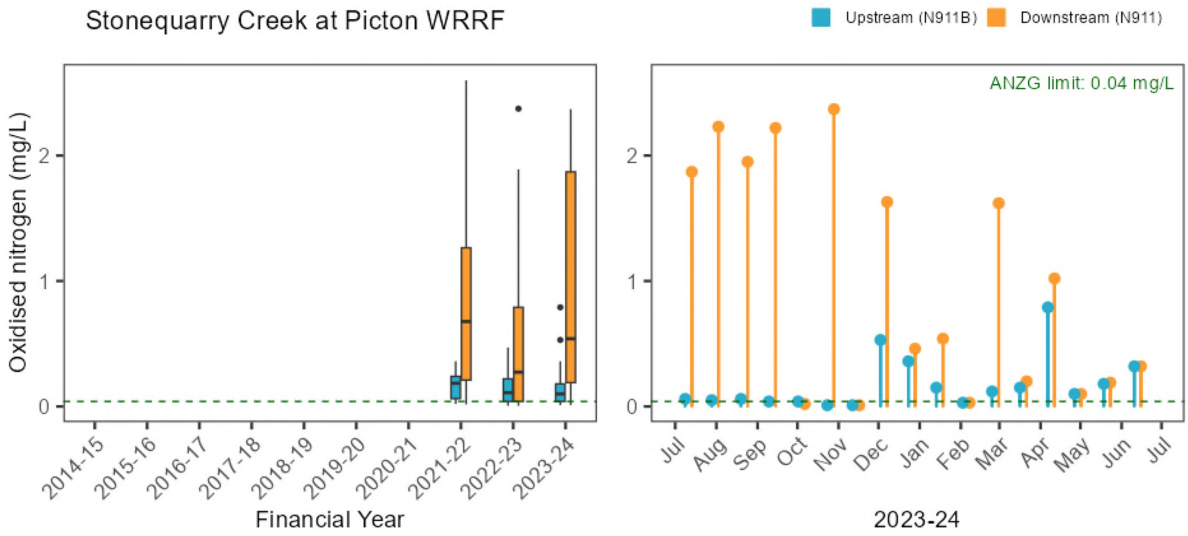
The median total ammonia nitrogen and total phosphorus at both Stonequarry Creek and Nepean River sites were within the guideline limits during the 2023-24 reporting year. The median oxidised nitrogen concentrations at all four upstream and downstream monitoring sites for Picton WRRF were higher than the guideline value. Total nitrogen concentrations also exceeded the guideline at three of the sites, the exception was upstream Nepean River at Maldon Weir (N92). The median turbidity levels at both Nepean River sites (N92 and N91) were below the lower guideline value.

Statistical analysis confirmed that total ammonia nitrogen, oxidised nitrogen and total nitrogen concentrations in 2023-24 were significantly higher at the downstream Stonequarry Creek site (N911) in comparison to the upstream site (N911B) indicating a nitrogen impact from the Picton WRRF discharge. At the downstream Nepean River site (N91), total ammonia nitrogen, and total and filterable phosphorus concentrations were significantly higher in comparison to upstream concentrations. The increased total ammonia nitrogen concentration at the downstream Nepean River site was most likely in response to the increased concentrations in the discharge from Picton WRRF. Whereas the increased concentration of phosphorus at the downstream site may indicate other catchment sources of Stonequarry Creek.

There was no statistically significant difference in the results of all six physico-chemical analytes between upstream and downstream sites of Stonequarry Creek or the Nepean River in 2023-24.






Stonequarry Creek at Picton WRRF
Upstream (N911B)
Downstream (N911)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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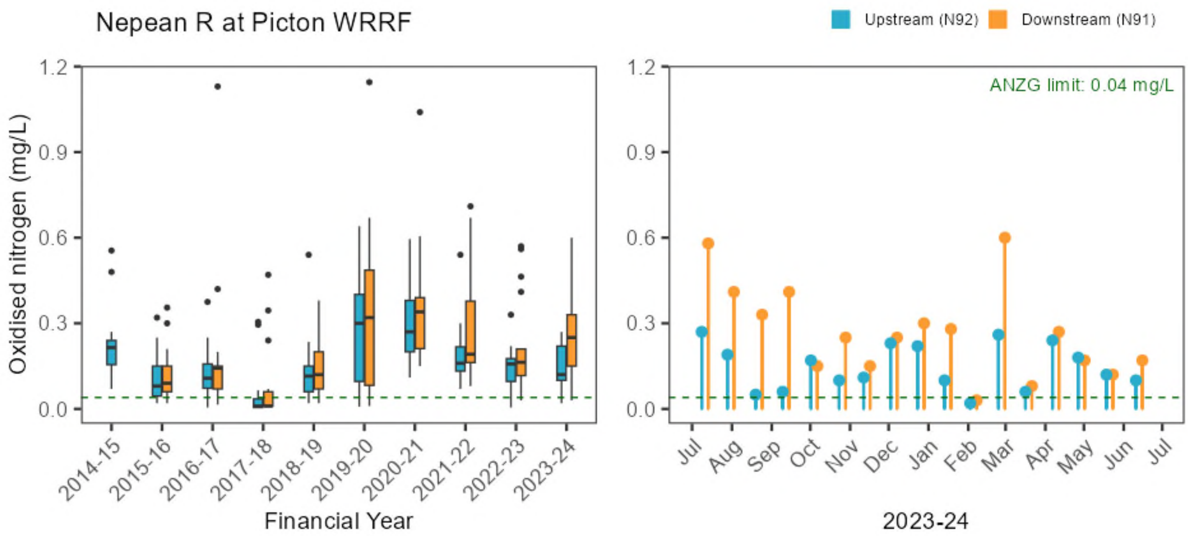
2023-24


Nepean R at Picton WRRF
Upstream (N92)
Downstream (N91)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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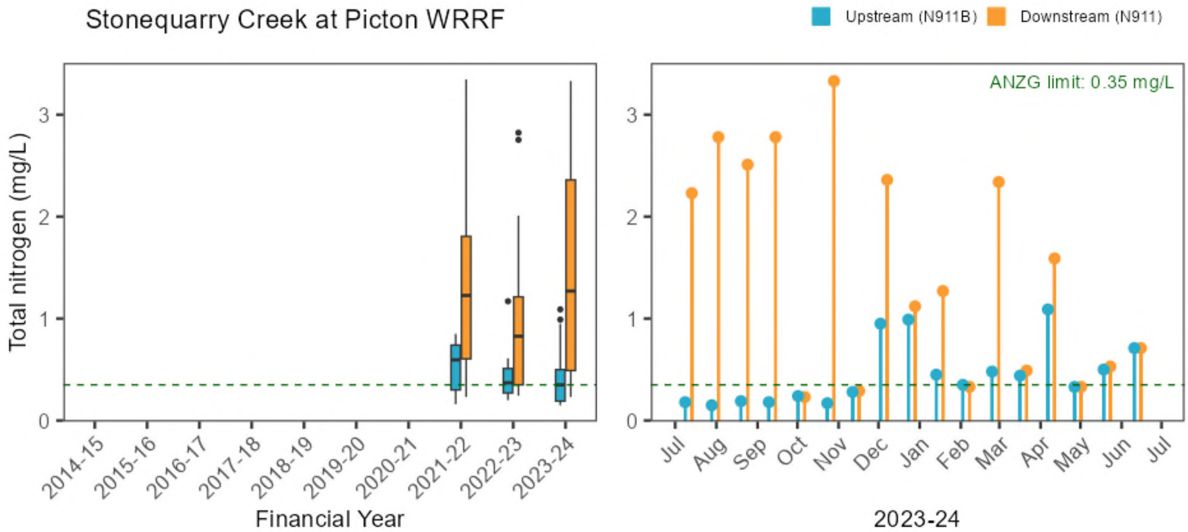
2023-24


Stonequarry Creek at Picton WRRF
Upstream (N911B)
Downstream (N911)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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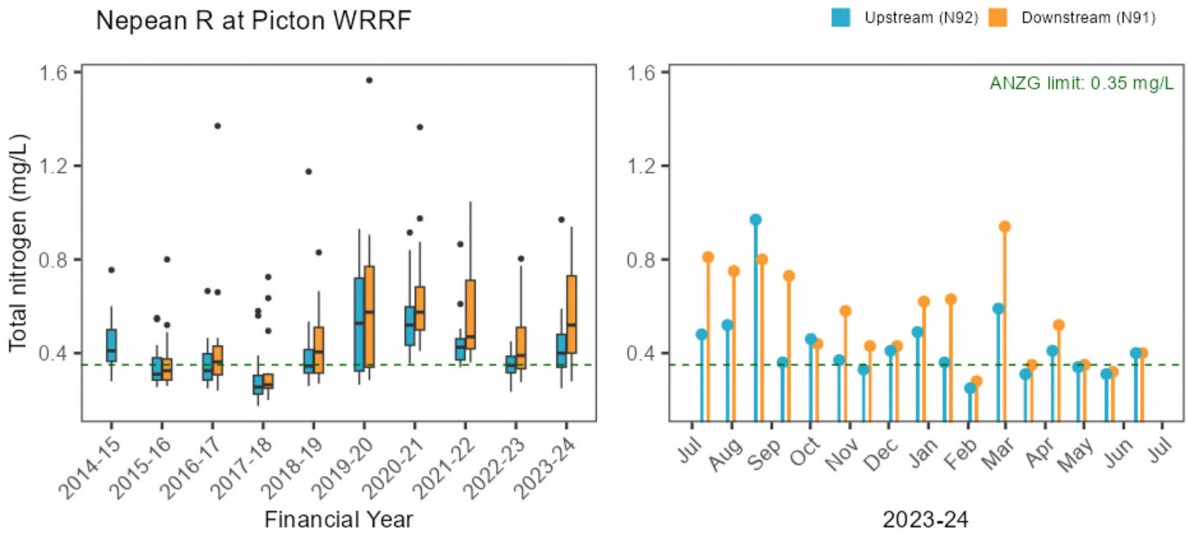
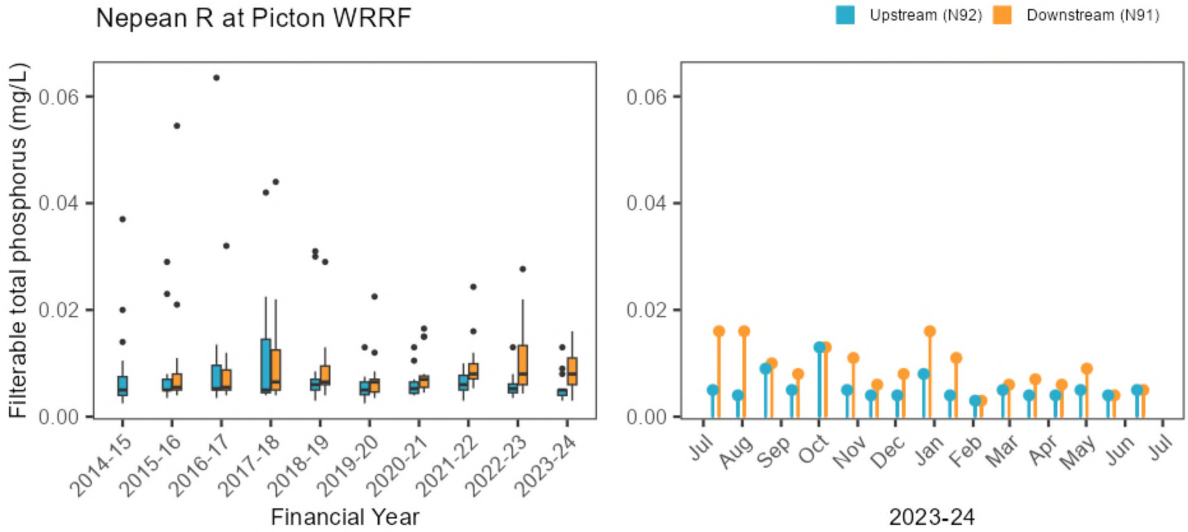
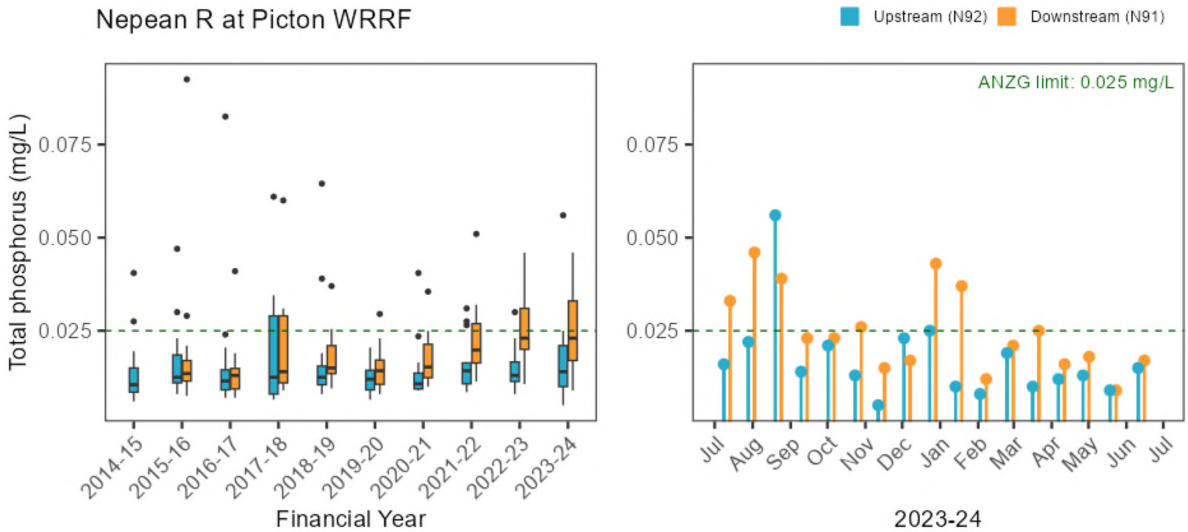
2023-24


Nepean R at Picton WRRF
Upstream (N92)
Downstream (N91)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
Financial Year
2023-24


Nepean R at Picton WRRF
Upstream (N92)
Downstream (N91)
Filterable total phosphorus (mg/L)
Financial Year
2023-24


Nepean R at Picton WRRF
Upstream (N92)
Downstream (N91)
Total phosphorus (mg/L)
ANZG limit: 0.025 mg/L
Financial Year
2023-24

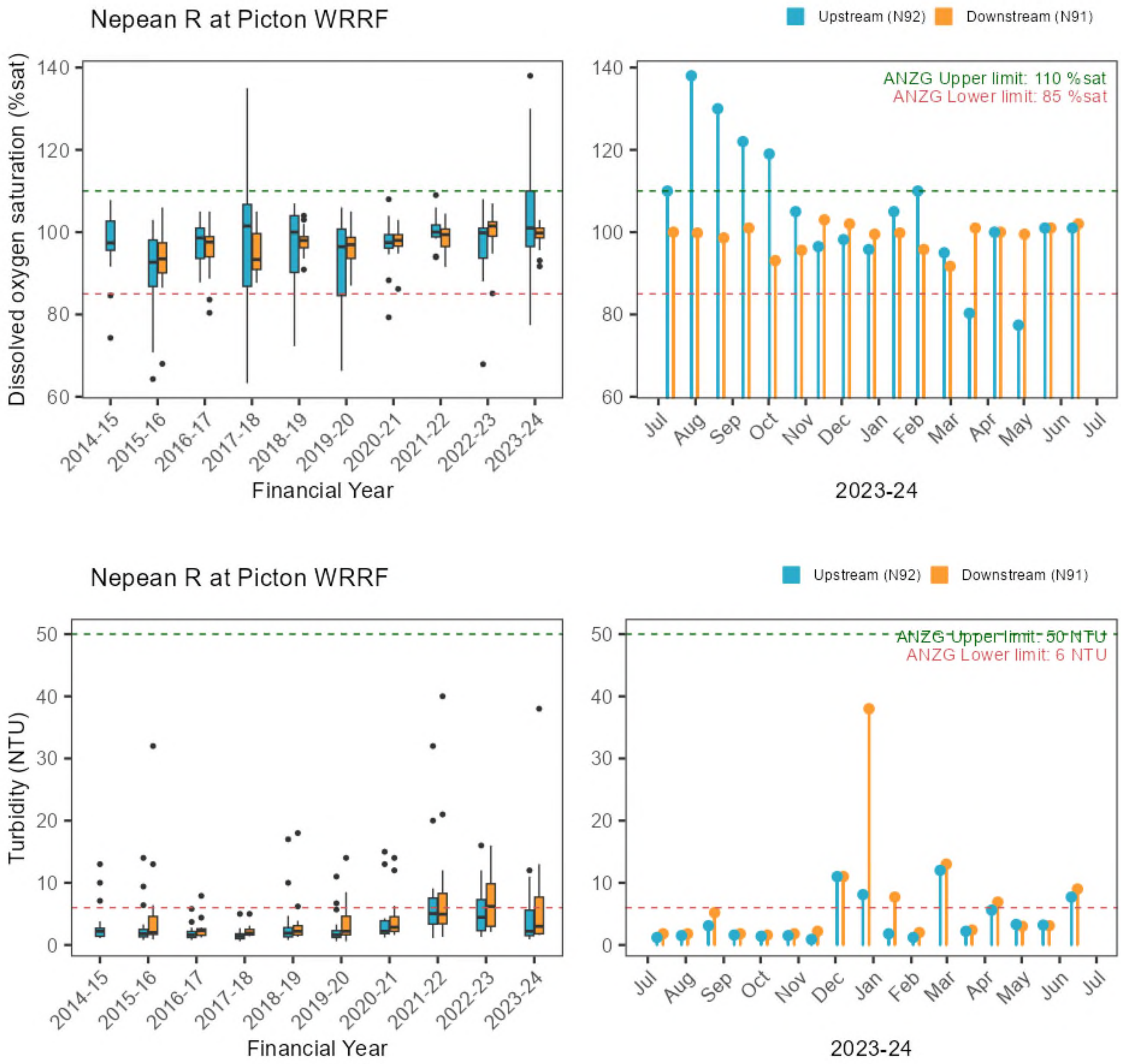


Figure 4-3 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Picton WRRF

Ecosystem Receptor – Phytoplankton

Table 4-4 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Picton WRRF treated discharge

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (N911B)	→
Downstream tributary (N911)	→
Upstream river (N92)	→
Downstream river (N91)	→

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary current year (N911B vs N911)	-
Upstream vs downstream river (N92 vs N91)	-

D	Downstream higher ($p<0.05$)	U	Upstream higher ($p<0.05$)	-	No difference ($p>0.05$)

In 2023-24, there was no statistically significant increasing/decreasing trend identified in chlorophyll-a at any Stonequarry Creek or Nepean River sites compared to the previous years.

The median chlorophyll-a concentration was within the ANZG (2018) guideline at both upstream and downstream Stonequarry Creek sites. At the downstream site (N911) chlorophyll-a reached a maximum of 57.4 µg/L (16 January 2024). The median chlorophyll-a concentration was higher than the ANZG (2018) guideline at both upstream and downstream Nepean River sites in 2023-24. At the upstream Nepean River site (N92), chlorophyll-a reached a maximum of 43.9 µg/L (31 July 2023).

Statistical analysis confirmed that there was no significant difference in 2023-24 chlorophyll-a concentrations between upstream and downstream Stonequarry Creek or Nepean River sites.

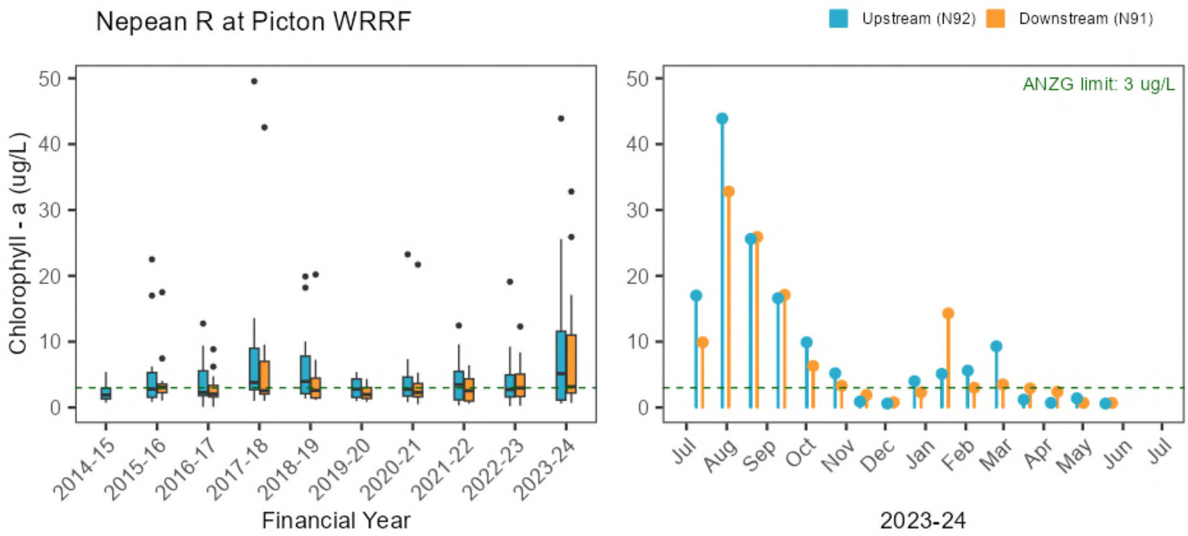


Figure 4-4 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Picton WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested a localised ecosystem impact in Stonequarry Creek, downstream of Picton WRRF. There was no evidence these impacts had any effect on the Nepean River system to which this creek flows.

Table 4-5 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Picton WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (N911B vs N911)	D
Upstream vs downstream river (N92A vs N91)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

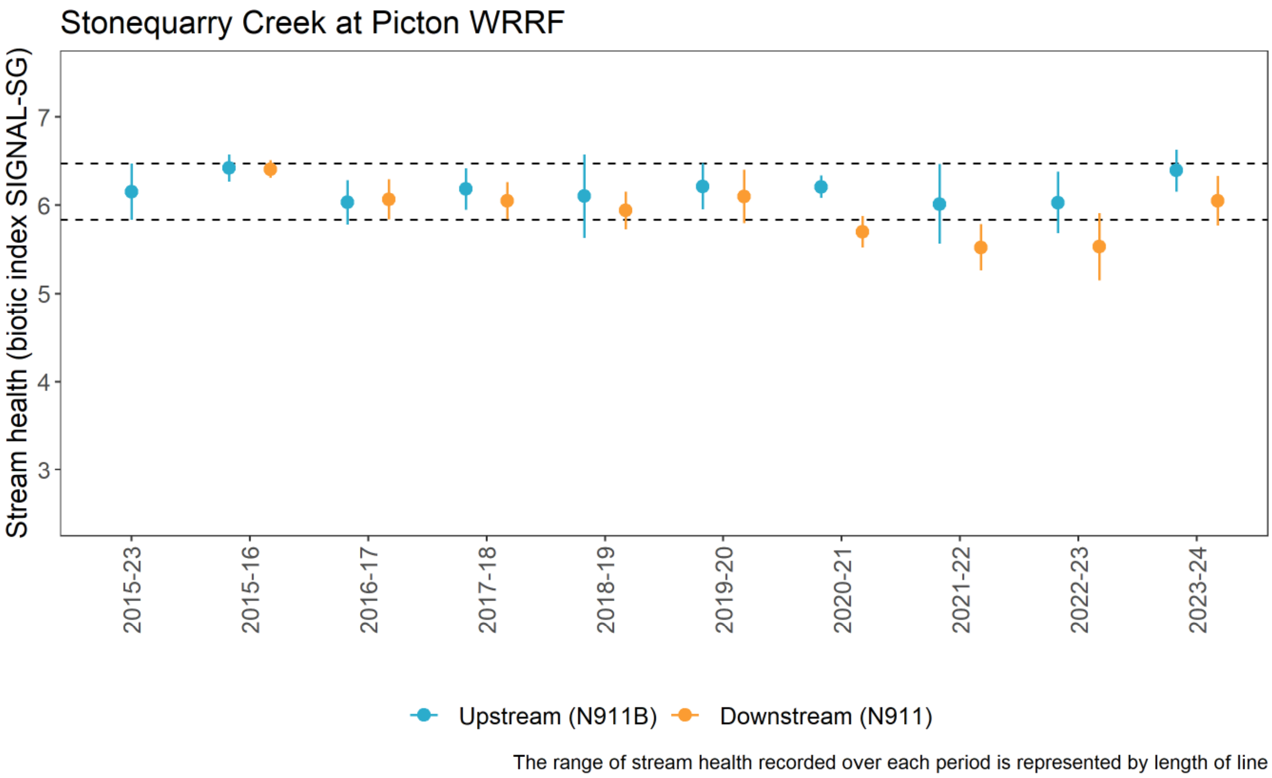


Figure 4-5 Stream health of Stonequarry Creek upstream and downstream of Picton WRRF

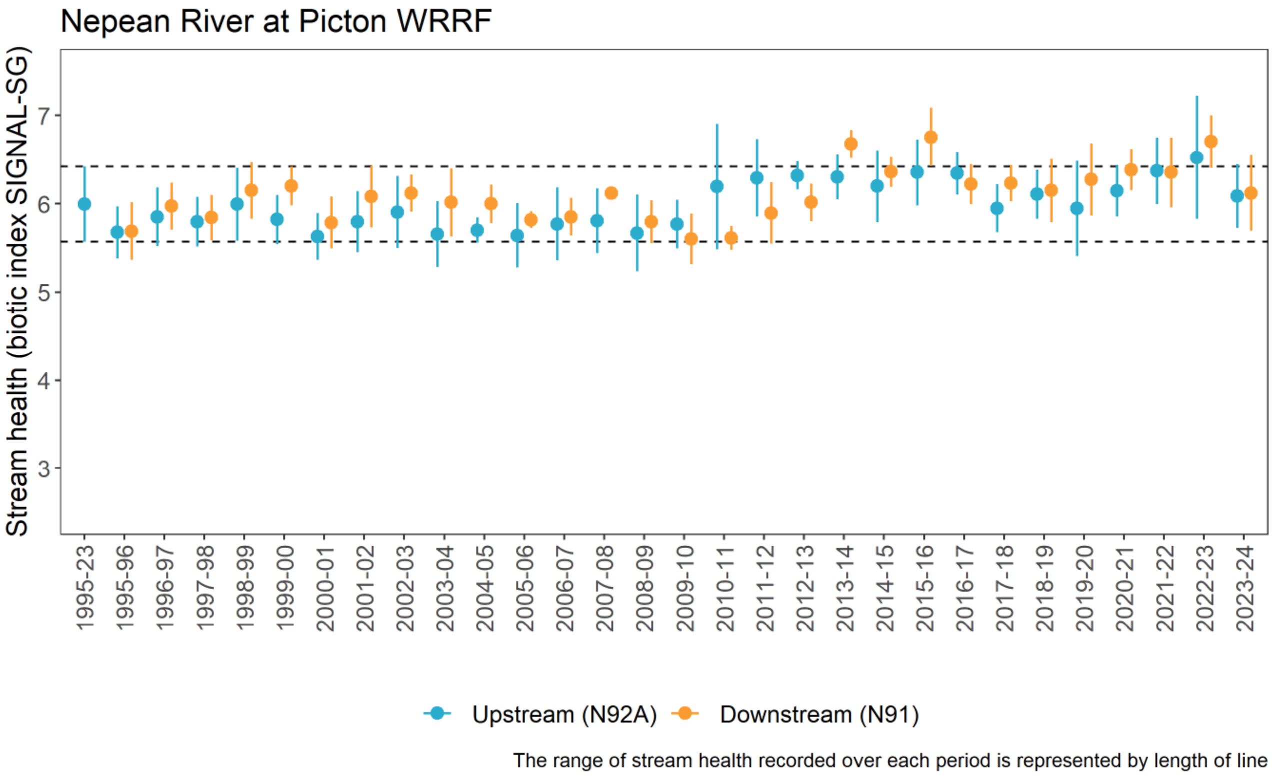


Figure 4-6 Stream health of the Nepean River upstream and downstream of the confluence of Stonequarry Creek near Picton WRRF

Gate 2 – Synthesis of impact of Picton WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as Chlorophyll-a		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Ammonia nitrogen	↗	D	D	-	-	D	-	Increased total ammonia nitrogen in Picton WRRF discharges triggered a subsequent increase in downstream receiving water concentration of both Stonequarry Creek and Nepean River. Stream health as indicated by macroinvertebrates was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D	-					
Total nitrogen	→	D	-					
Filterable total phosphorus		-	D					
Total phosphorus	↘	-	D					
Conductivity		-	-					
Dissolved oxygen		-	-					
Dissolved oxygen saturation		-	-					
pH		-	-					
Temperature		-	-					
Turbidity		-	-					

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
D	Downstream impact ($p<0.05$)	U	Upstream impact ($p<0.05$)	-	No difference ($p>0.05$)
	EPL limit exceedance		Analyte not monitored		

4.1.2. West Camden WRRF

- All parameters (concentrations and loads) monitored in the discharge from West Camden WRRF in 2023-24 were within EPL limits. There was an increasing trend in total nitrogen concentrations in the treated discharge compared to the last nine years.
- Total and filterable phosphorus concentrations increased significantly at the downstream tributary to Matahil Creek site in 2023-24 compared to the previous five years. There was no comparable increase in phosphorus concentration in the WRRF treated discharge which remained steady in 2023-24.
- All nitrogen analytes and filterable total phosphorus concentrations were significantly higher at the downstream tributary to Matahil Creek site. All nutrients were significantly higher at downstream Nepean River site. Nitrogen enrichment at these downstream sites is likely due to elevated nitrogen concentrations and loads in the West Camden WRRF treated discharge.
- Chlorophyll-a was significantly higher at the upstream Matahil Creek site compared to the downstream site. Routine discharge flows likely had a positive influence in diluting or displacing phytoplankton downstream. This also confirms no likely negative impact of elevated nitrogen in the discharge on phytoplankton, as chlorophyl-a did not significantly differ between upstream and downstream river sites.
- Stream health results (as indicated by macroinvertebrates) suggested adverse localised ecological impact in Matahil Creek, downstream of West Camden WRRF. This was likely linked to elevated ammonia nitrogen concentrations. There was no evidence these impacts had any effect on the Nepean River system to which this creek flows.

Pressure – Wastewater discharge

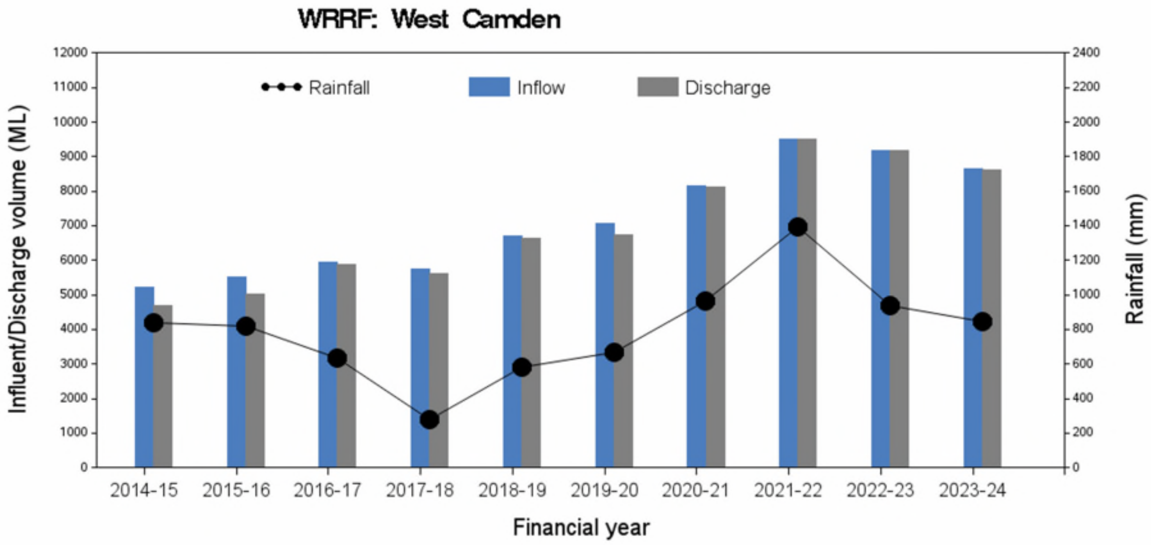
Table 4-6 Gate 1 Analysis outcome summary – West Camden WRRF

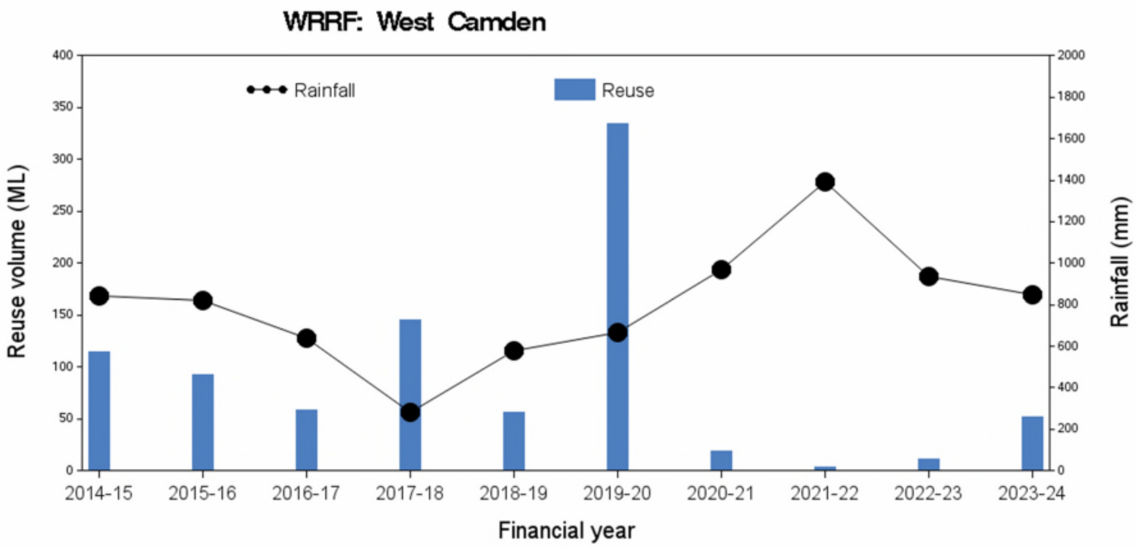
Analytes / West Camden WRRF	Nutrients			Conventional analytes						Trace Metals				Other	
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC50 toxicity	Aluminium	Copper	Iron	Zinc	Diazinon	Hydrogen sulfide (un-ionised)
Concentration	→	↗	→	→	→	→		→	→	→	→	→	→	→	→
Load															

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge from West Camden WRRF were within the EPL limits in 2023-24. Statistical analysis identified a significant increasing trend in total nitrogen concentration in the 2023-24 reporting period compared to the previous nine years.

The increasing trend in total nitrogen concentration is largely influenced by catchment growth and subsequent increasing inflows to West Camden WRRF exceeding the current treatment capacity of the biological processes. West Camden WRRF is currently progressing a major $220M amplification, including the construction of a new Membrane Biological Reactor (MBR). During the current amplification project, ammonia removal was prioritised which subsequently impacted total nitrogen performance. Commissioning of the new MBR is expected to be completed by the end of May 2025 and will increase the treatment capacity to cater for population growth in the Camden district.





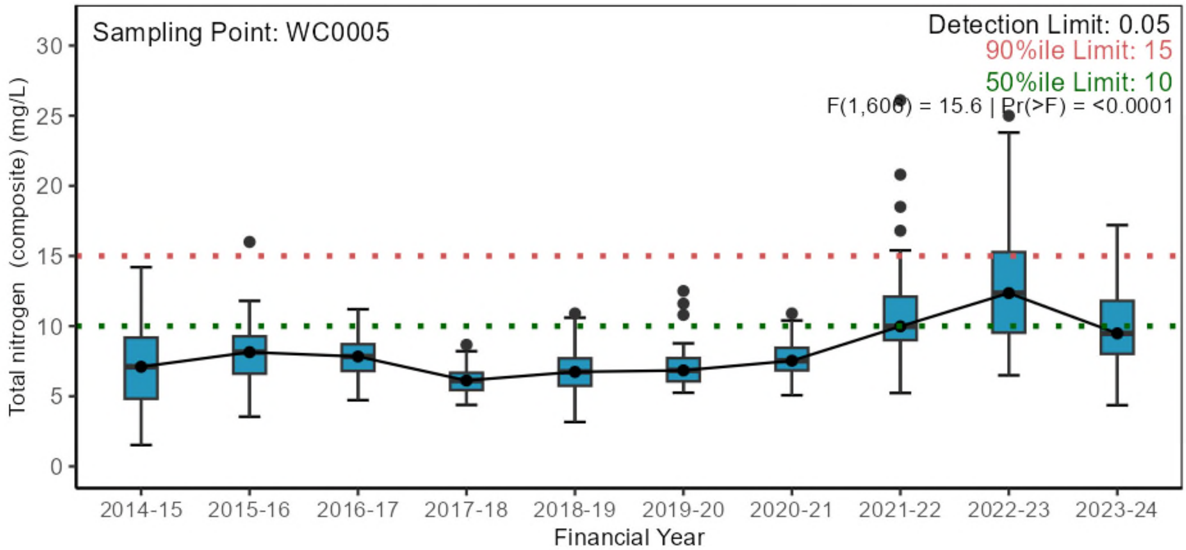


Figure 4-7 West Camden WRRF treated discharge quality exceptions

Stressor – Water quality

Table 4-7 Gate 1 Analysis outcome summary – water quality upstream and downstream of West Camden WRRF treated discharge

West Camden WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (N7824A)	→	→	→ (yellow)	→	→ (yellow)	→ (yellow)	→	↘ (yellow)	→	→	→
	Downstream tributary (N7824)	→	→ (yellow)	→ (yellow)	↗	↗ (yellow)	→	→	→	→	→	→ (yellow)
River	Upstream river (N78)	→	→ (yellow)	→ (yellow)	→	→	→	→	→	→	→	→
	Downstream river (N75)	→	→ (yellow)	→ (yellow)	→	→	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	Median value outside the guideline limit in 2023-24				

West Camden WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (N7824A vs N7824)	D	D	D	D	-	U	D	D	U	D	U
River	Upstream vs downstream current year (N78 vs N75)	D	D	D	D	D	-	-	-	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

West Camden WRRF discharges into an unnamed tributary that joins with Matahil Creek and flows about 1 km before joining with the Nepean River. The water quality of the control site at Matahil Creek (N7824A) is influenced by the upstream catchment with mixed land uses including agricultural run-off and increased urbanisation. In the Nepean River, the control site is located at Macquarie Grove Road upstream of Matahil Creek (N78). The water quality at this site is influenced by mixed upstream catchment factors including Picton WWRF (about 39 km upstream) which discharges predominantly in wet weather.

Statistical analysis confirmed that total and filterable total phosphorus concentrations in 2023-24 were significantly higher at the downstream Matahil Creek site (N7824) in comparison to the previous five years. At the upstream site (N7824A), all five nutrient analytes were steady. Nutrient concentrations were also steady at both upstream and downstream monitoring sites in the Nepean River (N78 and N75).

Dissolved oxygen saturation decreased significantly in 2023-24 at the upstream Matahil Creek site (N7824A) in comparison to the previous five years. Concentrations or levels of other physico-chemical water quality analytes were steady at both upstream and downstream creek sites. All six physico-chemical water quality analytes results were steady at both upstream and downstream Nepean River sites.

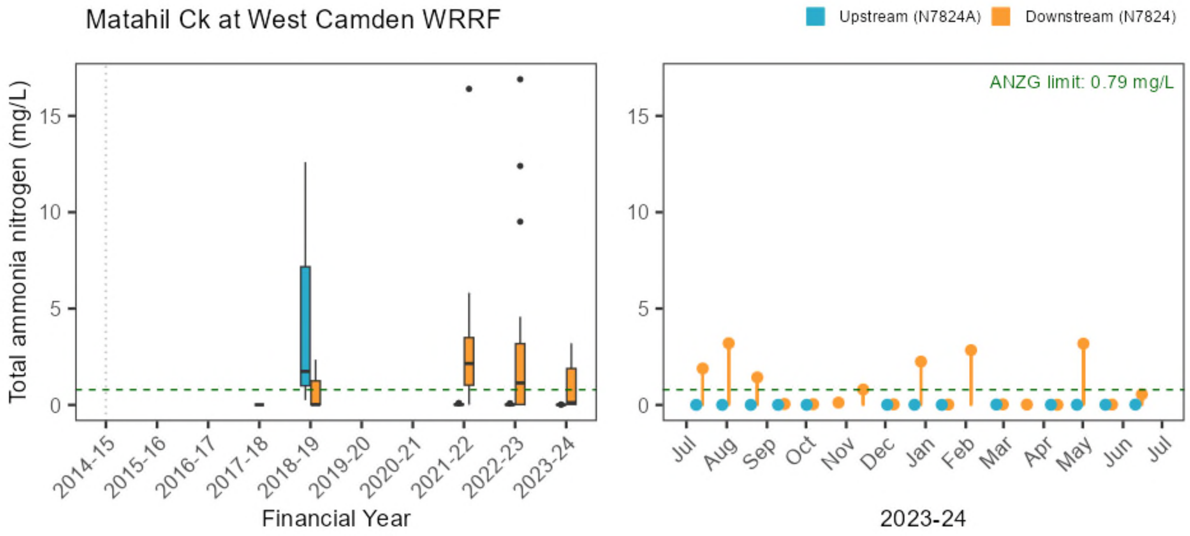
The median concentration of total ammonia nitrogen was less than the guideline value at the downstream tributary site (N7824) during the 2023-24 reporting period. However, it is important to note that seven out of 17 total ammonia nitrogen results were above the ANZG (2023) toxicant guideline for 95% species protection (0.79 mg/L). At the upstream Matahil Creek site (N7824A), median total nitrogen and total phosphorus concentrations were above the respective guidelines. At the downstream Matahil Creek site (N7824), median oxidised nitrogen, total nitrogen and total phosphorus concentrations were above the respective guidelines. At both upstream and downstream Nepean River sites (N78 and N75), oxidised nitrogen and total nitrogen concentrations were higher than the respective guidelines.

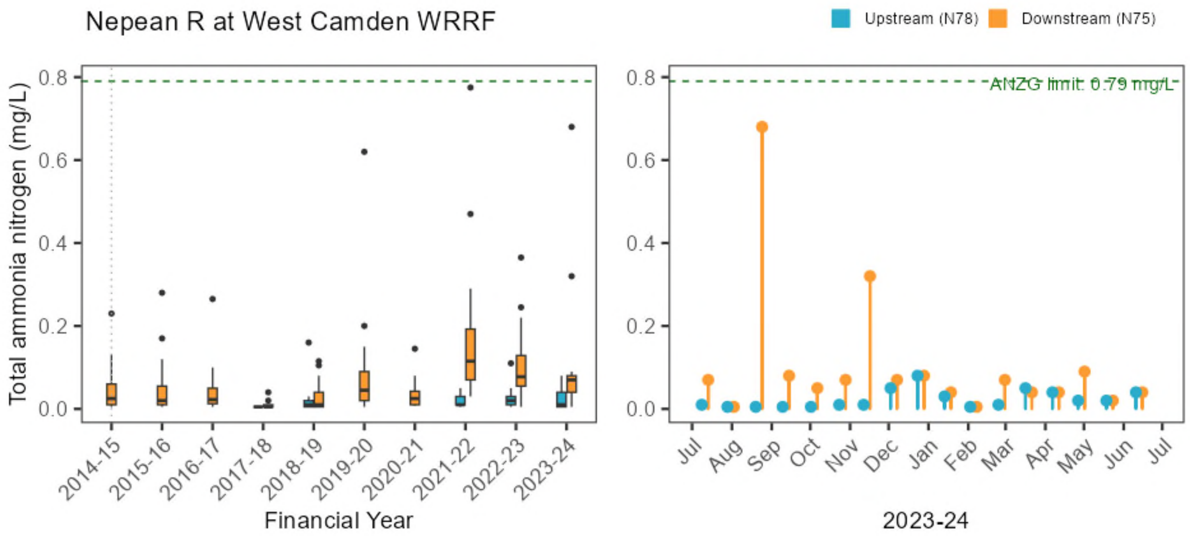
The median turbidity level at the downstream Matahil Creek site (N7824) was below the lower guideline value, while conductivity and dissolved oxygen saturation were outside the guideline range at upstream site (N7824A). Median concentrations or levels of all six physico-chemical analytes were within the guideline ranges at both upstream and downstream Nepean River sites.

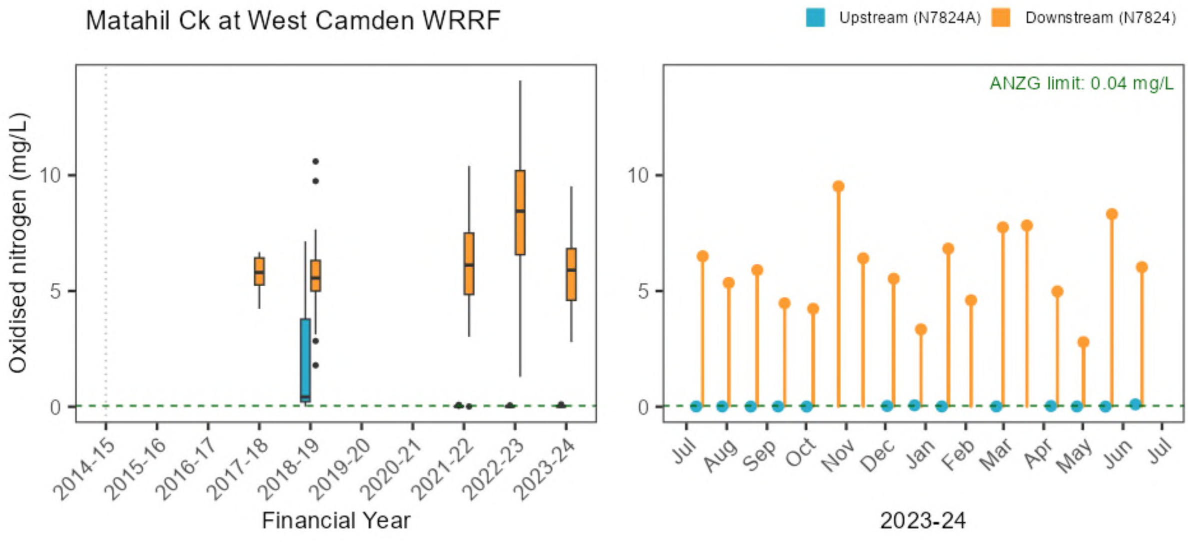
Statistical analysis confirmed that total ammonia nitrogen, oxidised nitrogen, total nitrogen and filterable total phosphorus in 2023-24 were significantly higher at the downstream Matahil Creek site (N7824) in comparison to the upstream site. At the downstream Nepean River site (N75), concentrations of all five nutrient analytes were significantly higher compared to the upstream concentrations. The elevated nitrogen concentrations in the West Camden WRRF discharge have likely resulted in the elevated downstream concentrations, however the high phosphorus concentrations may also be due to other catchment sources.

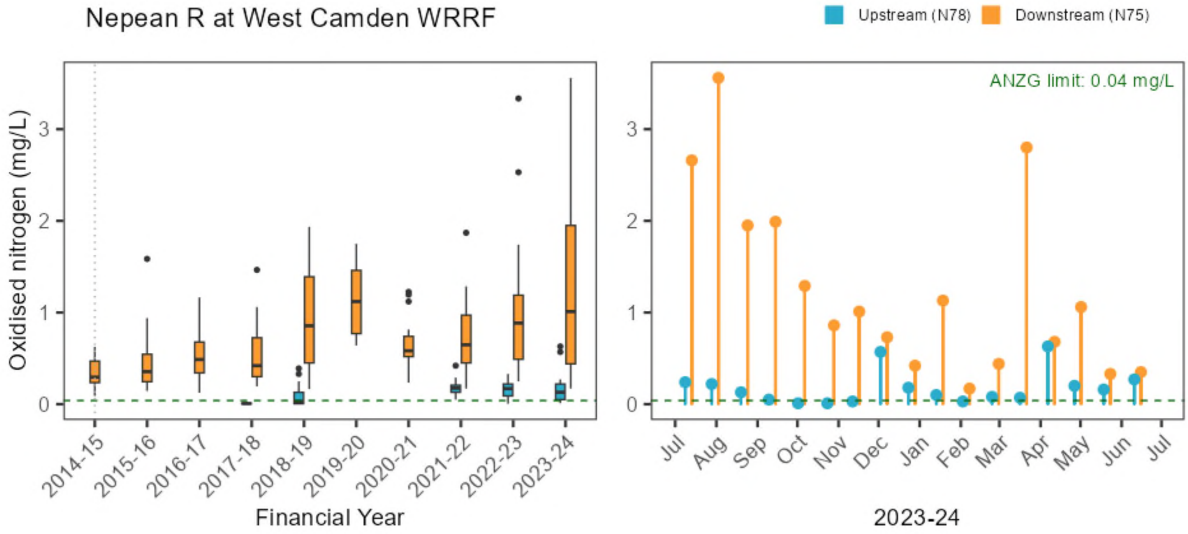
Among physico-chemical analytes, dissolved oxygen (concentration and saturation) and water temperature were significantly higher at the downstream Matahil Creek site (N7824) in comparison to the upstream site (N7824A). Dissolved oxygen saturation was 22% higher at the downstream site in 2023-24 indicating a positive influence of routine discharges.

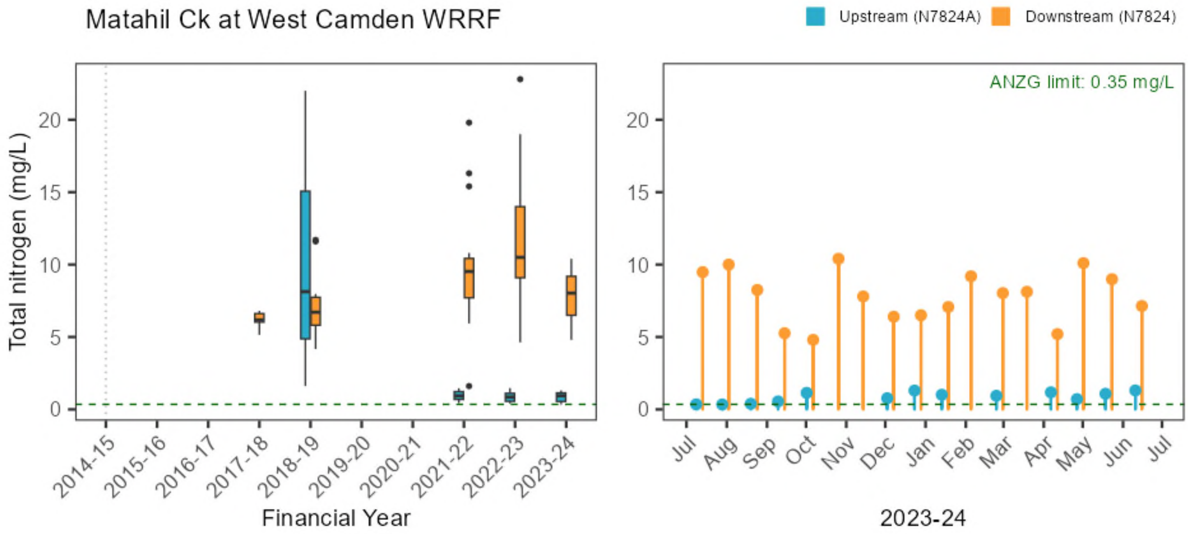
At the upstream Matahil Creek site (N7824A), conductivity, pH and turbidity levels were significantly higher compared to the downstream site, showing an influence from upstream catchment run-off with high salinity and increased particulate matter. In the Nepean River, there was no significant difference between the upstream and downstream sites for any physico-chemical analyte.

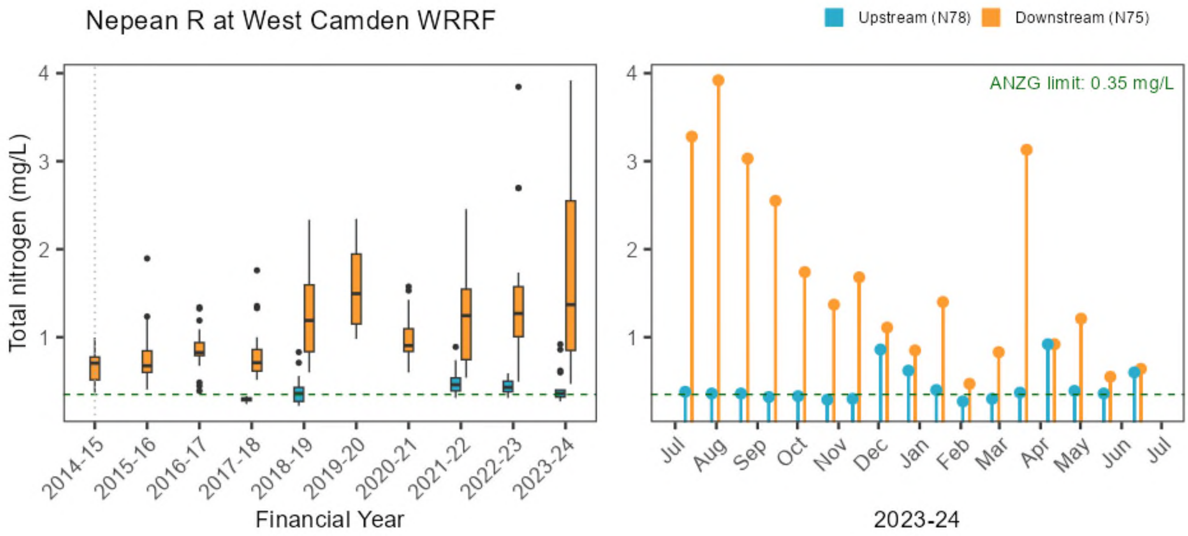





Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
Financial Year
2023-24


Nepean R at West Camden WRRF
Upstream (N78)
Downstream (N75)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
Financial Year
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
Financial Year
2023-24


Nepean R at West Camden WRRF
Upstream (N78)
Downstream (N75)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
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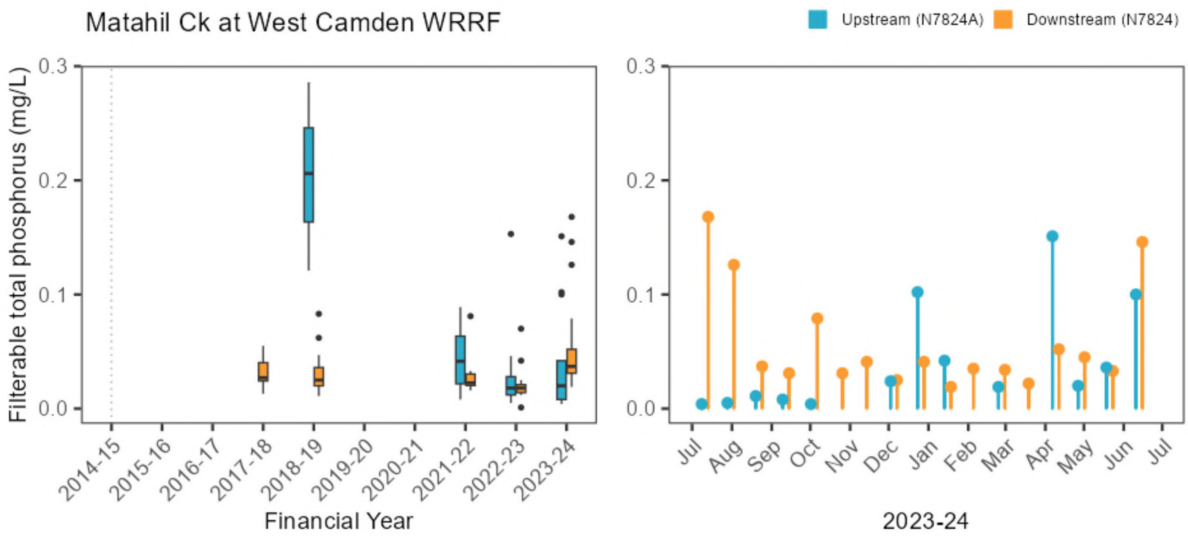
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
Filterable total phosphorus (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
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Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
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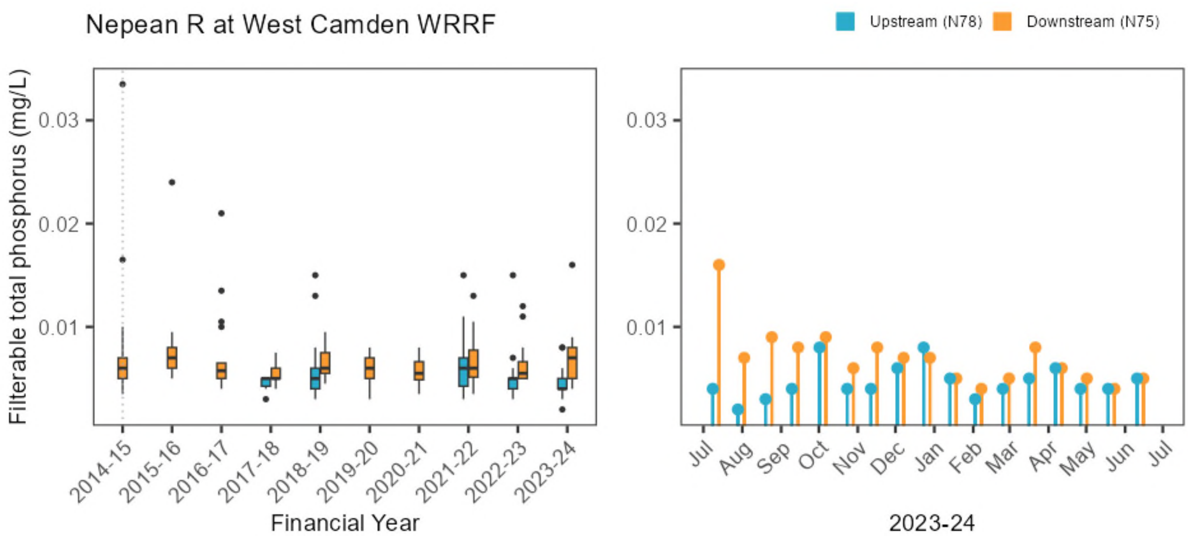
Nepean R at West Camden WRRF
Upstream (N78)
Downstream (N75)
Filterable total phosphorus (mg/L)
Financial Year
2014-15
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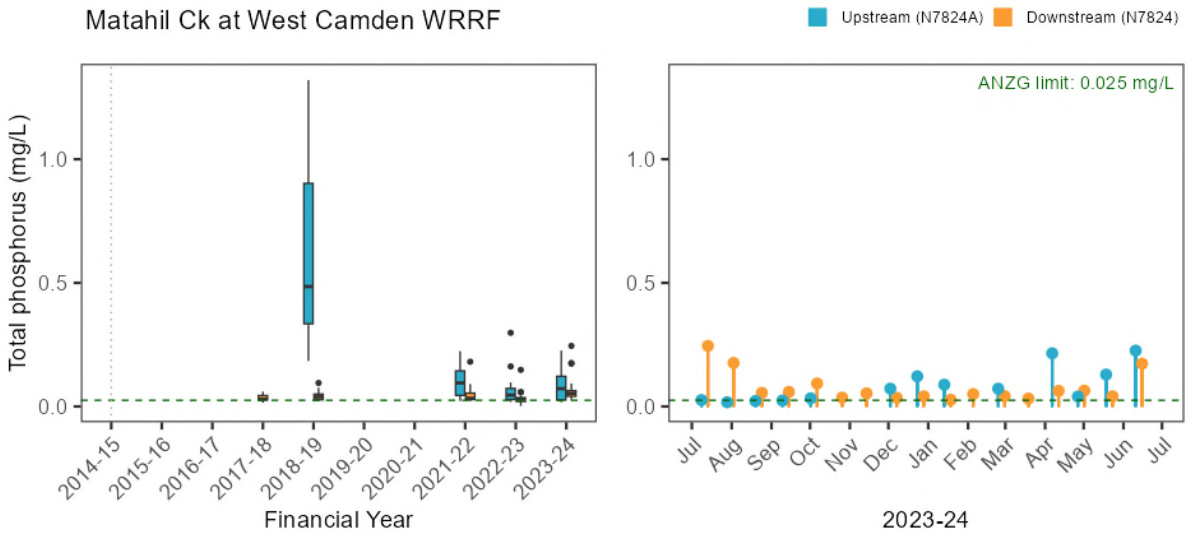
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
0.0
0.5
1.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
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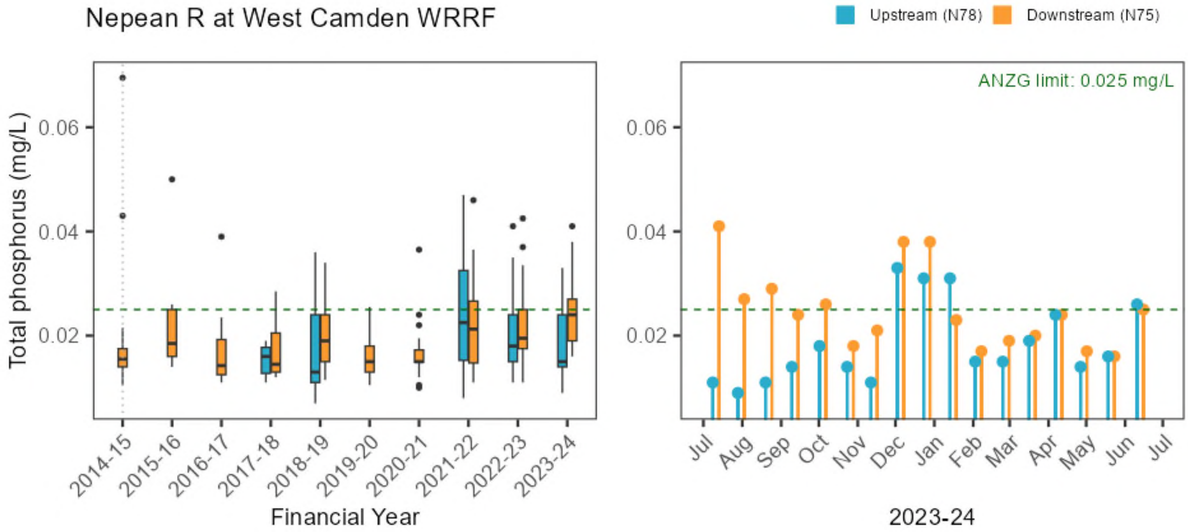
Nepean R at West Camden WRRF
Upstream (N78)
Downstream (N75)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
0.02
0.04
0.06
2014-15
2015-16
2016-17
2017-18
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Financial Year
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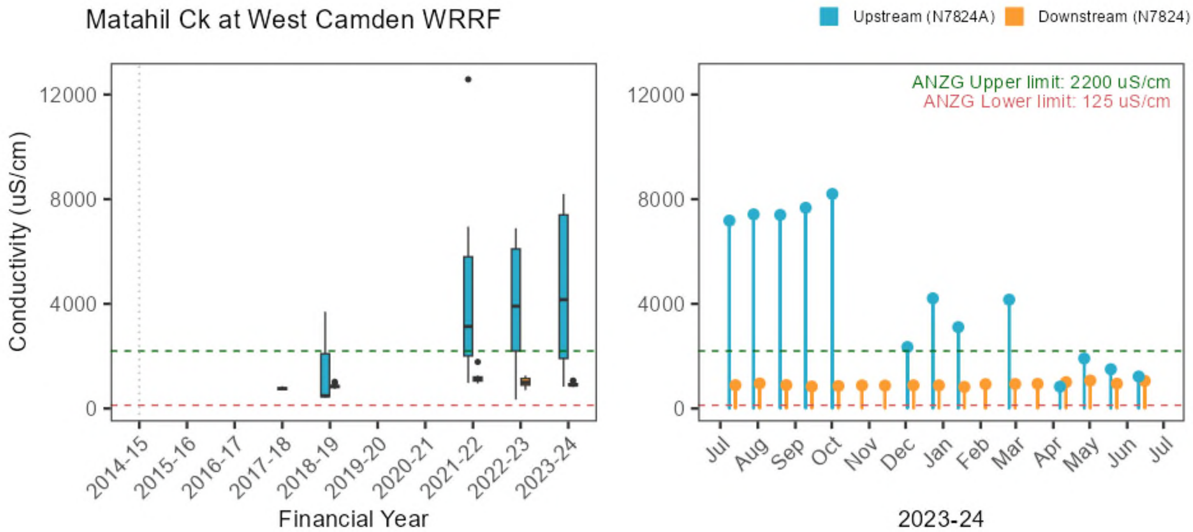
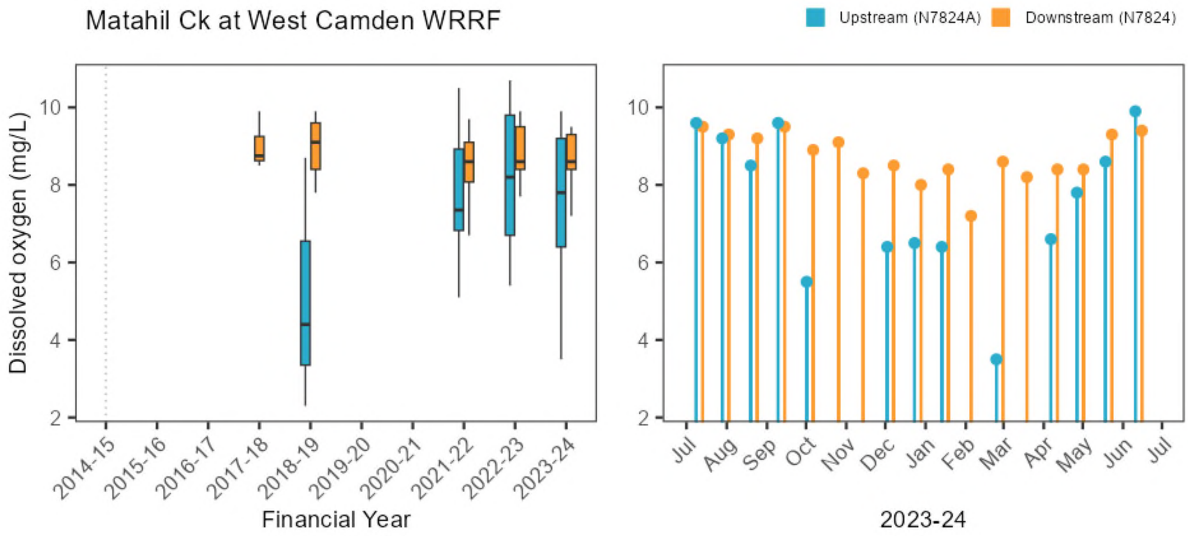
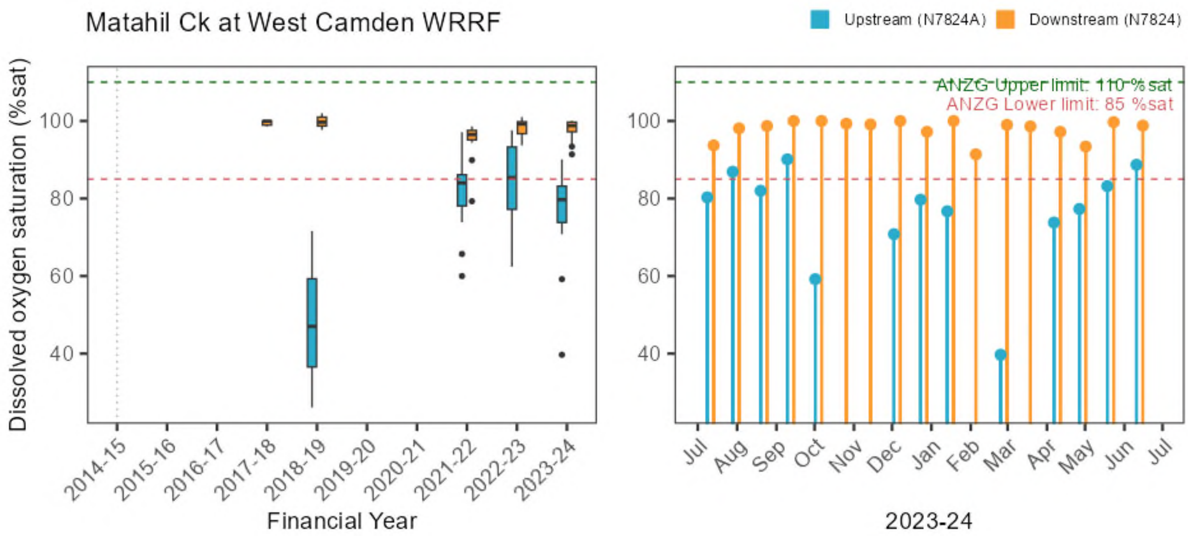
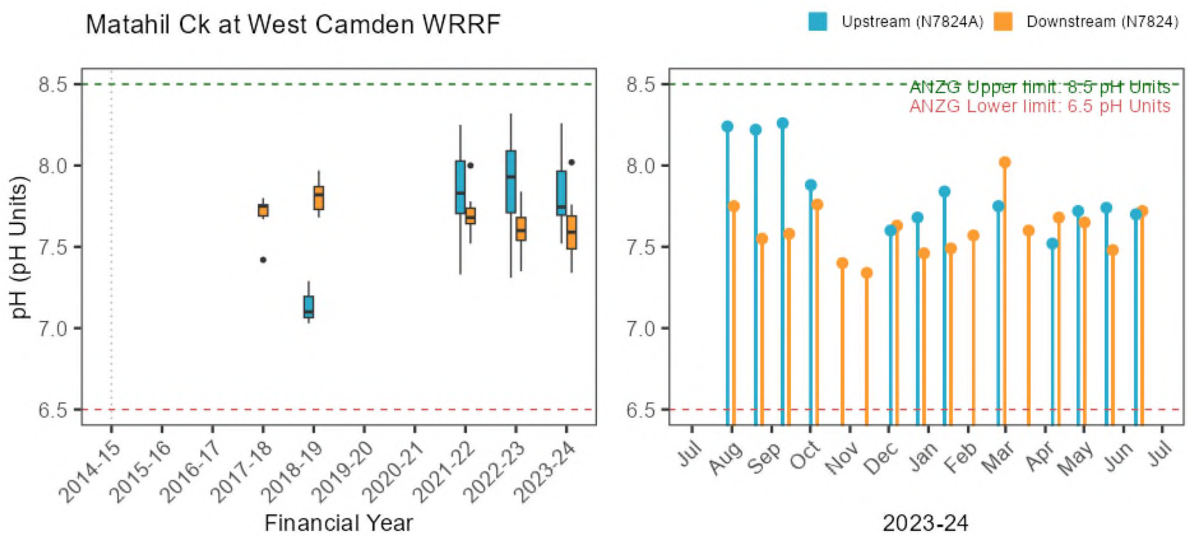
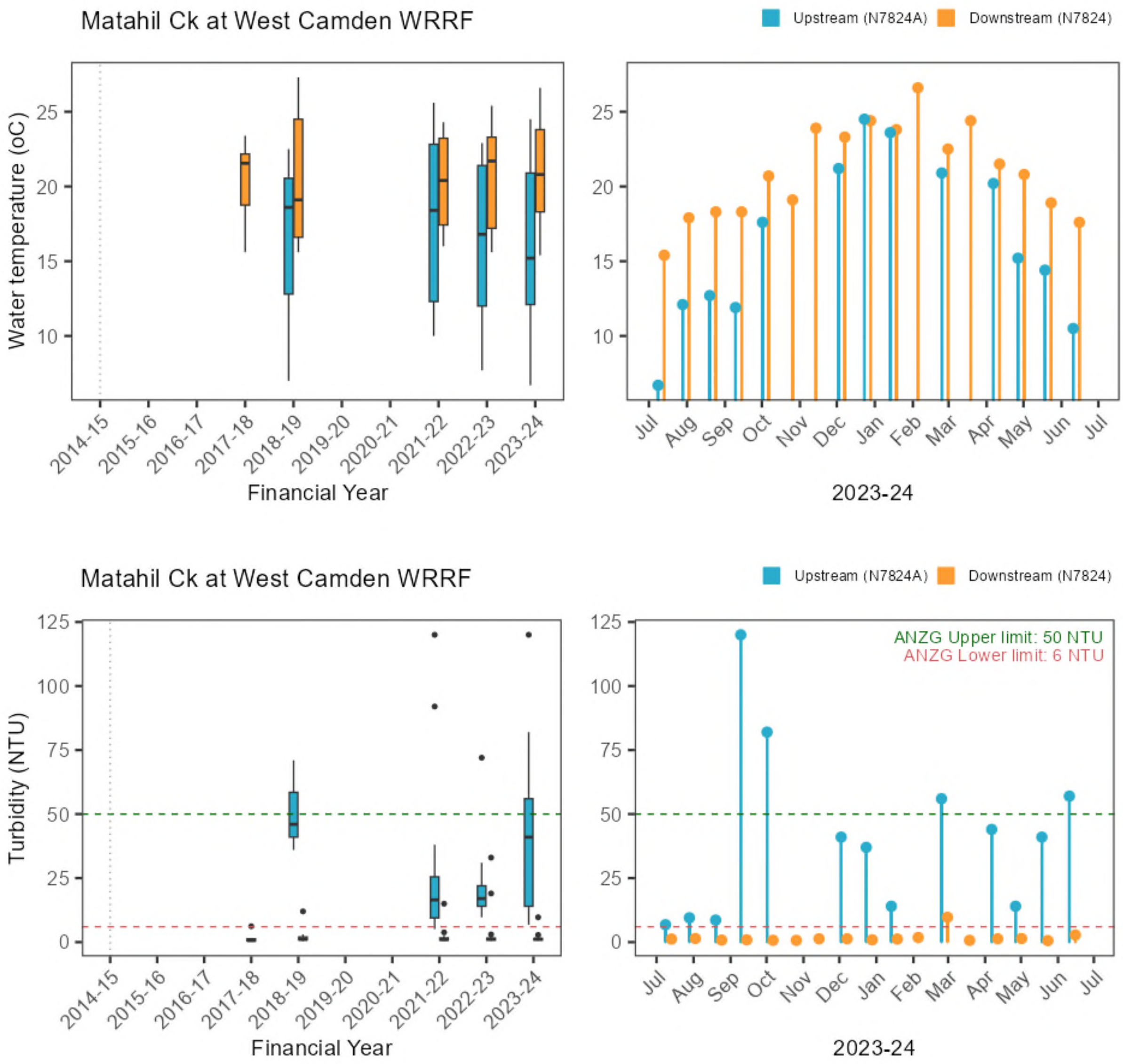
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Conductivity (uS/cm)
0
4000
8000
12000
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
Dissolved oxygen (mg/L)
Financial Year
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
Dissolved oxygen saturation (%sat)
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
Financial Year
2023-24


Matahil Ck at West Camden WRRF
Upstream (N7824A)
Downstream (N7824)
pH (pH Units)
ANZG Upper limit: 8.5 pH Units
ANZG Lower limit: 6.5 pH Units
Financial Year
2023-24



Vertical dashed line in 2014-15 year: Intervention date on nitrogen treatment process upgrade

Figure 4-8 Nutrients and physico-chemical water quality exception plots, upstream and downstream of West Camden WRRF

Ecosystem Receptor – Phytoplankton as chlorophyll-a

Table 4-8 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of West Camden WRRF treated discharge

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (N7824A)	→
Downstream tributary (N7824)	→
Upstream river (N78)	→
Downstream river (N75)	→

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
	Median value outside the guideline limit in 2023-24				

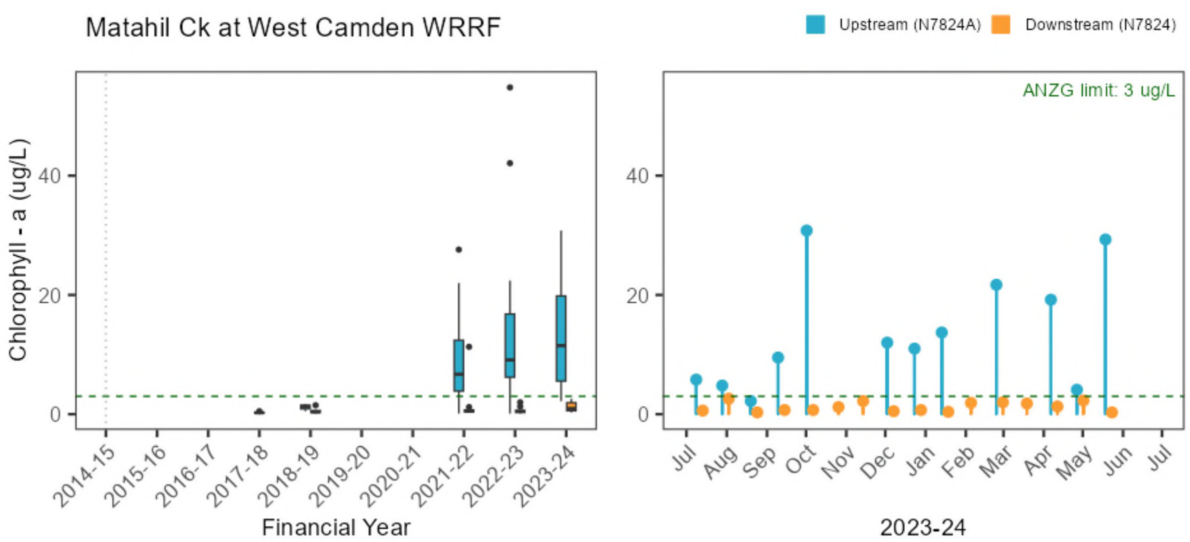
Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary current year (N7824A vs N7824)	U
Upstream vs downstream river (N78 vs N75)	-

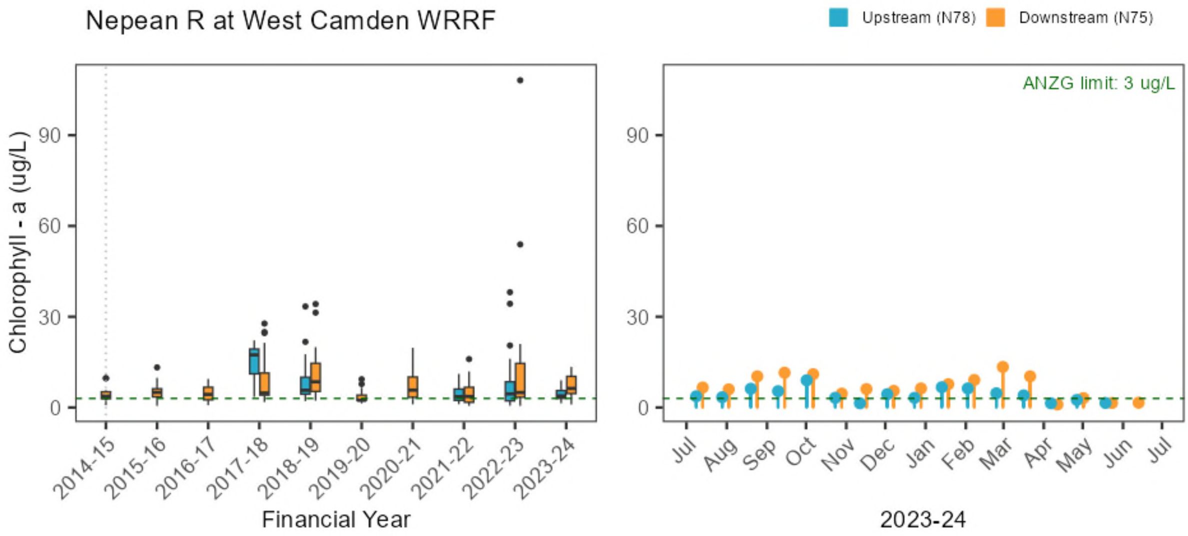
D	Downstream higher ($p<0.05$)	U	Upstream higher ($p<0.05$)	-	No difference ($p>0.05$)

Statistical analysis confirmed that the 2023-24 chlorophyll-a concentrations were steady at both upstream and downstream Matahil Creek and Nepean River sites in comparison to the previous five years.

The median chlorophyll-a concentration exceeded the ANZG (2018) guideline at the upstream Matahil Creek (N7824A) and both upstream/downstream Nepean River sites in 2023-24. At the upstream Matahil Creek site (N7824A) chlorophyll-a reached a maximum of 30.8 µg/L (4 October 2023).

Statistical analysis also confirmed that the chlorophyll-a concentration in 2023-24 was significantly higher at the upstream Matahil Creek site (N7824A) in comparison to the downstream site. Routine discharge flows had a positive influence here in diluting or displacing phytoplankton downstream. There was no such significant difference found between upstream and downstream Nepean River sites. This confirmed there was no negative impact of the nitrogen rich discharges on the ecosystem receptor (chlorophyll-a) at the downstream creek or river sites.





Vertical dashed line in 2014-15 year: Intervention date on nitrogen treatment process upgrade

Figure 4-9 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of West Camden WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested a localised ecosystem impact in Matahil Creek, downstream of West Camden WRRF. There was no evidence these impacts had any effect on the Nepean River system to which this creek flows.

Table 4-9 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of West Camden WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (N7824A vs N7824)	D
Upstream vs downstream river (N78 vs N75)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

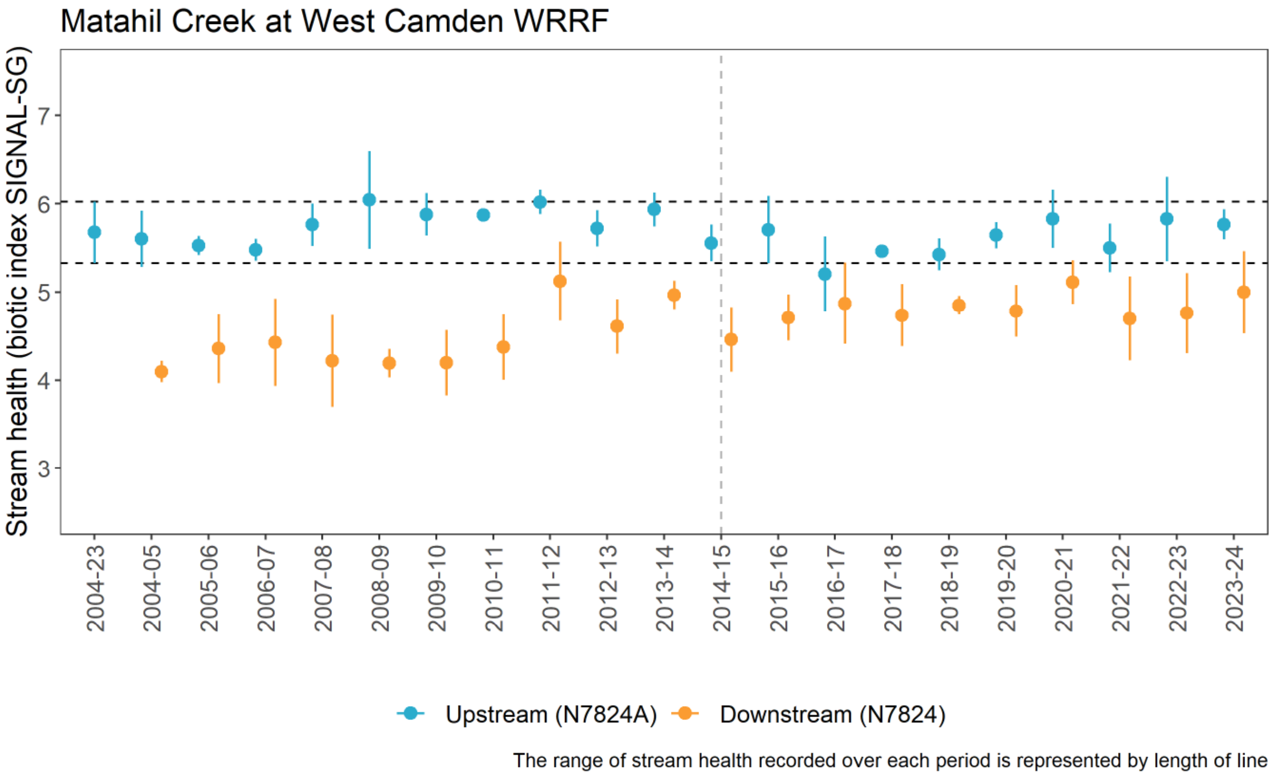


Figure 4-10 Stream health of Matahil Creek upstream and downstream of West Camden WRRF. Grey line indicates beginning of WRRF upgrade.

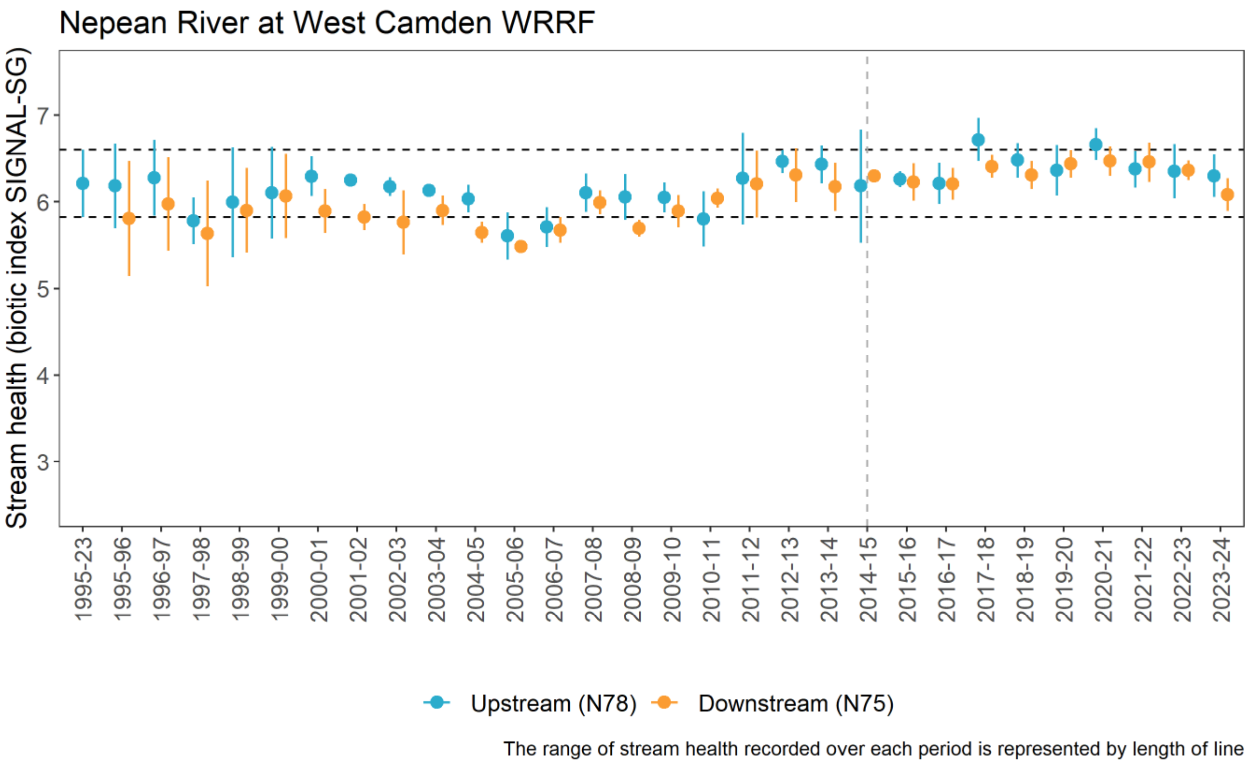


Figure 4-11 Stream health of Nepean River upstream and downstream of the confluence of Matahil Creek near West Camden WRRF. Grey line indicates beginning of WRRF upgrade.

Gate 2 – Synthesis of impact of West Camden WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as Chlorophyll-a		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Ammonia nitrogen	→	D	D	U	-	D	-	The elevated nitrogen in the discharge from West Camden WRRF increased the downstream receiving water concentration at both Matahil Creek and the Nepean River. In 2023-24, seven out of 17 total ammonia nitrogen results were above the ANZG 2023 toxicant guideline for 95% species protection. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation (multivariate analysis) was carried out (Gate 3 analysis).
Oxidised nitrogen		D	D					
Total nitrogen	↗	D	D					
Filterable total phosphorus		D	D					
Total phosphorus	→	-	D					
Conductivity		U	-					
Dissolved oxygen		D	-					
Dissolved oxygen saturation		D	-					
pH		U	-					
Temperature		D	-					
Turbidity		U	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

Gate 3 – Special investigation on downstream water quality and ecosystem health impact

West Camden WRRF was selected to proceed through a full Gate 3 analysis as a sole case study for the 2023-24 data report. Gate 2 outcomes suggest a potential adverse localised ecological impact occurring from West Camden WRRF on the downstream tributary to Matahil Creek macroinvertebrate community. Methodology for this case study is outlined in Section 3 and involved multivariate regression of both SIGNAL-SG and chlorophyll-a ecosystem receptor results against key water quality parameters, to understand linkages between stressors as potential drivers of waterway health. In future interpretive reports, further Gate 3 analysis on all Gate 2 results that indicate potential adverse ecological impact from Sydney Water's WRRF will be investigated and reported.

SIGNAL-SG

Two DISTLM models were run on the Nepean River and Matahil Creek data with output fitted variation acceptable at 100% return based on AICc selection criterion. Model output for the Nepean River captured only 26% of the total variation between SIGNAL-SG scores and predictor variables. This relatively low level of variation suggests other unaccounted for variables likely contributed to the pattern, and placement of individual sample points should not be over interpreted. In contrast, the model output for Matahil Creek captured 86% of the total variation, suggesting the latter model is more relevant in explaining patterns between SIGNAL-SG scores with predictor variables.

Ammonia NH3-N nitrogen and filtered total phosphorus together formed the best-fit predictor solution with an AICc of -38.3 for Matahil Creek (Table 4-11). Multiple partial correlation coefficients (R) of individual predictors (with standardised partial regression coefficients (weights)) were highest for the predictor ammonia NH_3-N (R = -0.97 (-0.51)) and lower for that of filtered total phosphorus (R = -0.26 (-0.20)) on axis 1, suggesting ammonia and other omitted nitrogen variables (due to multicollinearity) were the most important determinants of SIGNAL-SG scores.

Total nitrogen formed the best-fit predictor solution with an AICc of -70.2 for Nepean River (Table 4-12). When this single predictor variable was assigned by the model, a maximal partial correlation coefficient (R) of -1 was returned. While the standardised partial regression coefficient (weight) was low (-0.09) on axis 1, it suggests total nitrogen and the omitted oxidised nitrogen (due to multicollinearity) was of little importance in determining SIGNAL-SG scores. Notably the ammonia predictor variable was non-significant in model output for the Nepean River. Hence the DISTLM identified predictor variables better encapsulated more of the total variation in SIGNAL-SG scores in Matahil Creek than in the Nepean River as reflected by the lower AICc (-38.3) returned for the Matahil Creek model compared with a higher AICc (-70.2) for the Nepean River model.

Ammonia has been identified as the major toxicant of concern in wastewater treatment plant effluents (Adams et al., 2008). Ammonia has been previously identified together with chlorine as the most important toxicants immediately downstream of effluent (treated sewage) discharges (Davis 1997). Environment Canada (2001) also noted that unionised ammonia was the most frequent cause of toxicity from wastewater effluent. Camargo and Alonso (2006) suggested ammonia, nitrite, and nitrate can contribute to direct toxicity of aquatic organisms. Besley et al. (2023) reported that ammonia concentrations in the influent did pose a risk to ecosystem health, although receiving water dilution diminished this risk. Companion toxicity test by Kumar et al. (2024) of influent in dry-weather and under wet-weather inflow and infiltration conditions determined ammonia to be the primary concern in influent with a secondary concern from copper and zinc. Based on hazard quotient assessments, copper, zinc, and ammonia are likely to exceed water quality guidelines in wet-weather influents eliciting potential toxicity (Kumar et al., 2024). They also stated that the impact of metals may be reduced if the bioavailable fractions of the dissolved metal concentrations were considered.

While West Camden WRRF effluent is subject to chlorine disinfection, the de-chlorination process (introduced in the early 2000's) that occurs to effluent before discharge to the receiving waters ameliorates the risk of toxicity from chlorine.

As outlined in Kumar et al (2024) the dissolved (filterable) trace metal and ammonia concentrations were converted into Hazard Quotients (HQs). This is a measure used in ecological risk assessments to evaluate the potential risk of exposure of an organism to a particular substance, such as metals. The method consists of calculating the ratio (or quotient) which is expressed as a "Predicted Environmental Concentration" (PEC) divided by a "Predicted No Effect Concentration" (PNEC). The PEC is the water column measured concentration. The PNEC value is usually the DGV or, in its absence, the concentration in an unimpacted reference site. When the quotient value is >1, the hazard is considered as significant, and becomes more extreme as the quotient increases. Conversely, the more the quotient falls below 1, the more the hazard is regarded as low. This approach was used to assess dissolved (filterable) metal data for which collection commenced in the 2024-25 financial year. HQs were calculated for each dissolved (filterable) trace metal (aluminium, copper, nickel and zinc) and for total ammonia in terms of the 95% species protection default guideline values (DGVs).

All HQs were returned below 1 for both the four metal species (aluminium, copper, nickel and zinc) and ammonia examined for Nepean River sites with respective HQs shown in (Table 4-13) for the 17 collection events. In contrast receiving water measurements from the downstream site on Matahil Creek returned HQs above 1, suggesting these represented a hazard, with the highest risk from ammonia HQs that recorded a HQ of 4 on two occasions (Table 4-12). HQs from all downstream samples exceeded 1 for zinc with HQs that ranged from 1.1 to 2.8 (Table 4-12). No HQ exceedances of 1 were returned for nickel while only two exceedances occurred for aluminium (1.1 and 1.5) from 17 sample collection events at the downstream site on Matahil Creek (Table 4-12).

The data pattern in the case of copper was unexpected. As nine of the 17 HQs exceed 1 for the upstream site while a single exceedance of the HQ of 1 was documented for the downstream site. Data were reextracted to sanity check no error had been made in constructing the HQ Tables in Table 4-12 and Table 4-13. The copper results seemed out of context as a literature review of sources of metal contaminants in domestic wastewater from household studies in Australia indicated that major inputs were from the metals lead, zinc, and copper, with arsenic, nickel, and Hg near detection limits. Inputs of lead appeared to originate from the laundry and bathroom, while zinc mainly originated from the bathroom, and the major sources of copper were from plumbing and water supply (Tjadraatmadja and Diaper 2006). Further support for these copper measurements being unexpected context is provide by Besley et al. (2023, see Table 6), as they documented influent concentrations of zinc to be typically three times the ANZG (2018) DGV while influent concentrations of copper were three times to eight times the DGV measured across three sewer carriers.

Birch (2024) recently identified road-derived metals as the chief contributor of metals to stormwater from a review and critical assessment of over three decades of research supplemented by global studies. Birch (2024) stated copper, lead and zinc are commonly studied road-derived metals. Roads comprise almost 25% of a typical urban catchment and generate a considerable metal load from highly effective impervious surfaces which is transported directly to the adjacent receiving waterways (Birch, 2024). Copper and zinc were amongst those 12 contaminants identified by Bickford et al. (1999) risk assessment of the Sydney region, with 85% of the load of those chemicals contained in stormwater. Investigations of highly urbanised sub-catchments of the Sydney estuary (Davis and Birch, 2009) showed that the contaminants copper, lead and zinc were predominantly (79-87%) derived from diffuse sources (residential properties and roads). This raises the question, does monitoring copper and zinc in the receiving water column provide a meaningful evaluation of the risk posed for adverse ecological risk from Sydney Water discharges?

A strong correlation between the toxic pressure of dissolved metals and invertebrate species was observed by Liess et al. (2017) from reviewing a wide geographical range of Australian streams that were contaminated with heavy metals (mainly copper and zinc). They determined that heavy metal toxicity was positively related to the proportion of predators within the invertebrate assemblage and that taxa richness was negatively affected. A relevant study of metal contaminated streams that also received organic contamination (sewage) was conducted on Japanese streams by Iwasaki et al. (2018). They predicted that total zinc concentrations of 60 µg/L, twice the Japanese environmental quality standard, do not lead to significant reductions in richness or abundance of macroinvertebrates in organic-contaminated rivers (BOD > 3mg/L). They found at a regional and local scale very few species were present, and that metal-sensitive mayflies were absent. From this study, Iwasaki et al. (2018) stated that an important implication was that macroinvertebrate taxa that are susceptible to metal pollution should be sparse or absent in organic contaminated rivers, so the impacts of metals, such as zinc may be limited as the communities are already species poor. Sydney Water’s recent Wet-Weather Overflow Monitoring

(WWOM) program pilot study of urban streams meet the Iwasaki et al. (2018) criterion (BOD > 3 mg/L) as organic-contaminated, as our companion BOD measurements taken when water samples were collected for toxicity testing from the downstream receiving waters of Vineyard, Darling Mills and Buffalo creeks were 9, 3 and 5 mg/L, respectively (Sydney Water 2024c, Wet Weather Overflow Monitoring program 2016 to 2024 Synthesis Report).

Evidence for lack of metal sensitive macroinvertebrate taxa was documented under this recent WWOM program (see shade plots in Section 5) with sporadic collection of a single mayfly taxa Caenidae Tasmanocoenis in Girraween Creek in (Figure 5.25). A single mayfly Baetidae Cloeon larva was observed in Frenchs Creek (Figure 5.33). In Blacktown Creek, both these two mayfly genera were encountered (Figure 5.44). While no mayfly larvae were observed in Avondale Creek (Figure 5.4), Vineyard Creek (Figure 5.13), Buffalo Creek (Figure 5.17), Kittys Creek (Figure 5.29), or in the Darling Mills Creek system (Figure 5.38). In contrast, in near-pristine streams an average of 3 genera (standard deviation of 1) and 5 genera (standard deviation of 2) of mayfly larvae were collected in samples. These near-pristine freshwater stream sites were McCarrs Creek at McCarrs Creek Bridge Road in Garigal National Park and at McKell Avenue at the Hacking River in the Royal National Park. These sites were sampled 27 times each spring and autumn between 2008 and 2021 from the edge habitat of stream pools under the SWAM (Sydney Water 2023).

As Kumar et al. (2024) states, it was not appropriate to calculate hazard quotients for total metals. They go onto state these will always be high as these are comparing the total concentration against a dissolved metal DGV. The bioavailability of the particulate metal contribution is unknown, so the HQ is almost meaningless except to indicate the presence of high particulate metals where the value is high. Hence total metal concentrations are not discussed.

As outlined within Kumar et al. (2024) copper and zinc appeared to be of secondary concern, with ammonia the primary concern from wet-weather overflows in low dilution receiving water settings. The above outlined stormwater delivered road-derived metal loadings to receiving streams of the Sydney region suggests ammonia is the likely primary toxicant in wastewater discharges, with evidence for this from the West Camden WRRF provided by the documented concentration exceedances of the ANZG (2018) DGV and the calculated HQs that indicate a high risk under several collection events from the downstream site of Matahil Creek.

Box plots of water quality concentrations from Nepean River sites situated upstream and downstream of the confluence of Matahil Creek with box plots of water quality concentrations from Matahil Creek sites situated upstream and downstream of the discharge from West Camden WRRF (from 75 collection events between March 2018 and June 2024) enabled the following visual observations. In the Nepean River at the downstream site the range of concentrations of nitrogen variables were clearly higher than those from the upstream site. While ranges of concentrations were generally similar for the other seven variables (Figure 4-13). Notably the range of ammonia concentrations were below the ANZG (2018) DGV of 0.79 mg/L at the Nepean River downstream site (Figure 4-13). This suggests dilution occurred at this more distant site from the West Camden WRRF discharge as the companion box plot of ammonia for the downstream Matahil Creek site illustrated higher concentrations that were above this DGV (Figure 4-12). This dilution aspect with distance from the discharge was also illustrated in the comparison of box plots of the other nitrogen variables, oxidised nitrogen and total nitrogen (Figure 4-12 and Figure 4-13).

Box plots of conductivity illustrate the range of conductivity was much higher at the upstream site than at the downstream site at Matahil Creek (Figure 4-12). This suggests stream flows from the upstream site are diluted by the release of treated effluent from West Camden WRRF. Areas of moderate-high salinity potential exist within the catchment of Matahil Creek (Figure 4-14), which is a likely upstream source of the documented relatively high conductivity measurements. The NSW Department of Infrastructure, Planning and Natural Resources 'Salinity Potential in Western Sydney Map and Guidelines' (2002) has determined four categories for areas of:

- known salinity
- high salinity potential
- moderate salinity potential
- very low salinity potential

A note accompanying that map states 'These categories give an indication of salinity potential based on certain general assumptions (Figure 4-14). However, concept modelling of salinity processes in Western Sydney has shown that salinity may be an issue almost anywhere in Western Sydney, with certain geologic and management conditions.' Thus, the categories on this map provide an indication of the likelihood of a site to have a salinity problem due to its geology, soil characteristics, and topology and catchment position.

Hence the identification of ammonia and conductivity in the marginal test from (Table 4-10) DISTLM modelling of SIGNAL-SG scores to water quality predictor variables collected from Matahil Creek seem robust. The best model solution for Matahil Creek data identified ammonia (and other omitted nitrogen variables due to multicollinearity) as the most important determinants of SIGNAL-SG scores, which appears to provide a robust model given the literature discussed above.

The identification of total nitrogen (Table 4-11) in marginal tests also seems robust given the apparent elevated nitrogen variable concentrations in the receiving waters at the Nepean River downstream site (Figure 4-13). While the returned best model solution for DISTLM, selected total nitrogen as a single predictor variable, the standardised partial regression coefficients (weight) was low (-0.09), which suggested total nitrogen and omitted oxidised nitrogen (due to multicollinearity) was of little importance in determining SIGNAL-SG scores. This model outcome was also illustrated by the total variation captured 26% of the variation between the matrices of SIGNAL-SG scores and predictor variables of the Nepean River sites. This relatively low level of total variation explained suggested other unaccounted-for variables contributed to shaping the data pattern of SIGNAL-SG scores within the Nepean River.

In summary, the adverse ecological effects documented in SIGNAL-SG scores at the downstream site of Matahil Creek (Figure 4-10) appear to from the primary toxicant of ammonia. The increased dilution of discharges from West Camden WRRF within the Nepean River over the limited dilution afforded in Matahil Creek, has diminished the risk of adverse ecological effect in this larger receiving waterway, as indicated by the statistically non-significant SIGNAL-SG scores between upstream and downstream sites (Table 4-9).

Table 4-10 Results from DISTLM for the Matahil Creek sites of marginal tests. Variable are listed in order of contribution explaining variation in the SIGNAL-SG scores. % variation represents the explained variation attributable to each predictor variable included in the model

Predictor variables	Pseudo-F	P-value	% variation
Total ammonia nitrogen*	33.39	0.0001	73.6
Conductivity	17.43	0.002	59.2
Turbidity	4.8	ns	28.6
pH	2.77	ns	18.8
Temperature	1.83	ns	13.2
Total phosphorus*	0.45	ns	3.6
Dissolved oxygen (mg/L)	0.18	ns	1.5
Filtered total phosphorus*	0.17	ns	1.4

** represents natural log +1 transformed; ns = non-significant*

Table 4-11 Results from DISTLM for the Nepean River sites of marginal tests. Variable are listed in order of contribution explaining variation in the SIGNAL-SG scores. % variation represents the explained variation attributable to each predictor variable included in the model

Predictor variables	Pseudo-F	P-value	% variation
Total nitrogen*	6.4577	0.0204	26.4
Temperature	1.7768	ns	9
Total phosphorus*	1.3487	ns	7
Total ammonia nitrogen*	1.2688	ns	6.6
pH	0.72985	ns	3.9
Filtered total phosphorus*	0.48903	ns	2.6
Turbidity	0.2234	ns	1.2
Dissolved oxygen (mg/L)	0.079222	ns	0.4
Conductivity*	0.000584	ns	0.003

**represents natural log +1 transformed; ns = non-significant*

Table 4-12 Hazard quotients from metals and ammonia from 13 collection events in 2023/24 at Matahil Creek sites situated upstream and downstream of the discharge from West Camden WRRF

Collection event	Site	Position to WWRF	Toxicant	Aluminium	Nickel	Copper	Zinc	Total ammonia NH3-N
11/07/2023	N7824A	Upstream	Dissolved	0.05	0.1	**1.5**	0.1	0.01
31/07/2023	N7824A	Upstream	Dissolved	0.05	0.1	0.4	0.3	0.01
22/08/2023	N7824A	Upstream	Dissolved	0.05	0.1	0.7	0.3	0.01
12/09/2023	N7824A	Upstream	Dissolved	0.2	0.1	0.9	**1.3**	0.01
4/10/2023	N7824A	Upstream	Dissolved	0.05	0.2	**2.3**	0.5	0.01
5/12/2023	N7824A	Upstream	Dissolved	0.4	0.1	**4.3**	0.0	0.01
26/12/2023	N7824A	Upstream	Dissolved	0.1	0.2	**3.1**	0.5	0.01
16/01/2024	N7824A	Upstream	Dissolved	0.05	0.2	**1.6**	0.3	0.01
27/02/2024	N7824A	Upstream	Dissolved	0.1	0.2	0.6	0.1	0.03
9/04/2024	N7824A	Upstream	Dissolved	0.1	0.1	**2.6**	0.1	0.01
29/04/2024	N7824A	Upstream	Dissolved	0.1	0.1	**1.2**	0.1	0.01
21/05/2024	N7824A	Upstream	Dissolved	0.05	0.1	**2.2**	0.3	0.01
13/06/2024	N7824A	Upstream	Dissolved	0.2	0.1	**2.1**	0.3	0.03
11/07/2023	N7824	Downstream	Dissolved	0.9	0.3	**1.2**	**2.6**	**2.4**
31/07/2023	N7824	Downstream	Dissolved	1.0	0.3	0.6	**2.8**	**4.0**
22/08/2023	N7824	Downstream	Dissolved	1.0	0.2	0.4	**2.1**	**1.8**
12/09/2023	N7824	Downstream	Dissolved	0.7	0.3	0.6	**2.1**	0.1
4/10/2023	N7824	Downstream	Dissolved	0.6	0.3	0.9	**2.1**	0.1
5/12/2023	N7824	Downstream	Dissolved	0.7	0.2	0.7	**2.1**	0.04

Collection event	Site	Position to WWRF	Toxicant	Aluminium	Nickel	Copper	Zinc	Total ammonia NH3-N
26/12/2023	N7824	Downstream	Dissolved	**1.5**	0.2	0.6	**1.1**	**2.8**
16/01/2024	N7824	Downstream	Dissolved	1.0	0.2	0.6	**1.3**	0.03
27/02/2024	N7824	Downstream	Dissolved	**1.1**	0.3	0.6	**1.5**	0.04
9/04/2024	N7824	Downstream	Dissolved	0.7	0.2	0.6	**1.4**	0.01
29/04/2024	N7824	Downstream	Dissolved	0.8	0.2	0.6	**2.0**	**4.0**
21/05/2024	N7824	Downstream	Dissolved	0.7	0.3	0.8	**2.1**	0.03
13/06/2024	N7824	Downstream	Dissolved	0.5	0.2	0.6	**1.8**	0.7
ANZG (2018) 95% species protection DGV (µg/L)				55	11	1.4	8	790

Bold = ratios of HQ that exceed 1

Table 4-13 Hazard quotients from metals and ammonia from 17 collection events in 2023/24 at Nepean River sites situated upstream and downstream of the confluence with Matahil Creek that receives the discharge from West Camden WRRF

Collection event	Site	Position to WRRF	Aluminium	Nickel	Copper	Zinc	Total ammonia NH_3-N
11/07/2023	N78	Upstream	0.3	0.1	0.9	0.3	0.01
31/07/2023	N78	Upstream	0.2	0.1	0.2	0.1	0.01
22/08/2023	N78	Upstream	0.1	0.1	0.5	0.1	0.01
12/09/2023	N78	Upstream	0.2	0.2	0.6	0.1	0.01
4/10/2023	N78	Upstream	0	0.2	0.6	0.1	0.01
26/10/2023	N78	Upstream	0.1	0.4	0.6	0.1	0.01
14/11/2023	N78	Upstream	0.2	0.2	0.2	0.1	0.01

Collection event	Site	Position to WRRF	Aluminium	Nickel	Copper	Zinc	Total ammonia NH_3-N
5/12/2023	N78	Upstream	0.6	0.1	0.8	0.3	0.06
26/12/2023	N78	Upstream	0.3	0.1	0.8	0.1	0.1
16/01/2024	N78	Upstream	0.3	0	0.5	0.1	0.04
5/02/2024	N78	Upstream	0.3	0	0.4	0.1	0.01
27/02/2024	N78	Upstream	0.2	0.1	0.5	0.1	0.01
19/03/2024	N78	Upstream	0.1	0.1	0.4	0.1	0.06
9/04/2024	N78	Upstream	0.9	0.1	0.6	0.3	0.05
29/04/2024	N78	Upstream	0.4	0	0.4	0.1	0.03
21/05/2024	N78	Upstream	0.8	0.1	0.5	0.1	0.03
13/06/2024	N78	Upstream	0.8	0.1	0.5	0.3	0.05
11/07/2023	N75	Downstream	0.5	0.1	0.6	0.6	0.09
31/07/2023	N75	Downstream	0.3	0.1	0.4	0.8	0.01
22/08/2023	N75	Downstream	0.3	0.1	0.6	0.6	0.86
12/09/2023	N75	Downstream	0.3	0.2	0.6	0.6	0.1
4/10/2023	N75	Downstream	0.1	0.2	0.7	0.4	0.06
26/10/2023	N75	Downstream	0.2	0.3	0.6	0.3	0.09
14/11/2023	N75	Downstream	0.3	0.3	0.4	0.4	0.41
5/12/2023	N75	Downstream	0.5	0.1	0.8	0.1	0.09
26/12/2023	N75	Downstream	0.6	0.1	0.9	0.3	0.1
16/01/2024	N75	Downstream	0.2	0.1	0.5	0.3	0.05
5/02/2024	N75	Downstream	0.3	0.1	0.4	0.1	0.01

Collection event	Site	Position to WRRF	Aluminium	Nickel	Copper	Zinc	Total ammonia NH_3-N
27/02/2024	N75	Downstream	0.2	0.1	0.6	0.1	0.09
19/03/2024	N75	Downstream	0.1	0.2	0.5	0.4	0.05
9/04/2024	N75	Downstream	0.9	0.1	0.6	0.4	0.05
29/04/2024	N75	Downstream	0.3	0.1	0.2	0.3	0.11
21/05/2024	N75	Downstream	0.7	0.1	0.7	0.1	0.03
13/06/2024	N75	Downstream	0.9	0.1	0.5	0.1	0.05
ANZG (2018) 95% species protection DGV (µg/L)			55	11	1.4	8	790

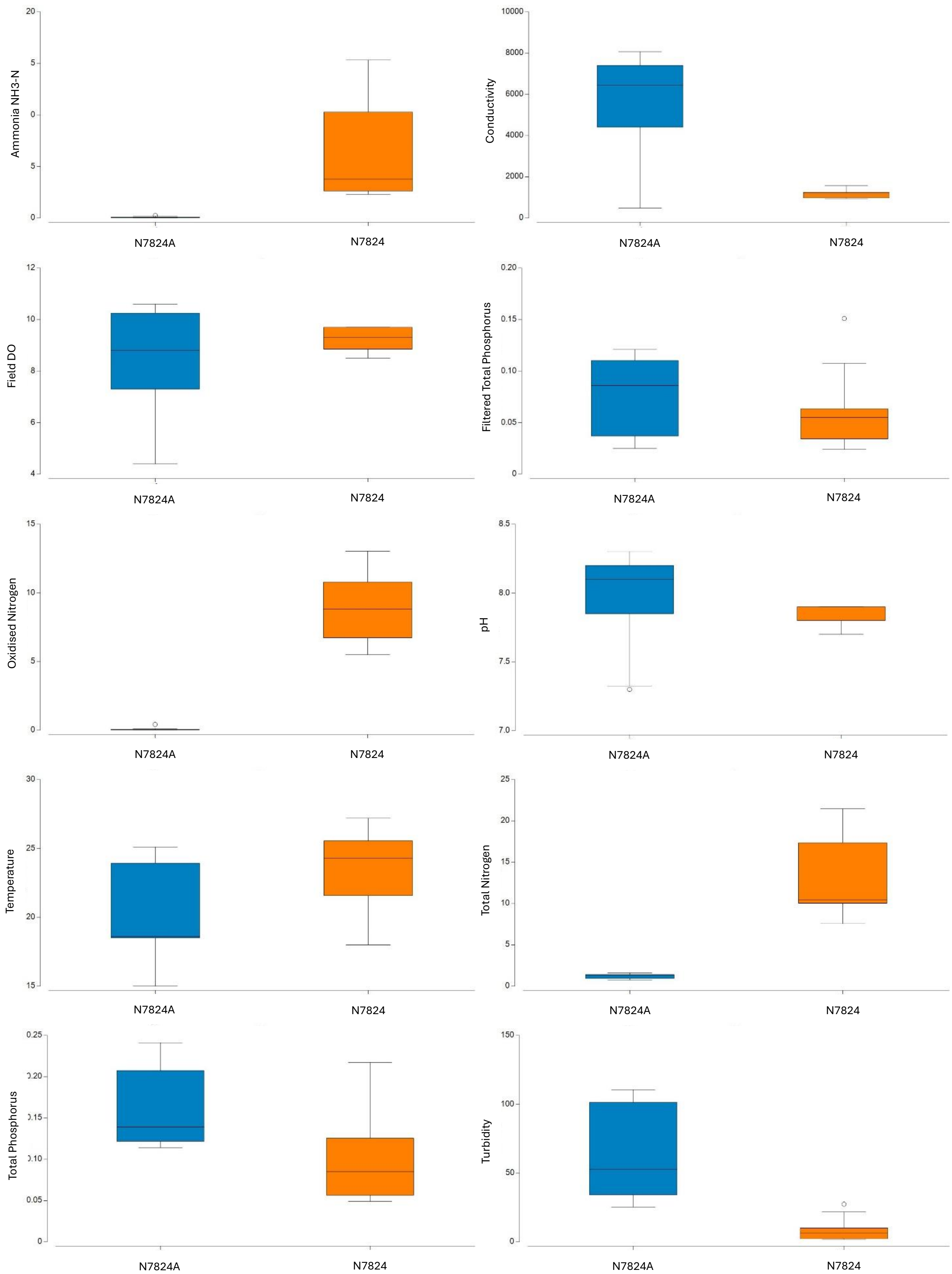


Figure 4-12 Water quality concentrations from Matahil Creek sites situated upstream (N7824A) and downstream (N7824) of the discharge from West Camden WRRF from collection events between March 2018 and June 2024

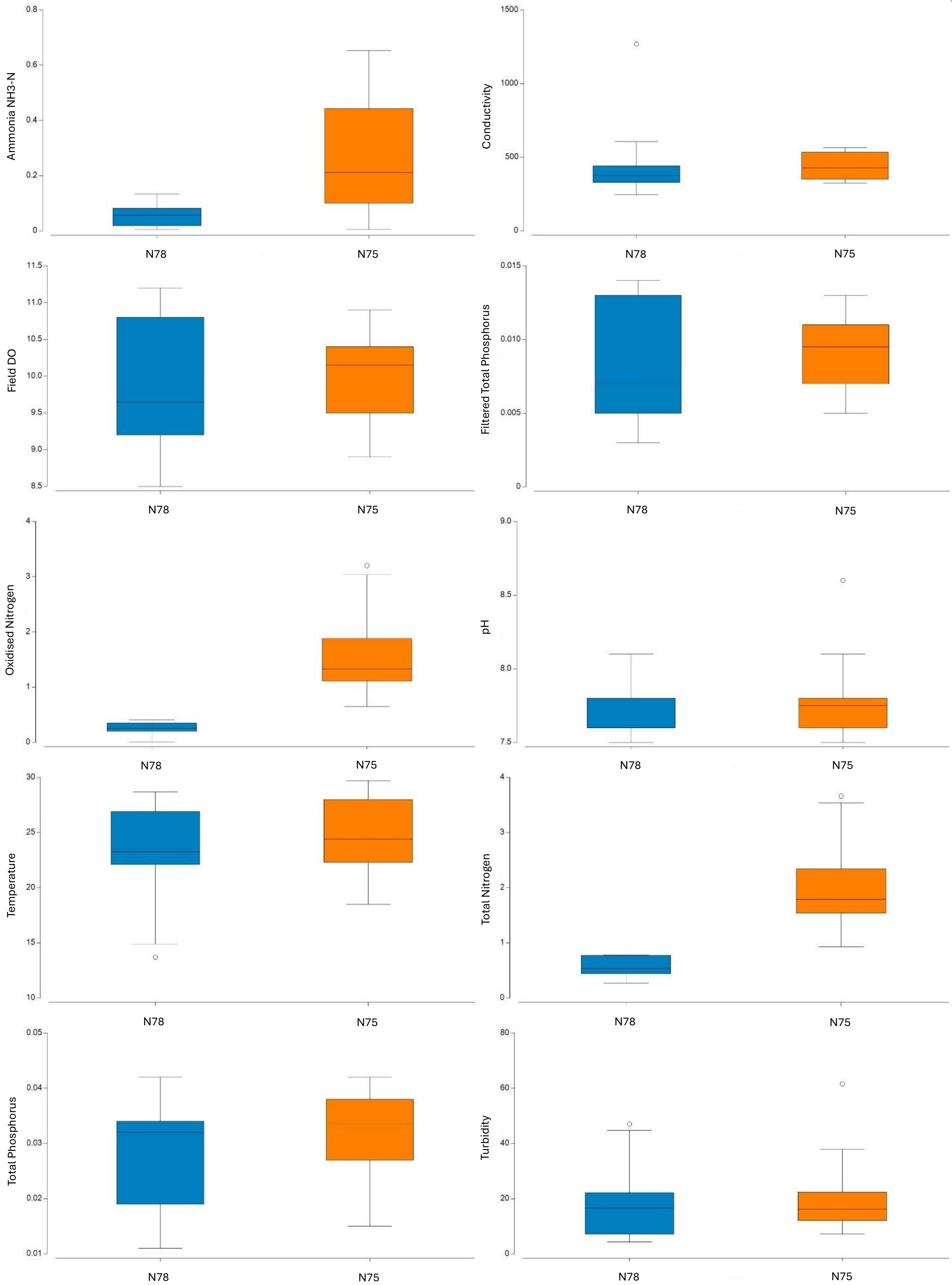


Figure 4-13 Water quality concentrations from Nepean River sites situated upstream (N7824A) and downstream (N7824) of the confluence of Matahil Creek that receives the discharge from West Camden WRRF from collection events between March 2018 and June 2024

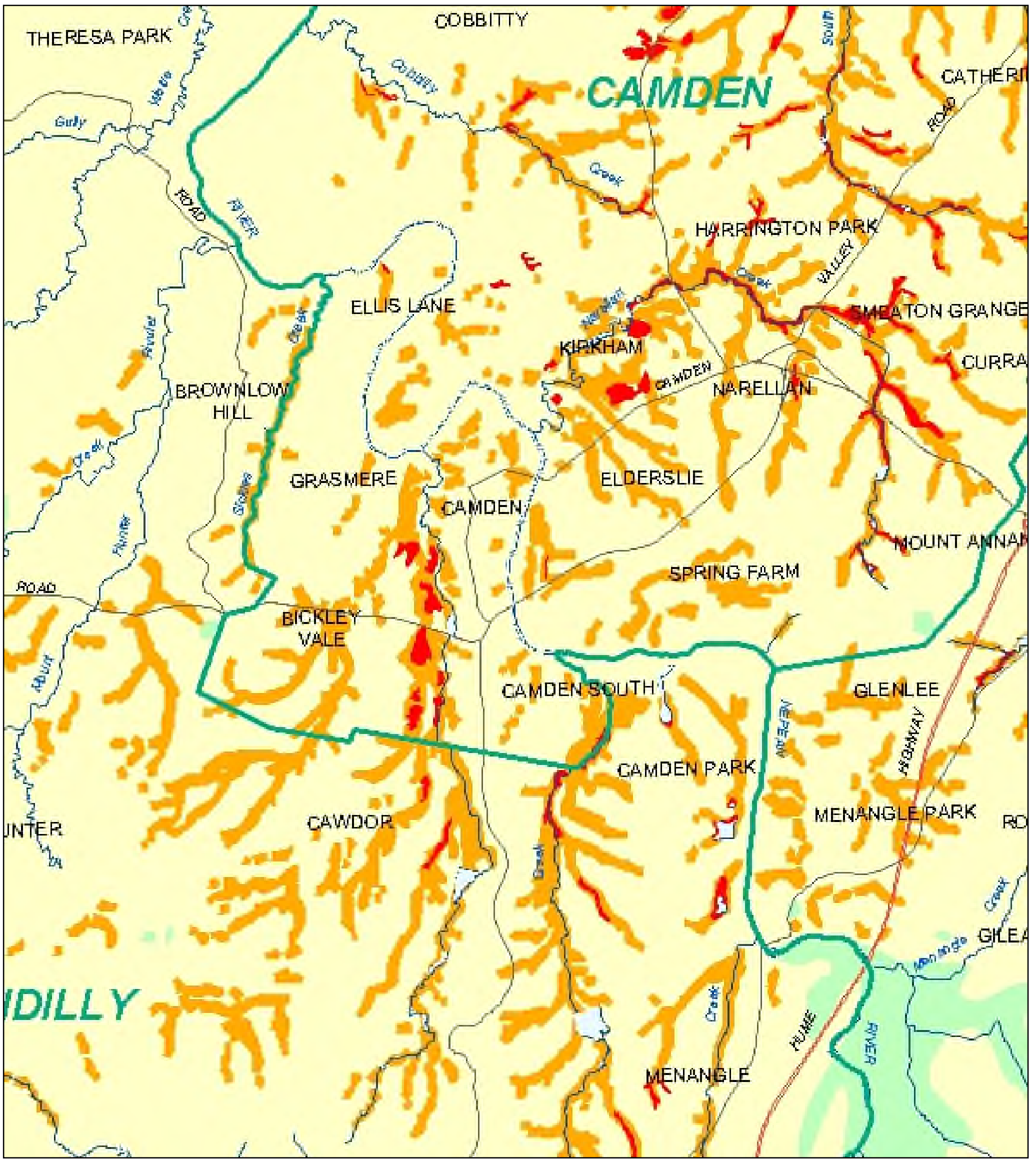


Figure 4-14 Section of Salinity Potential in Western Sydney map (DIPNR, 2002) showing Camden and surrounding districts

Chlorophyll-a

Two DISTLM models were run on Nepean River and Matahil Creek data with output fitted variation acceptable at 100% return based on AICc selection criterion. Model output for Nepean River captured only 46% of the total variation between chlorophyll-a concentrations and predictor variables. This level of total variation suggests other unaccounted-for variables contributed to shaping the pattern, and placement of individual sample points should not be over interpreted. Model output for Matahil Creek captured 64% of total variation, suggesting latter model is more relevant in explaining patterns between chlorophyll-a with predictor variables.

The Nepean River model indicates seven predictor variables (ammonia-NH_3-N, total nitrogen, filterable total phosphorus, total phosphorus, turbidity, temperature and pH) formed the best-fit solution although with a relatively high AICc of 654. The total nitrogen predictor variable also represented omitted oxidised nitrogen variable due to multicollinearity considerations outlined above. Under marginal tests the most variation explained by an individual variable was pH followed by total phosphorus (Table 4-). The highest multiple partial correlation coefficients (R) returned were for total phosphorus and pH which also had the relatively highest standardised partial regression coefficients (weights) (Table 4-). Notably the ammonia along with turbidity predictor variables in the marginal tests were non-significant under this model run of Nepean River data (Table 4-).

Table 4-14 Results from DISTLM for the Nepean River sites of marginal tests. Variable are listed in order of contribution explaining variation in the chlorophyll-a concentrations. % variation represents the explained variation attributable to each predictor variable included in the model

Predictor variables	Pseudo-F	P-value	% variation
pH	45.117	0.0001	23.6
Total phosphorus*	17.713	0.0001	10.8
Temperature	15.05	0.0001	9.3
Total nitrogen*	10.783	0.0016	6.9
Conductivity*	9.2934	0.006	6
Filtered total phosphorus*	4.4063	0.0442	2.9
Dissolved oxygen (mg/L)	4.137	0.0386	2.8
Total ammonia nitrogen*	0.2677	ns	0.2
Turbidity*	0.0155	ns	0.01

** represents natural log +1 transformed; ns = non-significant*

Table 4-15 Results from DISTLM for the Nepean River sites of multiple partial correlation coefficients (R) of individual predictors with standardised partial regression coefficients (weights). Variable are listed in order of weights

Predictor variables	Multiple partial correlation coefficients (R)	standardised partial regression coefficients (weights)
Total phosphorus*	0.5	6.03
pH	0.67	5.12
Filtered total phosphorus*	-0.06	-3.85
Temperature	0.41	3.13
Total nitrogen*	0.32	2.48
Turbidity*	-0.09	-1.76
Total ammonia nitrogen*	-0.13	-1.29

** represents natural log +1 transformed; ns = non-significant*

Under the model run for the Matahil Creek data, four predictor variables (filterable total phosphorus, total phosphorus, conductivity and field DO) formed the best-fit solution although with a relatively high AICc.of 338. Under marginal tests most variation explained by an individual variable was turbidity followed by conductivity, total nitrogen and field DO (Table 4-). The highest multiple partial correlation coefficients (R) returned were for conductivity and total phosphorus which also had the highest positive standardised partial regression coefficients (weights) (Table 4-). Filterable phosphorus and temperature variables in the marginal tests were non-significant under this model run for Matahil Creek data (Table 4-).

Table 4-16 Results from DISTLM for the Matahil Creek sites of marginal tests. Variable are listed in order of contribution explaining variation in the chlorophyll-a concentrations. % variation represents the explained variation attributable to each predictor variable included in the model

Predictor variables	Pseudo-F	P-value	% variation
Turbidity*	62.75	0.0001	40.5
Conductivity*	42.77	0.0001	31.7
Total nitrogen*	40.06	0.0001	30.3
Dissolved oxygen (mg/L)	39.46	0.0001	30
Total ammonia nitrogen*	14.53	0.0007	13.6
Total phosphorus*	11.38	0.0035	11
pH	3.67	0.0576	3.8
Filtered total phosphorus*	0.1	ns	0.1
Temperature	0.06	ns	0.1

** represents natural log +1 transformed; ns = non-significant*

Table 4-17 Results from DISTLM for the Matahil Creek sites of multiple partial correlation coefficients (R) of individual predictors with standardised partial regression coefficients (weights). Variable are listed in order of weights

Predictor variables	Multiple partial correlation coefficients (R)	standardised partial regression coefficients (weights)
Total phosphorus*	0.47	6.14
Conductivity*	0.65	4.22
Filtered total phosphorus*	-0.14	-4.25
Dissolved oxygen (mg/L)	-0.57	-3.48

** represents natural log +1 transformed; ns = non-significant*

Hence, the DISTLM identified predictor variables better encapsulated more of the variation in chlorophyll-a concentrations in Matahil Creek than in the Nepean River and was reflected by the relatively lower AICc value (338) returned for the Matahil Creek model compared with the higher AICc of 654 returned for the Nepean River model. Although these returned AICc are both high, and together with the returned amounts of total variation explained suggests there was potential for other unaccounted-for (unmeasured) variables that contributed to shaping the data patterns in chlorophyll-a that is a surrogate for algal assemblages.

Kumar et al. (2024) documented ammonia to exhibit relatively low toxicity to the microalga Chlorella vulgaris under toxicity testing of dry-weather influent (from a Sydney Water sewer carrier) where total ammonia NH_3-N was documented at 67 mg/L. This low toxicity was not surprising because ammonia can be a source of nitrogen for freshwater algal species and microalgae are less sensitive to ammonia compared to other taxa (invertebrates, vertebrates) (ANZG, 2023). This understanding of ammonia being a source of nitrogen for freshwater algal species, may explain the lack of selection of this predictor variable in the best DISTLM model solution for Matahil Creek samples under chlorophyll-a modelling while this predictor variable was returned as most influential under DISTLM modelling of SIGNAL-SG scores for Matahil Creek samples.

Conclusions from previous modelling of receiving water data between 2011-2017 determined no significant correlations between the site-specific WRRF nitrogen loads and downstream nitrogen concentrations at most sites of the Hawkesbury-Nepean River (Sydney Water, 2018). However, WRRF phosphorus loads correlated with instream phosphorus concentrations, despite contributing a small proportion compared to loads from other catchment sources (Sydney Water, 2018). This suggests the current DISLM multiple regression modelling outcome has some merit, as total phosphorus was the identified predictor variable with the relatively highest multiple partial correlation coefficient and also had the relatively highest standardised partial regression coefficients (weight) (Table 4- and Table 4-17). Another outcome from that prior modelling identified flow as the key driver controlling algal biovolume and chlorophyll-a concentrations at nine of the 11 key monitoring sites (Sydney Water, 2018). That is flow was negatively correlated with the chlorophyll-a concentrations and/or algal biovolume demonstrating a wash-out during high flow conditions and algal growth during static low flow conditions (Sydney Water, 2018). This suggests flow may be an unaccounted-for (unmeasured) variable in the current DISTLM modelling.

Prior modelling results of receiving water data from an 18-month dry weather period in 2018-2019, were available for the sites situated upstream and downstream of Matahil Creek and the Nepean River. In the Nepean River, nutrient concentrations, particularly nitrogen, were much higher at the downstream site (N75), although the chlorophyll-a concentration was lower indicating no direct influence of elevated nutrients on algal growth at this site (Sydney Water, 2020). West Camden WRRF total nitrogen and total phosphorus loads were significantly and positively correlated with the total nitrogen and total phosphorus concentrations in the Nepean River downstream (N75) of Matahil Creek, indicating a direct impact of wastewater discharge on nutrient elevation (Sydney Water, 2020). However, neither the total nitrogen nor total phosphorus load from West Camden WRRF was significantly correlated to the chlorophyll-a concentrations at the downstream site (N75) (Sydney Water, 2020). Comparative statistical analysis of flow and river nutrient concentrations indicated that, in wet weather increased river flow impacted the upstream site (N78) with nitrogen (total nitrogen and dissolved inorganic nitrogen) enrichment. However, at downstream site (N75), high river/creek flow was beneficial, reducing the nitrogen (total nitrogen and dissolved inorganic nitrogen) concentrations significantly (Sydney Water, 2020). Flow was significantly and inversely correlated with the chlorophyll-a concentration at the downstream site (N75) indicating algal washout during wet weather and lower retention time for algal growth (Sydney Water, 2020).

Another unaccounted-for (unmeasured) variable in the current DISTLM modelling that may also help explain an amount of total variation is soluble reactive phosphorus. As prior modelling under Sydney Water (2018) concluded approximately 51% of the total phosphorus load is in a readily available form of soluble reactive phosphorus. Measurements of soluble reactive phosphorus commenced in July 2023 under the SWAM.

Hence, it would seem prudent to include flow and soluble reactive phosphorus in future multiple regression modelling as part of the SWAM Gate 3 exploration of trends in the chlorophyll-a response variable datasets.

4.1.3. Wallacia WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Wallacia WRRF were within EPL limits in 2023-24 compared to the last nine years. There were increasing trends in total nitrogen and total phosphorus concentrations in the discharge.
- It is important to note that it is not possible to access the upstream Warragamba River site due to safety issues. As such a proxy site on the Nepean River has been used as the 'upstream' site.
- Nutrient concentrations were steady at both receiving water sites on Nepean and Warragamba rivers during 2023-24 compared to the previous years.
- Oxidised nitrogen and total nitrogen concentrations at the upstream proxy Nepean River site were significantly higher than the Warragamba River site, indicating influence from other upstream sources.
- No significant trends were observed in chlorophyll-a concentrations at the upstream proxy Nepean River or downstream Warragamba River sites. No impact on phytoplankton could be determined for Warragamba River downstream site.
- Macroinvertebrates results indicate a potential adverse ecological impact in stream health at downstream Warragamba River site compared to a reference site in the Nepean River in 2023-24. This will be further investigated in 2024-25 interpretive report.

Pressure – Wastewater discharge

Table 4-18 Gate 1 Analysis outcome summary –Wallacia WRRF

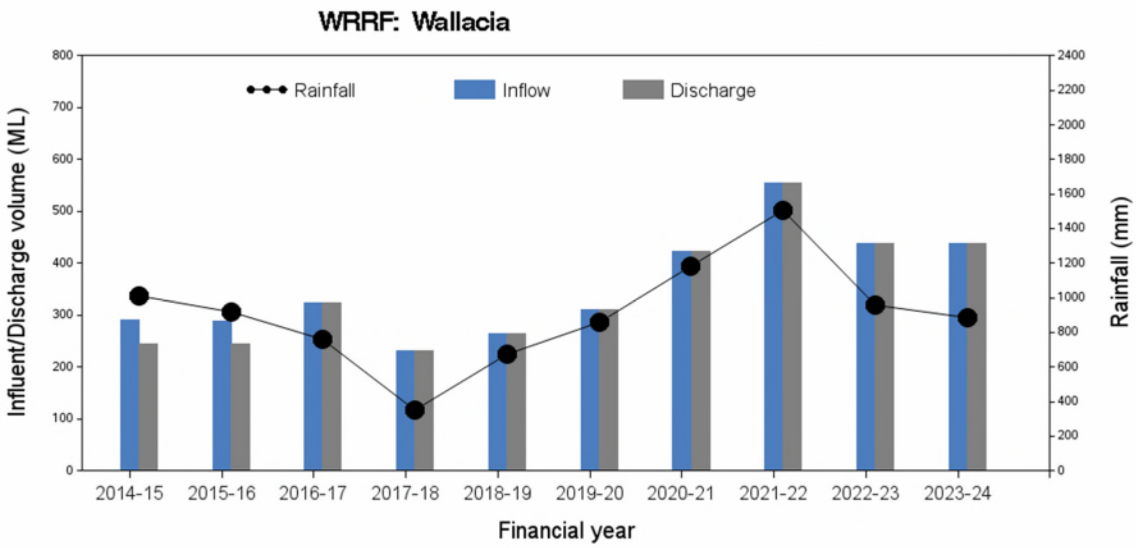
Analytes / Wallacia WRRF	Nutrients			Conventional analytes						Trace Metals			Other	
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC50 toxicity	Aluminium	Copper	Zinc	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate
Concentration	→	↗	↗	→	→	→		→	→	→	→	→	→	→
Load														

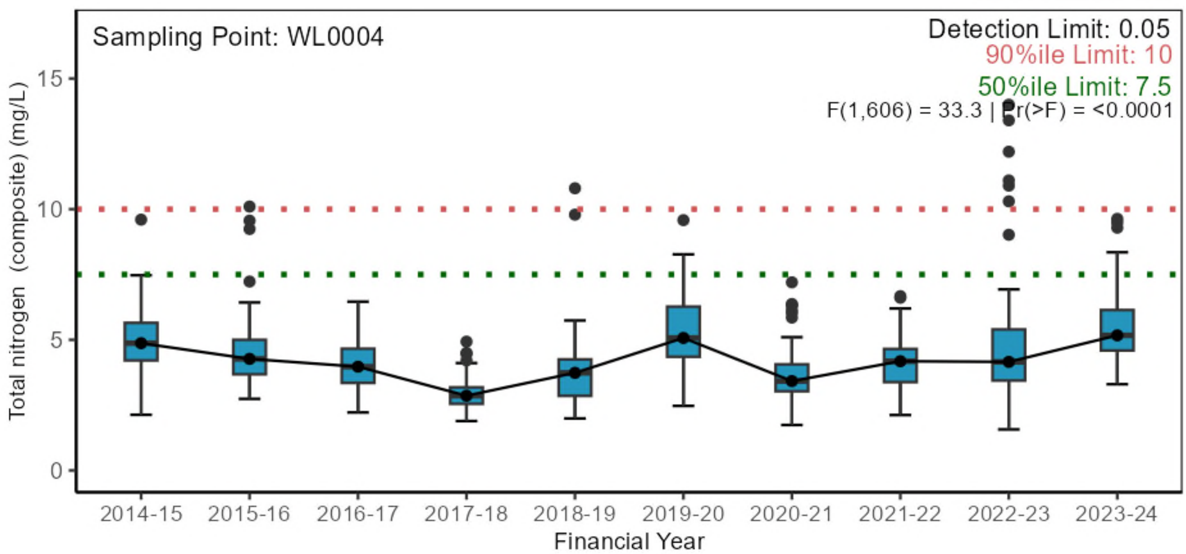
↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge from Wallacia WRRF were within the EPL limits in 2023-24. Statistical analysis identified significant increasing trends in total nitrogen and total phosphorus concentrations in 2023-24 compared to the previous nine years.

The increasing trend in total nitrogen concentrations can be linked to process optimisation in preparation for intermittently decanted aerated lagoon (IDAL) diffuser replacement and increased flows during wet weather. To prevent poor treatment performance observed during the first IDAL diffuser replacement in March 2023 at Wallacia WRRF, operational adjustments in the aeration profile were made to prioritise low ammonia concentration in the final effluent resulting in an increase of total nitrogen concentrations. As treatment performance was notably less effective, original treatment processes were reinstated in April 2024.The second IDAL diffuser was replaced in August 2024.

The increasing trend in total phosphorus concentrations is attributed to wet weather inflows in the second half of the 2023-24 reporting period. Low alkalinity and pH of the wastewater during wet weather resulted in the need to reduce ferric chloride dosing, limiting phosphorus removal in the final effluent.





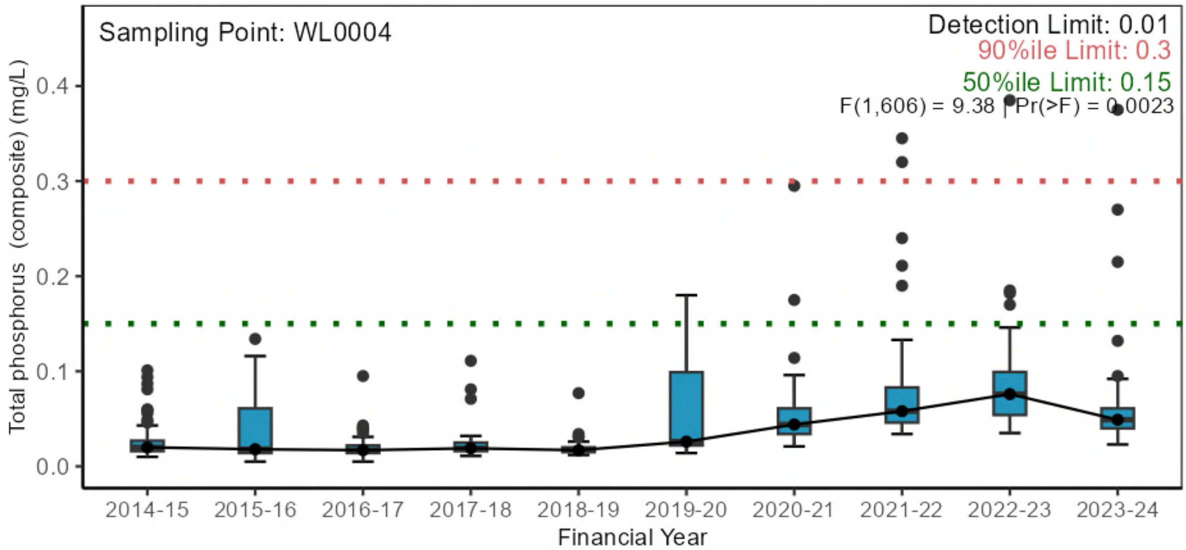


Figure 4-15 Wallacia WRRF treated discharge quality exceptions

Stressor – Water quality

Table 4-19 Gate 1 Analysis outcome summary – water quality upstream Nepean River proxy site and Warragamba River downstream of Wallacia WRRF discharge

Wallacia WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
River	Upstream proxy river (N67)	→	→	→	→	→	→	→	→	→	→	→
	Downstream river (N641)	→	→	→	→	→	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Wallacia WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
River	Upstream vs downstream current year (N67 vs N641)	-	U	U	-	-	U	-	D	D	-	-

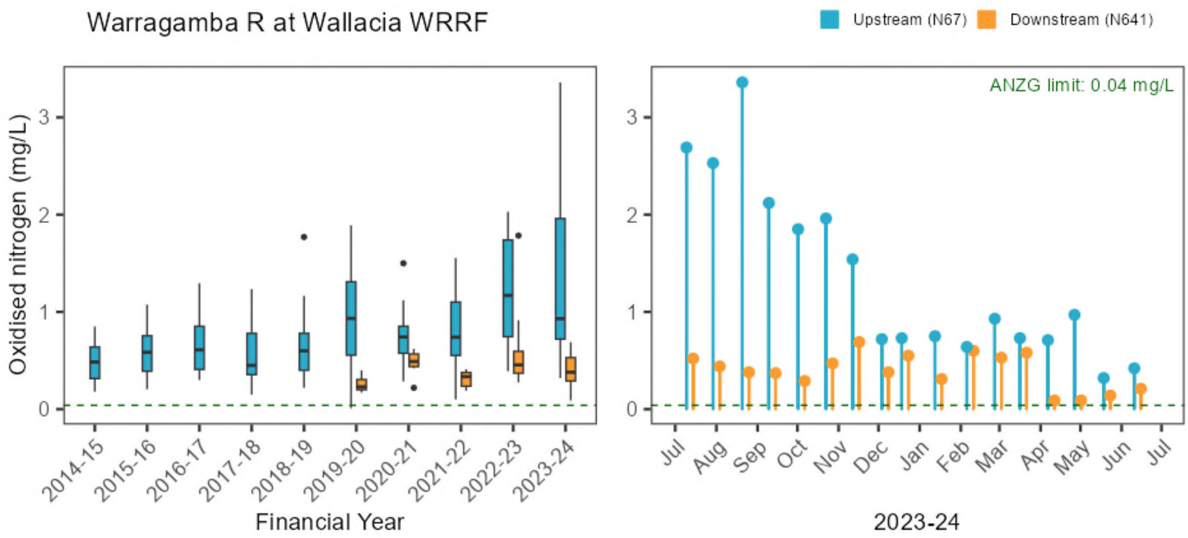
D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

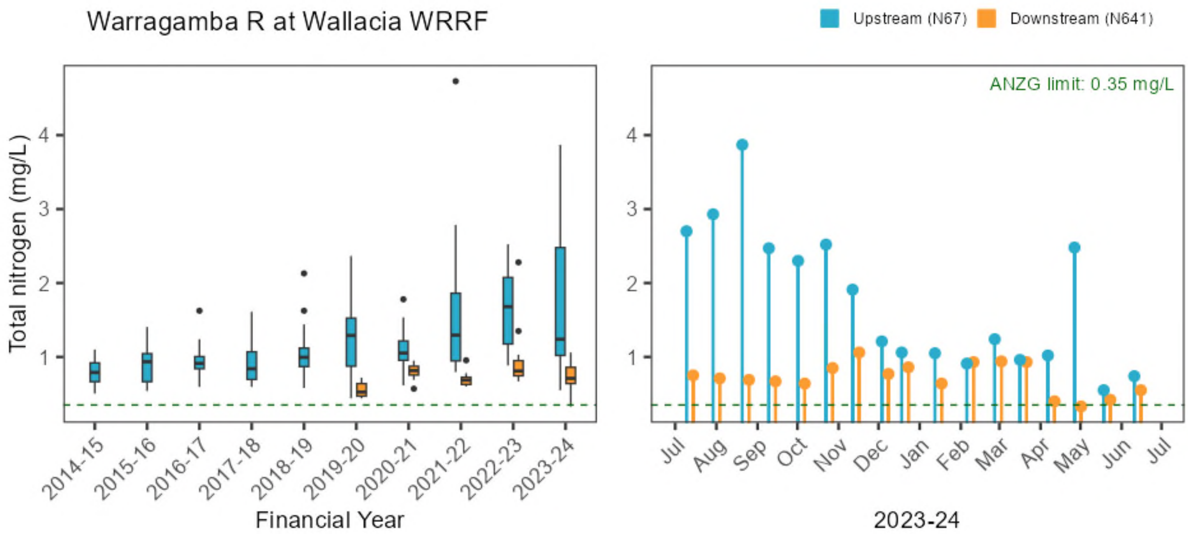
Wallacia WRRF discharges directly into Warragamba River which joins with the Nepean River. The water quality of this site is also influenced by environmental water releases from Warragamba Dam and urban run-off from Warragamba township draining via Megarritys Creek. The upstream control site for the Warragamba River is located downstream of Megarritys Creek and could not be sampled in 2023-24. Data from a nearby upstream Nepean River site was used as proxy site for comparison only. Therefore, effectively it was not possible to determine the impact of Wallacia WRRF on receiving water quality from the data set of these paired sites.

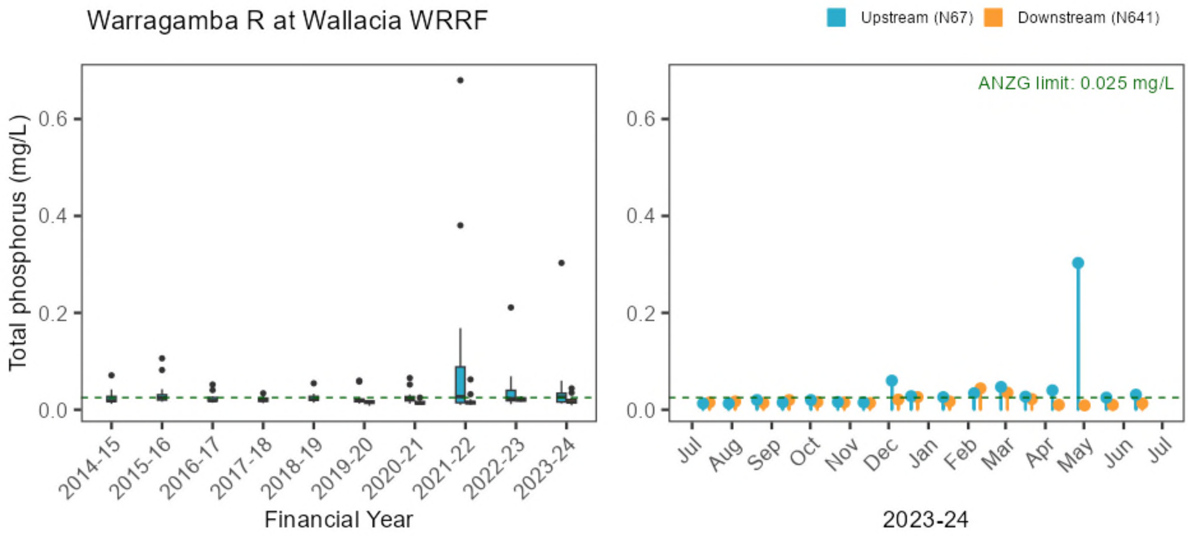
In 2023-24, none of the sites showed a statistically significant temporal trend for any nutrients or physico-chemical analytes in comparison to the previous years. Although the trends were steady, it is not possible to determine the impact of increasing nitrogen or phosphorus in Wallacia discharges on downstream receiving water quality over time due to using a proxy upstream control site.

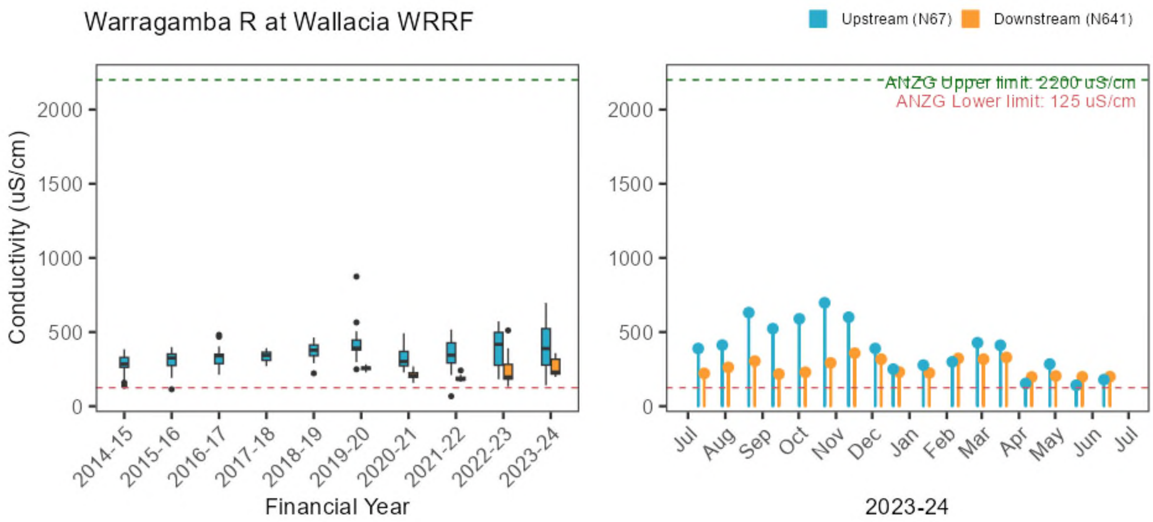
Median oxidised and total nitrogen concentrations exceeded the respective guidelines at both the upstream (Nepean) and downstream (Warragamba) sites. The median total phosphorus concentration also exceeded the guideline at the upstream Nepean River site.

Oxidised and total nitrogen concentrations at the Nepean River proxy site were significantly higher than the Warragamba River site, indicating a localised influence from other upstream sources. Conductivity was also significantly higher at the upstream Nepean River proxy site. Dissolved oxygen saturation and pH were significantly higher at the Warragamba River site.






Warragamba R at Wallacia WRRF
Upstream (N67)
Downstream (N641)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
0.0
0.2
0.4
0.6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Warragamba R at Wallacia WRRF
Upstream (N67)
Downstream (N641)
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Conductivity (uS/cm)
0
500
1000
1500
2000
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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May
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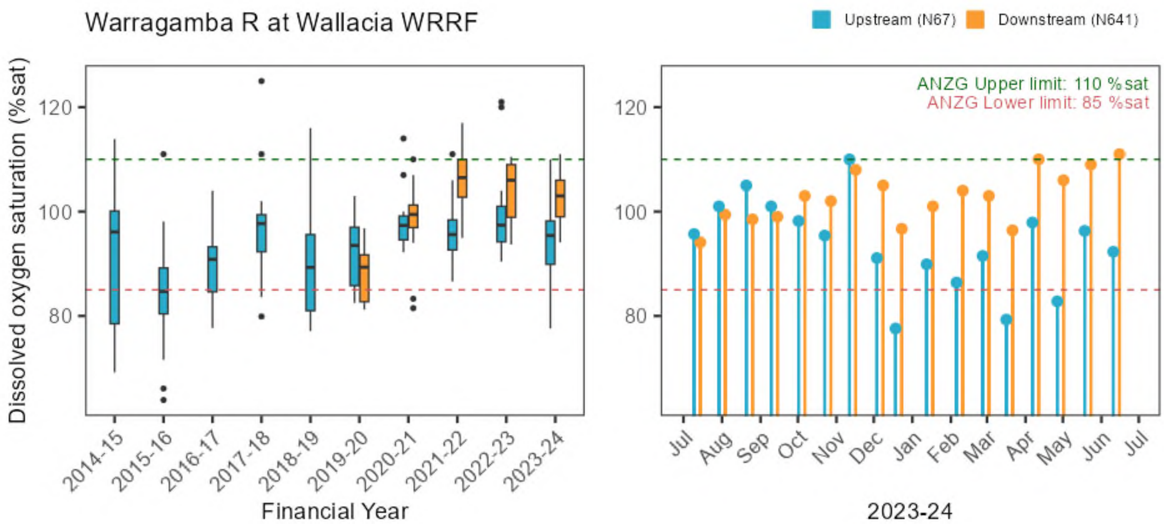
Jul
2023-24


Warragamba R at Wallacia WRRF
Upstream (N67)
Downstream (N641)
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
Dissolved oxygen saturation (%sat)
80
100
120
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

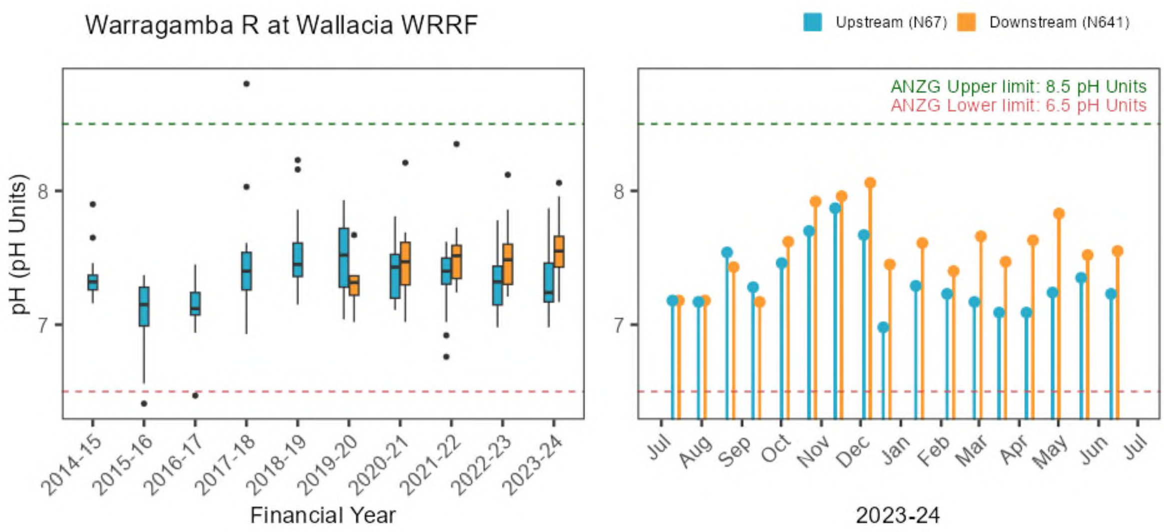


Figure 4-16 Nutrients and physico-chemical water quality exception plots, upstream Nepean River proxy site and Warragamba River downstream of Wallacia WRRF

Ecosystem Receptor – Phytoplankton

Table 4-20 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream Nepean River proxy site and Warragamba River downstream of Wallacia WRRF treated discharge

Statistical comparison (single site current vs past)	Chlorophyll-a
Proxy upstream river (N67)	→
Downstream river (N641)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Proxy upstream vs downstream river (N67 vs N641)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there was no significantly increasing or decreasing trend identified for chlorophyll- a in the proxy upstream or downstream sites in comparison to previous years. No impact on ecosystem receptor i.e. chlorophyll-a as phytoplankton could be determined.

The median chlorophyll-a concentrations were higher than the ANZG (2018) guideline limit at both the proxy upstream and downstream site.

Statistical analysis confirmed that there was no significant difference in 2023-24 chlorophyll-a concentrations between the proxy Nepean River and Nepean River sites.

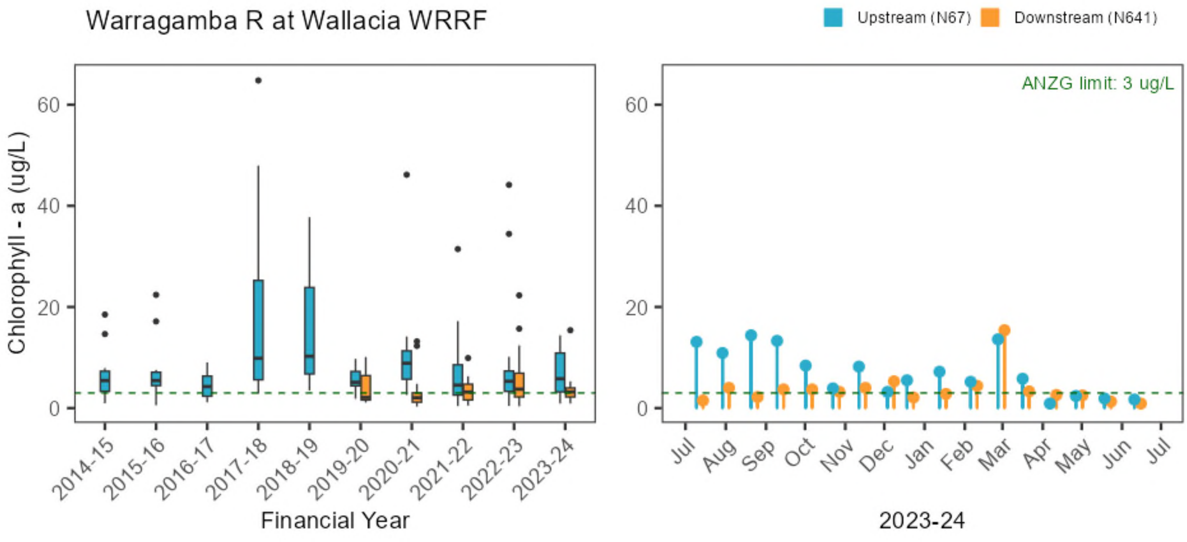


Figure 4-17 Phytoplankton as chlorophyll-a exception plots, upstream Nepean River proxy site and Warragamba River downstream of Wallacia WRRF

Ecosystem Receptor – Macroinvertebrates

As the site upstream of Wallacia WRRF was not accessible due to persistent high flows, the nearby upstream/SoE site (N67) along the Nepean River was used as a proxy upstream site. The 2023-24 macroinvertebrate results suggested a decline in stream health downstream of Wallacia WRRF relative to the proxy upstream site.

Table 4-21 Gate 1 Analysis outcome summary for macroinvertebrates – upstream Nepean River proxy site and downstream site Warragamba River at Wallacia WRRF

Statistical comparison (paired sites current year)	SIGNAL
Proxy upstream vs downstream river (N67 vs N641)	D

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

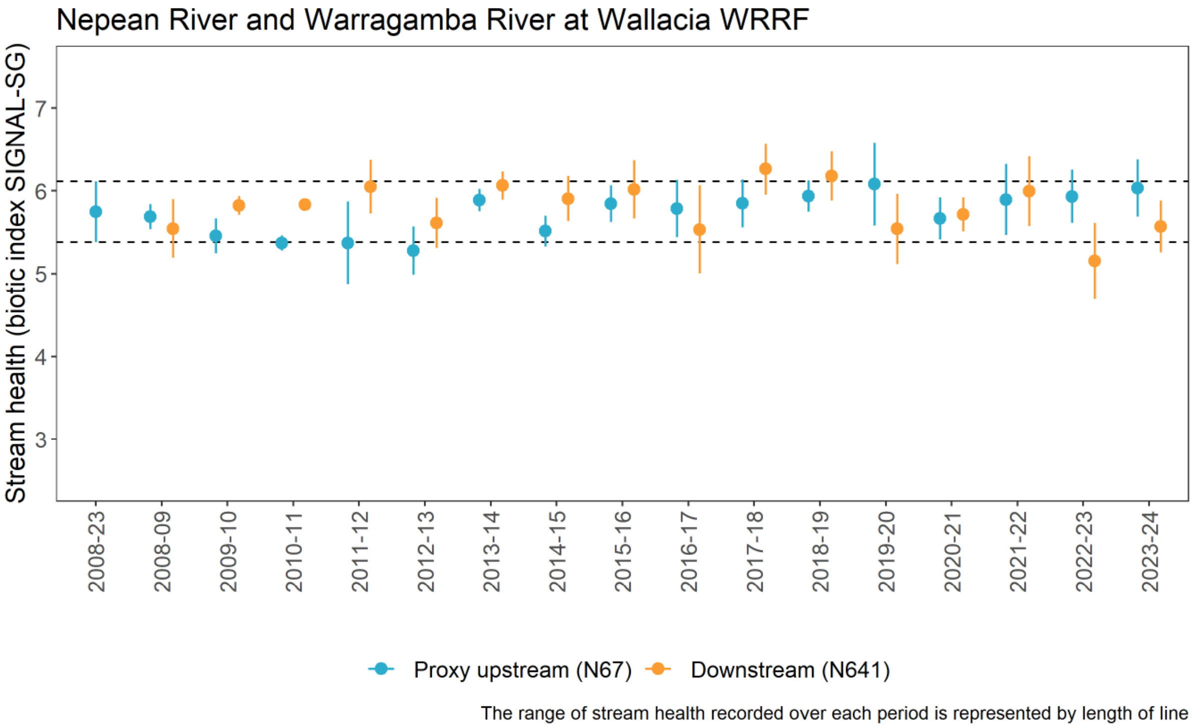


Figure 4-18 Stream health of waterways upstream and downstream of Wallacia WRRF

Gate 2 – Synthesis of impact of Wallacia WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as Chlorophyll-a	Macroinvertebrates	
	Effluent	Proxy us vs ds			
Ammonia nitrogen	→	-	-	D	The impact of increased nitrogen and phosphorus concentrations in Wallacia WRRF discharges on downstream receiving water could not be effectively determined because of missing data for the upstream site. Stream health as indicated by macroinvertebrates was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		U			
Total nitrogen	↗	U			
Filterable total phosphorus		-			
Total phosphorus	↗	-			
Conductivity		U			
Dissolved oxygen		-			
Dissolved oxygen saturation		D			
pH		D			
Temperature		-			
Turbidity		-			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.4. Penrith WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Penrith WRRF in 2023-24 were within EPL limits. There were increasing trends in total nitrogen, total phosphorus, faecal coliforms and copper concentrations in the treated discharge compared to the last nine years.
- Total ammonia nitrogen concentrations significantly increased and dissolved oxygen concentrations decreased in the upstream receiving waterway control site in Boundary Creek in 2023-24 compared to last five years. Two separate sewer overflow incidents (October and December 2023) corresponded with increased nutrients and other analytes at this upstream site.
- The upstream control site in the Nepean River showed a significant increase in oxidised and total nitrogen concentrations but a decrease in filterable total phosphorus concentration in 2023-24 compared to last five years.
- Oxidised nitrogen was significantly higher at the downstream Boundary Creek site compared to the upstream site, showing a link with the elevated nitrogen discharges from Penrith WRRF. Total ammonia nitrogen, filterable total phosphorus and total phosphorus concentrations were significantly higher at the upstream Boundary Creek site compared to the downstream site, indicating an impact from the two sewer overflows or other non-point sources.
- Total ammonia nitrogen concentrations were significantly higher in the downstream Nepean River site compared to upstream concentrations.
- Chlorophyll-a remained elevated at the upstream creek site and was significantly higher in comparison to the downstream site, suggesting routine discharge flow from Penrith WRRF had a positive influence by diluting or displacing phytoplankton further downstream.
- Stream health, as indicated by macroinvertebrates, was impacted at the upstream catchment site. Stream health improved downstream with no measurable impact from Penrith WRRF discharge.

Pressure – Wastewater discharge

Table 4-22 Gate 1 Analysis outcome summary – Penrith WRRF

Analytes / Penrith WRRF	Nutrients			Conventional analytes				
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration	→	↗	↗	→	↗		→	→
Load								

Analytes / Penrith WRRF	Trace Metals									Other	
	Aluminium	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Selenium	Zinc	Hydrogen sulfide (un-ionised)	Pesticides and PCBs
Concentration	→	→		↗	→				→	→	
Load											

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

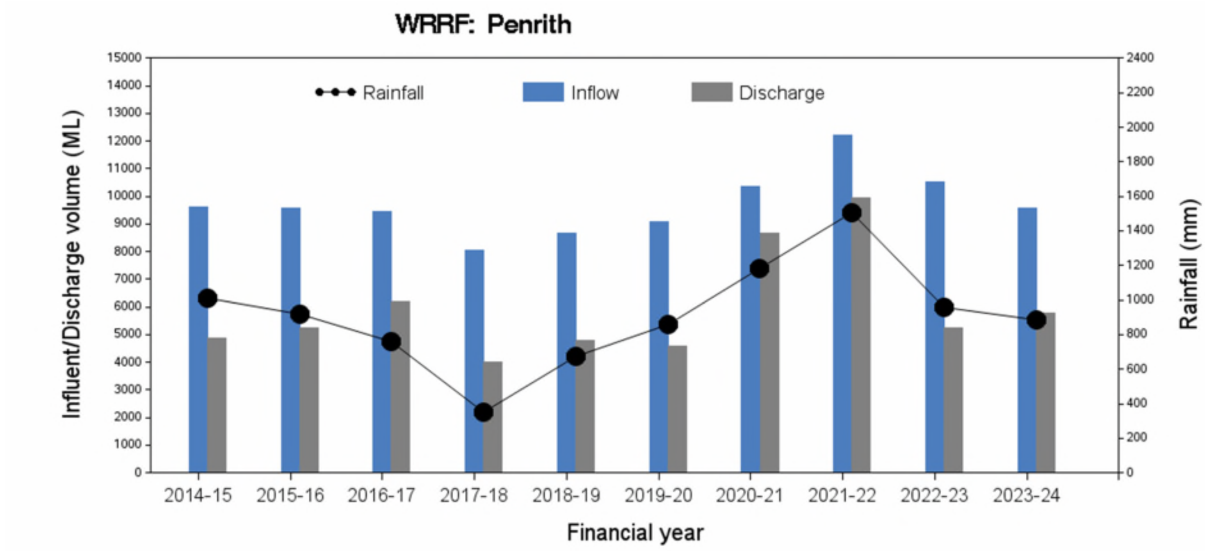
All concentration and load levels in the treated discharge from Penrith WRRF were within EPL limits in the 2023-24 reporting period.

Statistical analysis identified a significantly increasing trend in total nitrogen, total phosphorus, faecal coliforms and copper concentrations in the treated discharge compared to the previous nine years.

The increasing trend in total nitrogen and phosphorus can be attributed to the Stage 7 Biological Nutrient Removal (BNR) reactor refurbishment works, where treatment processes were offline during the entire 2023-24 reporting period with expected completion late 2025. The upgrade will improve performance and reliability, enable the plant to operate at its full capacity and service forecasted wastewater inflows (subject to future growth) and ensure improved process control, energy savings and reliable total nitrogen performance.

The increasing trend in faecal coliforms can be attributed to wet weather events whilst Penrith WRRF is operating at reduced treatment capacity because of the BNR refurbishment works. The increasing copper trend can also be attributed to the reduced treatment performance. Penrith WRRF has historically had effective copper removal through its treatment process despite processes not designed for metal removal.

Approximately half of the total tertiary treated effluent flow from Penrith WRRF during the 2023-24 reporting period was transferred to St Marys AWTP for additional treatment (including ultra filtration and reverse osmosis) before being discharged into Boundary Creek. There was minimal offsite reuse during the 2023-24 reporting period due to the continuation of wet weather patterns. Since 2021, there has been a reduced demand from the community for irrigation water.



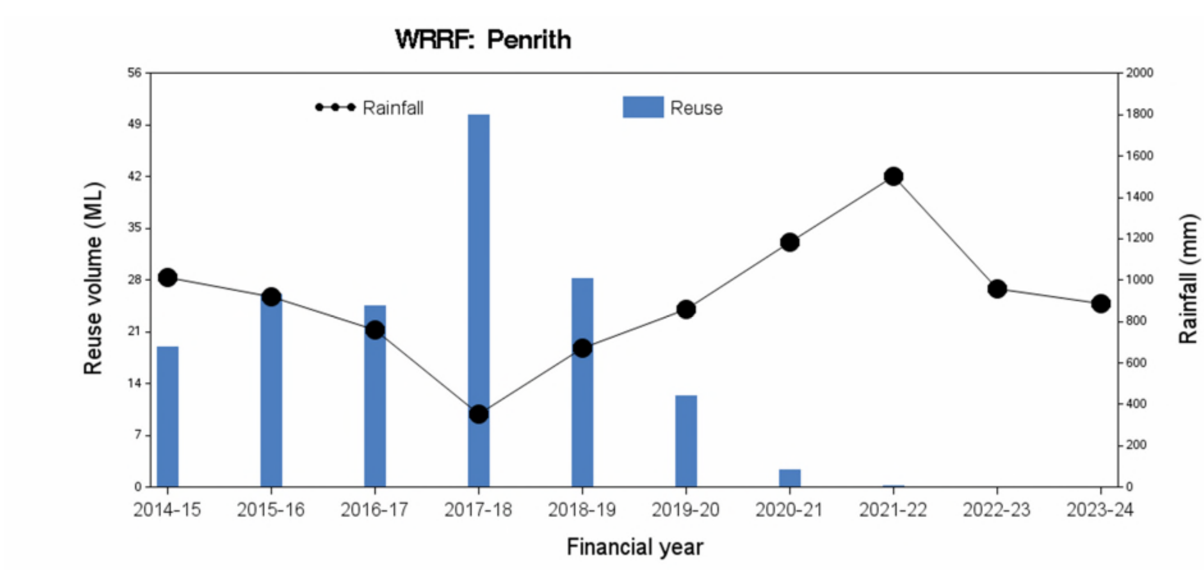
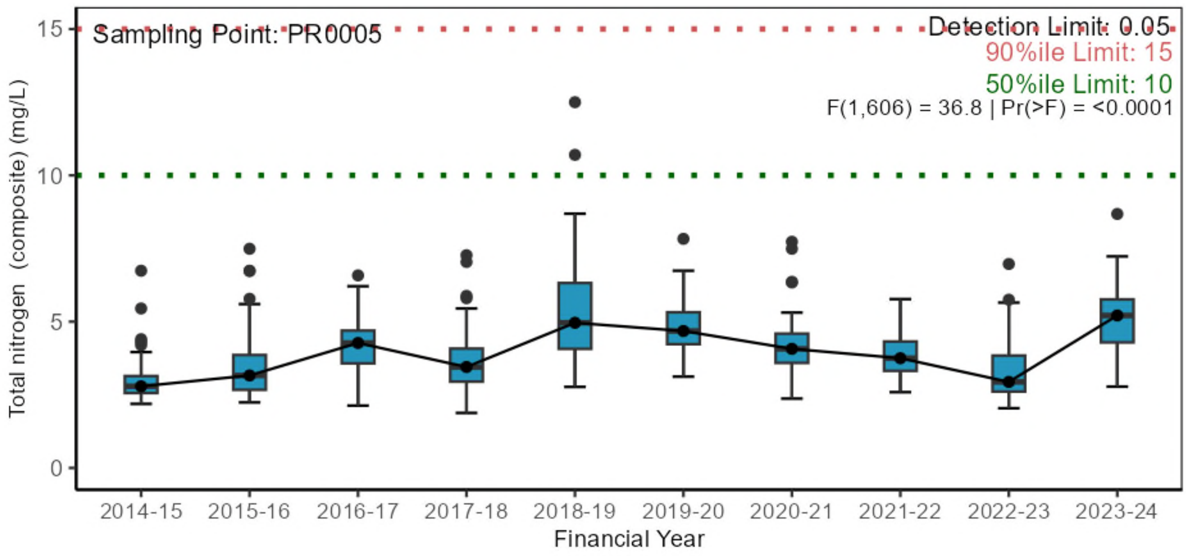
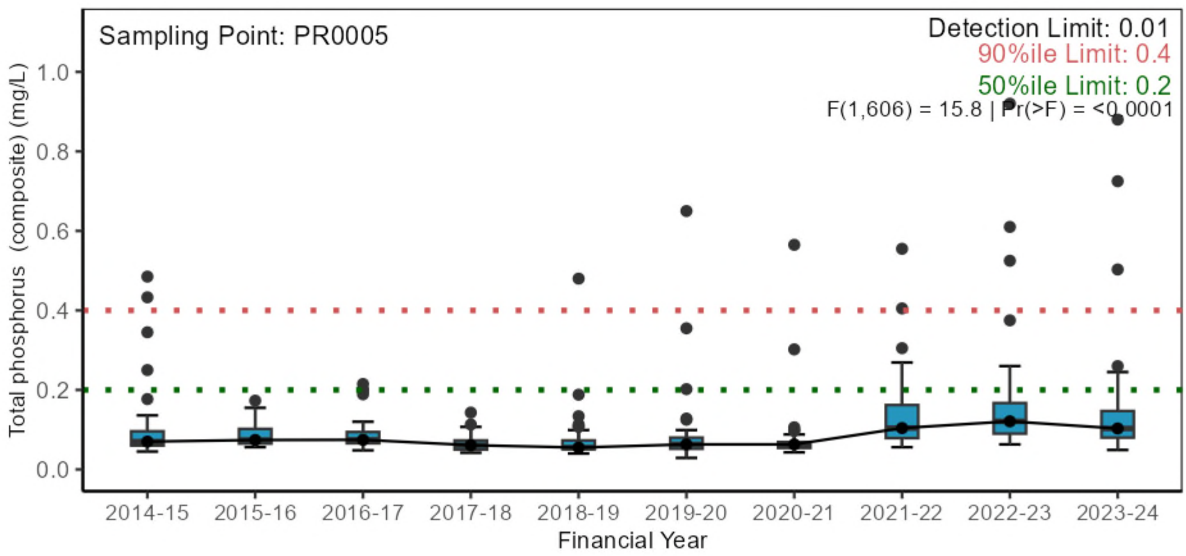
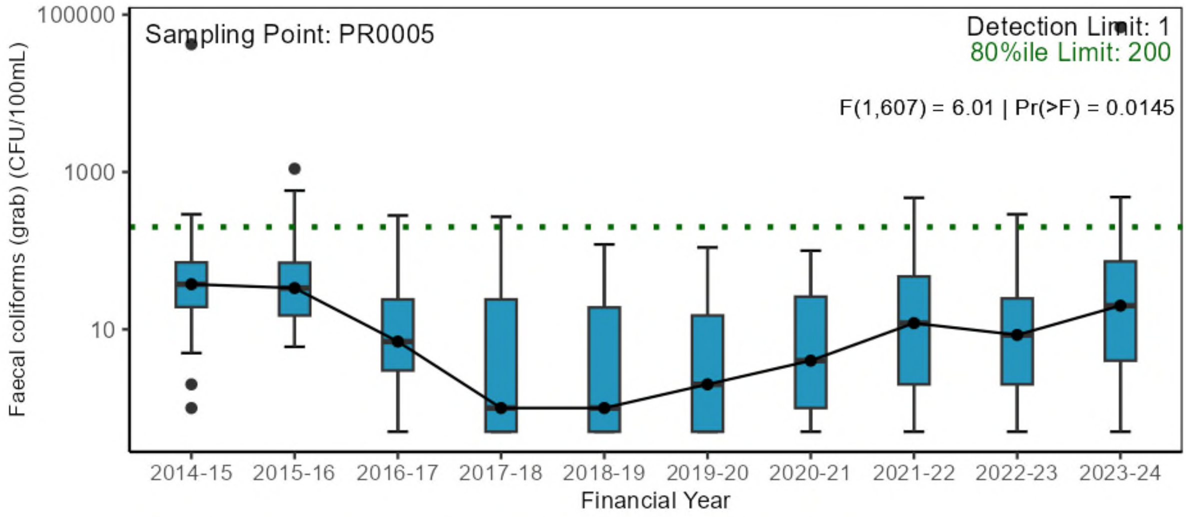


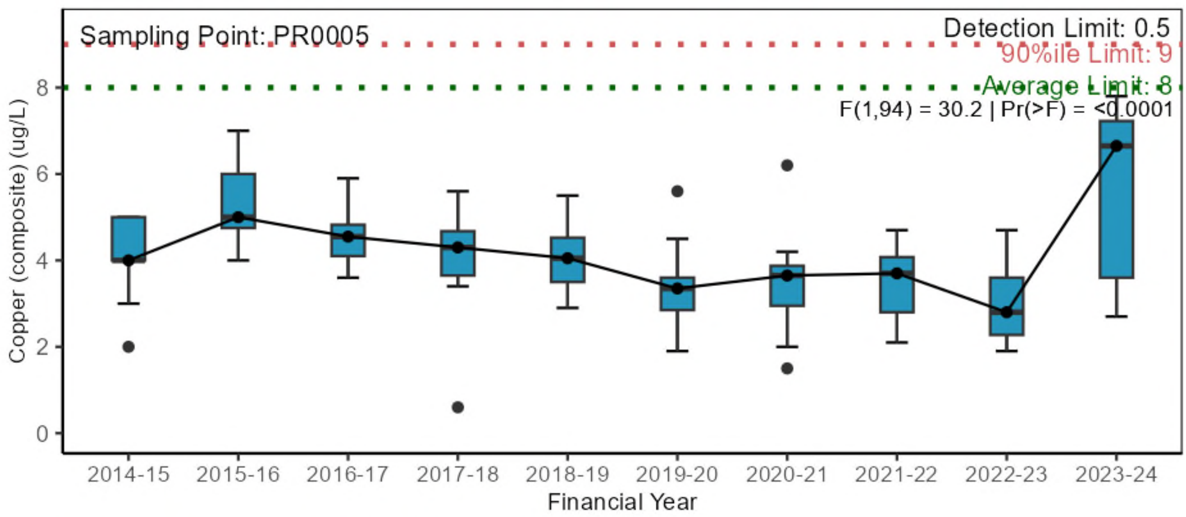
Figure 4-19 Penrith WRRF inflow, discharge and reuse volume with catchment rainfall


Sampling Point: PR0005
Detection Limit: 0.05
90%ile Limit: 15
50%ile Limit: 10
F(1,606) = 36.8 | Pr(>F) = <0.0001
Total nitrogen (composite) (mg/L)
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: PR0005
Detection Limit: 0.01
90%ile Limit: 0.4
50%ile Limit: 0.2
F(1,606) = 15.8 | Pr(>F) = <0.0001
Total phosphorus (composite) (mg/L)
1.0
0.8
0.6
0.4
0.2
0.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Data has been log10 transformed and y-axis backtransformed for ease of interpretation.



Statistical test excludes data prior to 2016-17 due to method detection limit change.

Figure 4-20 Penrith WRRF treated discharge and reuse quality exceptions plots

Stressor – Water quality

Table 4-23 Gate 1 analysis outcome summary for water quality – upstream and downstream of Penrith WRRF

Penrith WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Water temperature	Turbidity
Tributary	Upstream tributary (N542)	↗	→*	→*	→	→*	→	↘	↘*	↘	→	→
	Downstream tributary (N541)	→	→*	→*	→	→*	→	→	→	→	→	→*
River	Upstream river (N57)	→	↗*	↗*	↘	→	↗	→	→	→	→	→*
	Downstream river (N53)	→	→*	→*	→	→	→	→	→	→	→	→*

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	Median value outside the guideline limit in 2023-24				

(* = cell shaded yellow: median value outside the guideline limit in 2023-24)

Penrith WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Water temperature	Turbidity
Tributary	Upstream vs downstream current year (N542 vs N541)	U	D	-	U	U	U	D	-	-	-	U
River	Upstream vs downstream current year (N57 vs N53)	D	-	-	-	-	-	-	-	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

Penrith WRRF discharges into Boundary Creek that flows into the Nepean River downstream of Penrith Weir. Water quality at the upstream control site in Boundary Creek (N542) is influenced by urban run-off and also has a history of sewer overflows. The upstream Nepean River control site at Penrith Weir (N57) is mixed including new urban residential housings, rural, agricultural and protected catchment/national park. The Warragamba River joins the Nepean River about 18 km upstream of Penrith Weir. The Warragamba River receives discharge from Wallacia WRRF and environmental flow releases from Warragamba Dam.

There were two separate sewer overflow incidents in the immediate upstream catchment of Boundary Creek site (N542) prior to sampling on 4 October 2023 and 6 December 2023. All nutrient analytes concentrations were elevated on these days: total ammonia nitrogen 37.8 and 32.0 mg/L; total nitrogen 47.7 and 41.4 mg/L; soluble reactive phosphorus 4.54 and 3.69 mg/L; filterable total phosphorus 4.92 and 4.15 mg/L and total phosphorus 5.64 and 5.58 mg/L. The impact of these incidents was not recognised at the downstream Boundary Creek site (N541) or Nepean River (N53), likely due to dilution from the low nutrient discharges from Penrith WRRF and St Marys AWTP.

The total ammonia nitrogen concentration at the upstream Boundary Creek site (N542) significantly increased fourfold in 2023-24 compared to the previous five years. In contrast, the 2023-24 dissolved oxygen concentration decreased to half (50%) and dissolved oxygen saturation dropped to 36%. pH was also significantly lower at this site. At the downstream creek site (N541), nutrients and physico-chemical analyte levels/ concentrations in 2023-24 were statistically stable.

There was a significant increase in oxidised nitrogen and total nitrogen but a decrease in filterable total phosphorus concentration at the Penrith Weir (N57) upstream Nepean River control site in 2023-24 compared to previous nine years. Conductivity also increased significantly at this site in 2023-24. At the downstream river site (N53), nutrients and physico-chemical analyte levels/concentrations were statistically stable.

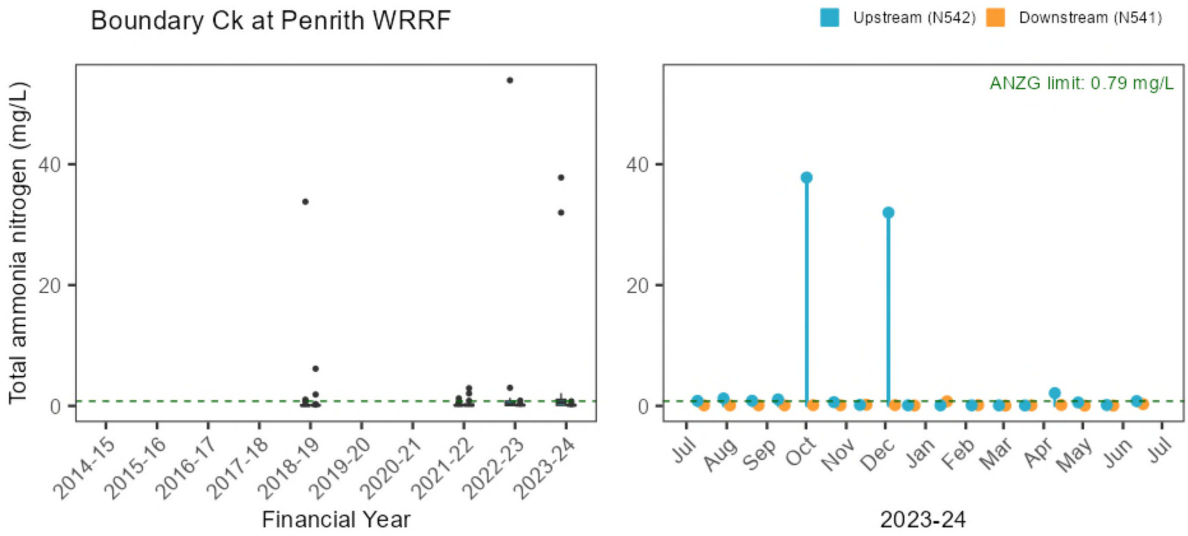
In 2023-24, the median oxidised nitrogen and total nitrogen concentrations at all four upstream and downstream tributary and river sites exceeded the respective ANZG (2018) guideline values. The median total phosphorus concentration for both Boundary Creek sites were higher than the guideline in 2023-24.

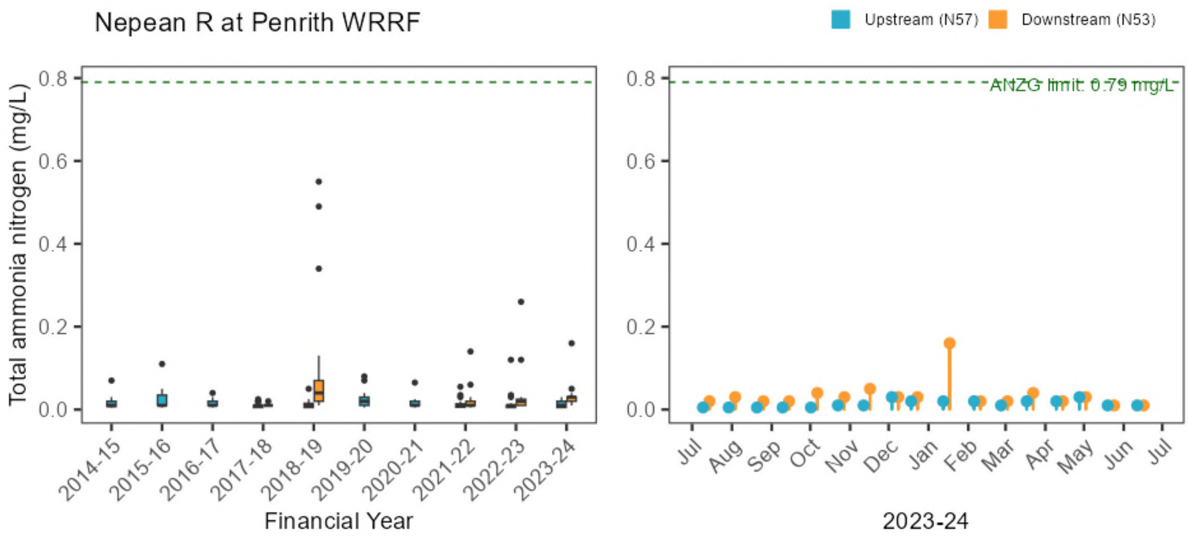
The median dissolved oxygen saturation was less than the lower guideline limit at the upstream Boundary Creek site (N542). Median turbidity was less than the lower guideline at downstream Boundary Creek site (N541) and both Nepean River sites (N57 and N53).

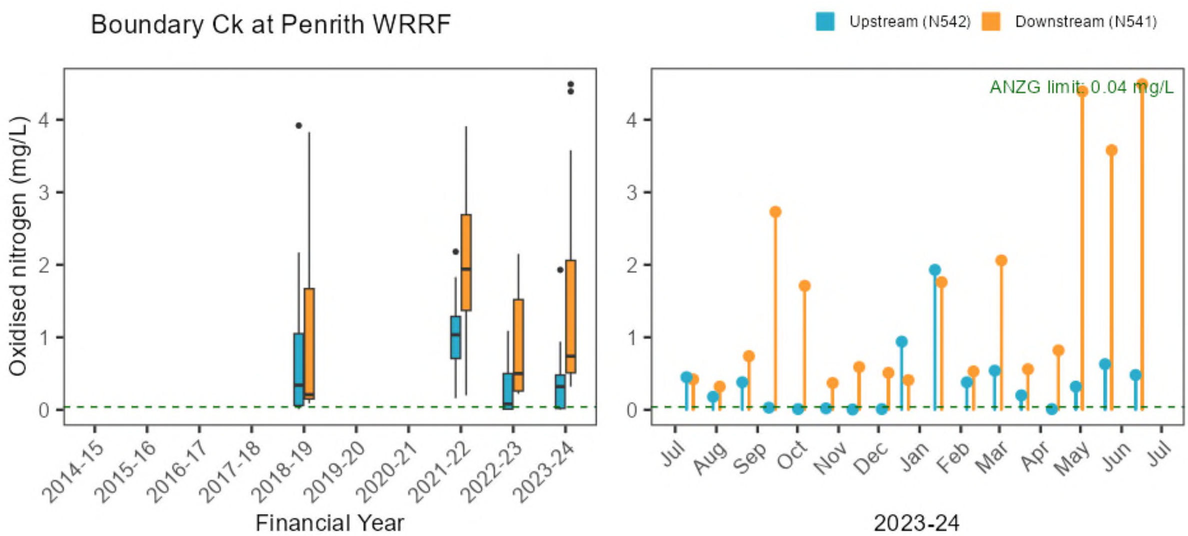
Statistical analysis confirmed that the oxidised nitrogen concentration at the downstream Boundary Creek site (N542) was significantly higher in 2023-24 compared with the upstream concentration. This indicates an impact of from the Penrith WRRF discharge. In contrast, the dissolved oxygen concentration was significantly higher at the downstream Boundary Creek site indicating a benefit from tertiary treated effluent discharged from Penrith WRRF.

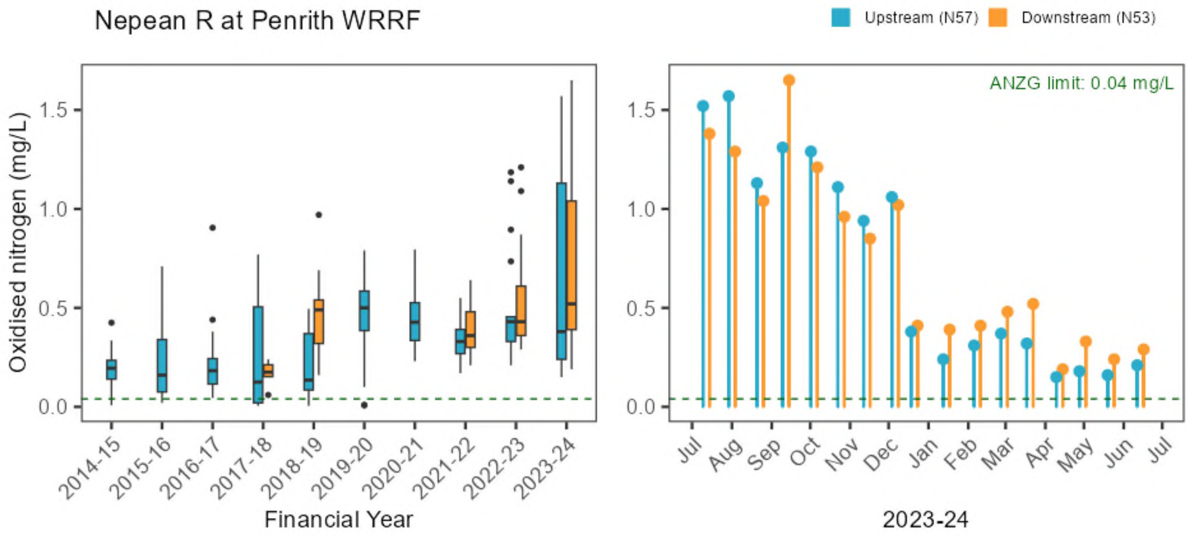
Total ammonia nitrogen, filterable total phosphorus and total phosphorus concentrations were significantly higher at the upstream Boundary Creek site (N542) in 2023-24 compared to downstream site. Conductivity and turbidity were significantly higher at this site. All The upstream Boundary Creek site was impacted by two sewage overflows in 2023-24 and receives run-off from the upstream urbanised catchment.

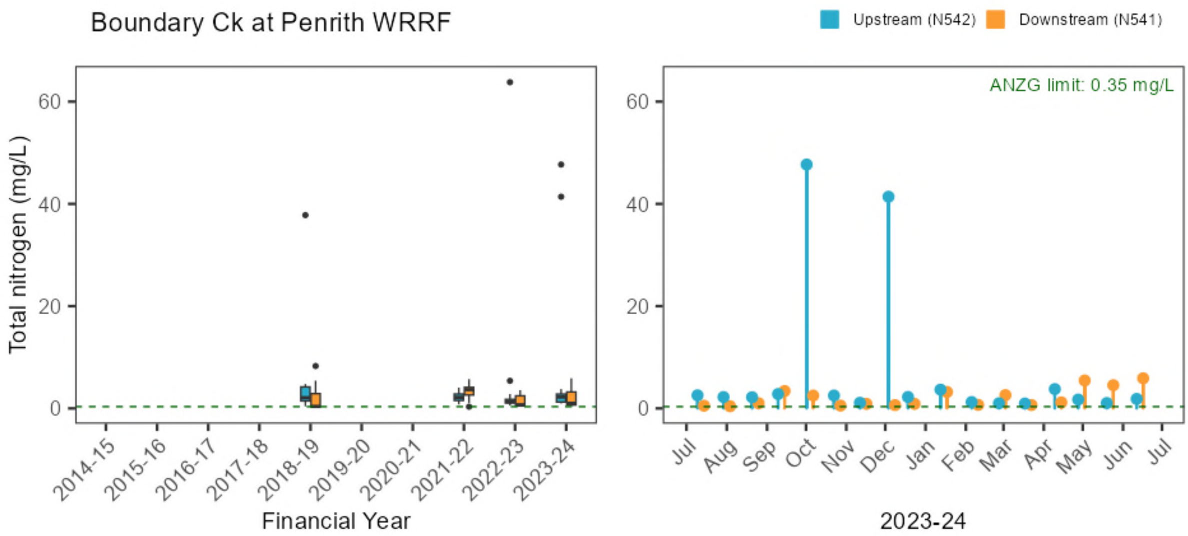
At the downstream Nepean River site (N53), the total ammonia nitrogen concentration were significantly higher in comparison to the upstream concentration. There were no significant differences in the physico-chemical analyte concentrations between the upstream and downstream Nepean River sites in 2023-24.

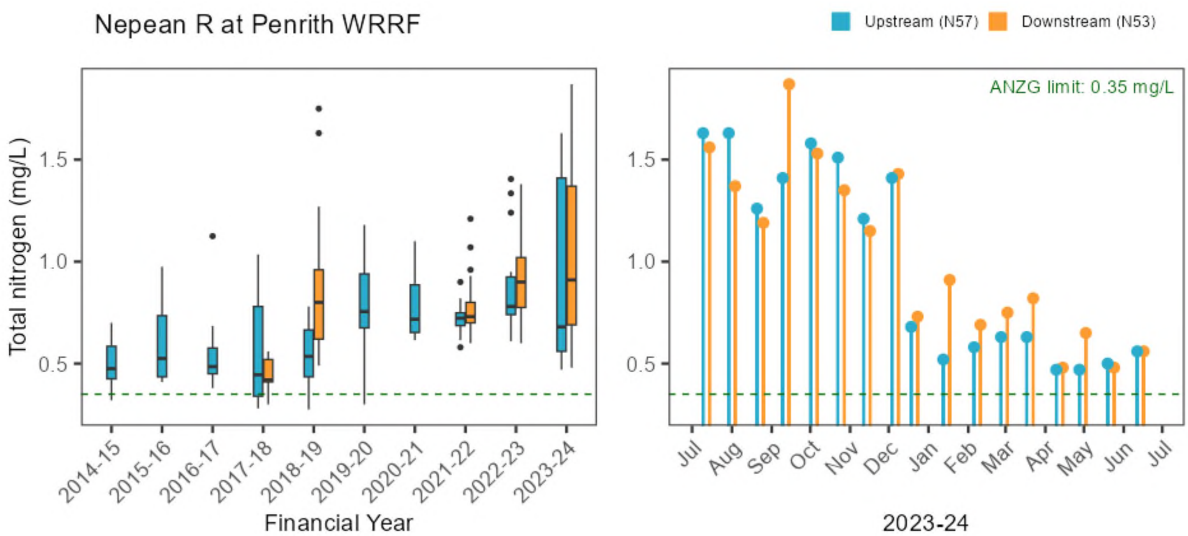

Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
ANZG limit: 0.79 mg/L
Total ammonia nitrogen (mg/L)
Financial Year
2023-24

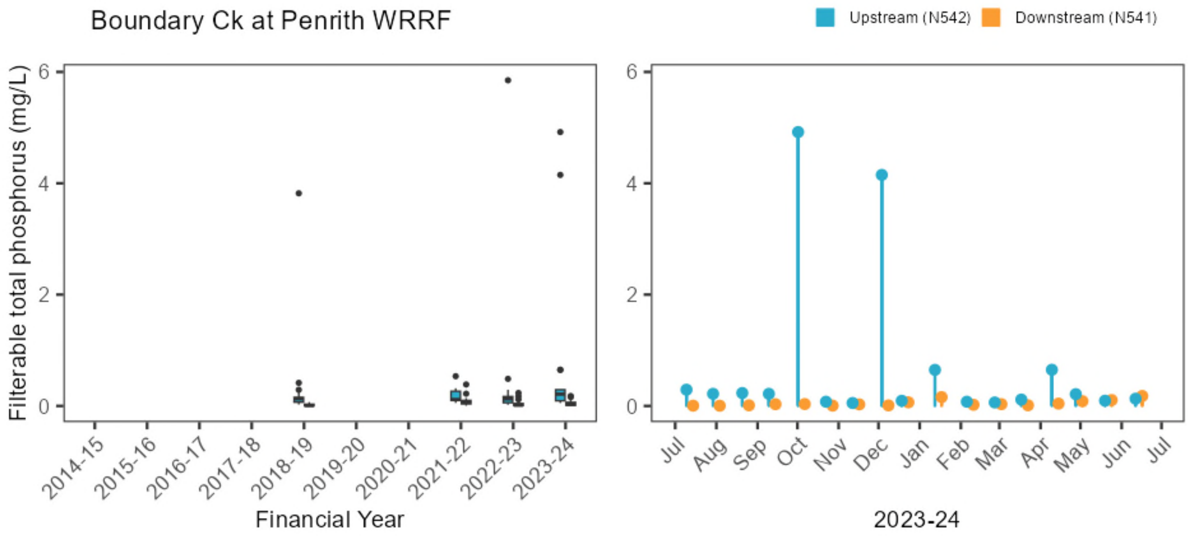

Nepean R at Penrith WRRF
Upstream (N57)
Downstream (N53)
ANZG limit: 0.79 mg/L
Total ammonia nitrogen (mg/L)
Financial Year
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
Financial Year
2023-24


Nepean R at Penrith WRRF
Upstream (N57)
Downstream (N53)
Oxidised nitrogen (mg/L)
ANZG limit: 0.04 mg/L
Financial Year
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
Financial Year
2023-24


Nepean R at Penrith WRRF
Upstream (N57)
Downstream (N53)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
Financial Year
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Filterable total phosphorus (mg/L)
0
2
4
6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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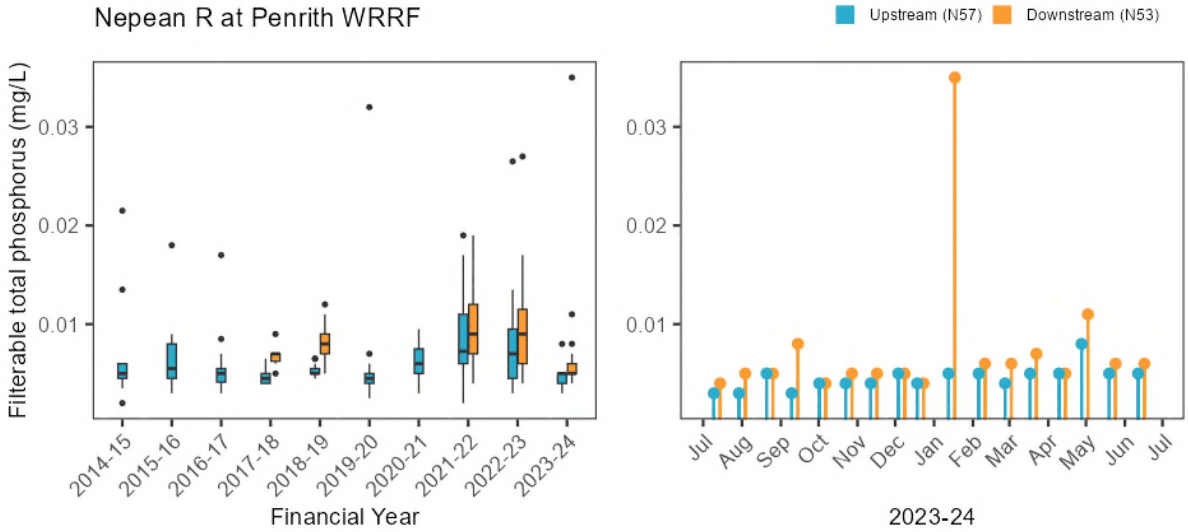
2023-24


Nepean R at Penrith WRRF
Upstream (N57)
Downstream (N53)
Filterable total phosphorus (mg/L)
0.01
0.02
0.03
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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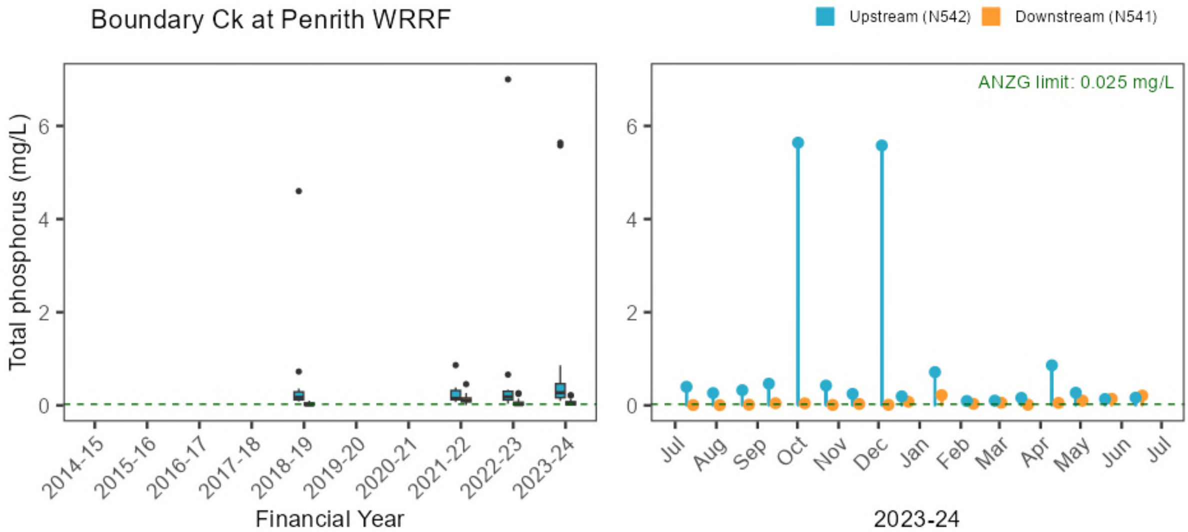
Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Total phosphorus (mg/L)
0
2
4
6
ANZG limit: 0.025 mg/L
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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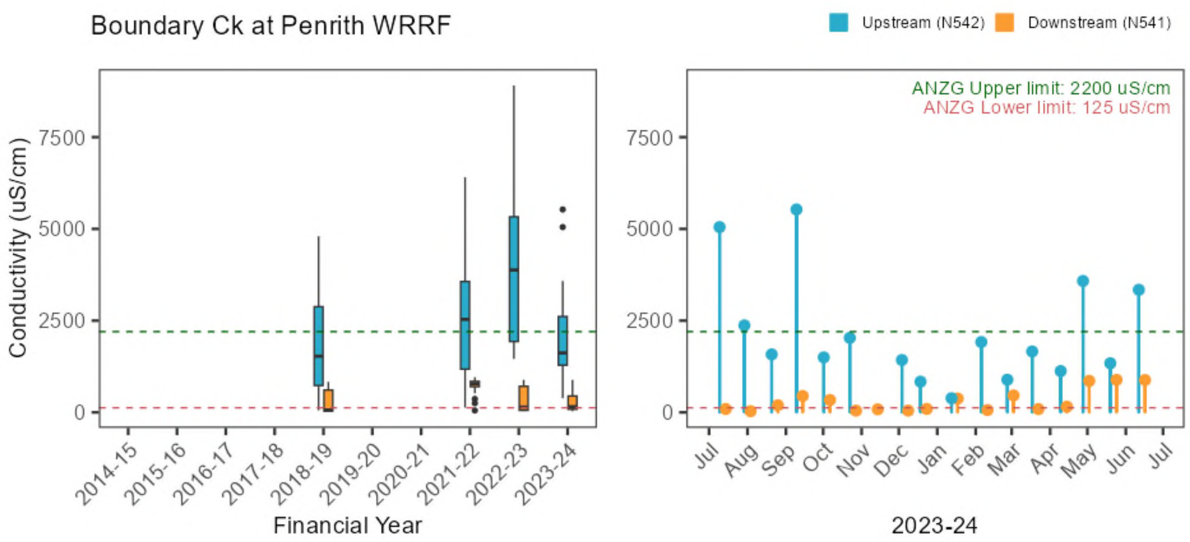
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Conductivity (uS/cm)
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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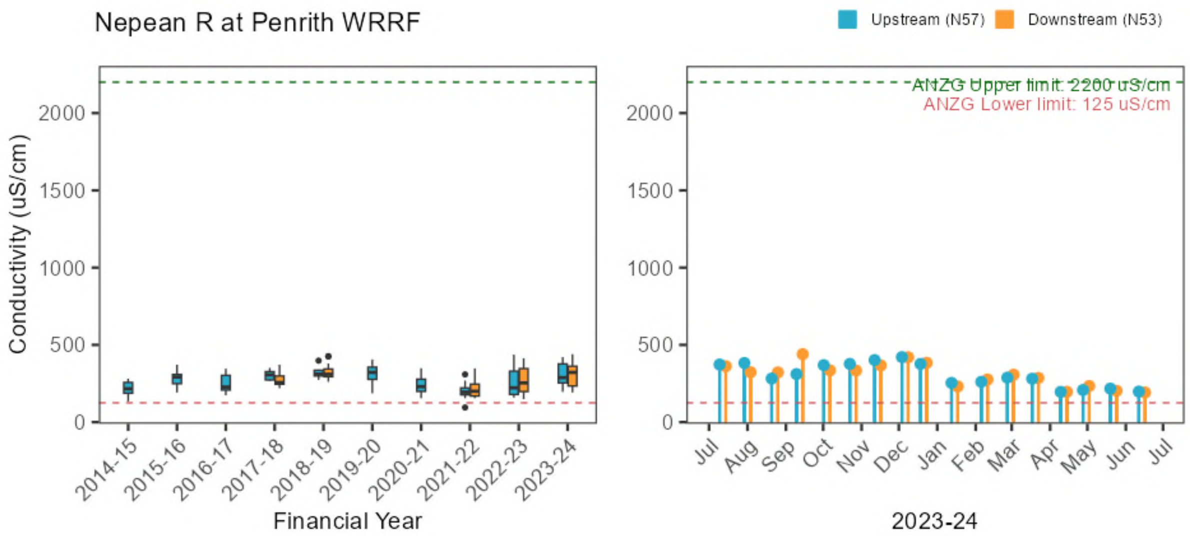
2023-24


Nepean R at Penrith WRRF
Upstream (N57)
Downstream (N53)
Conductivity (uS/cm)
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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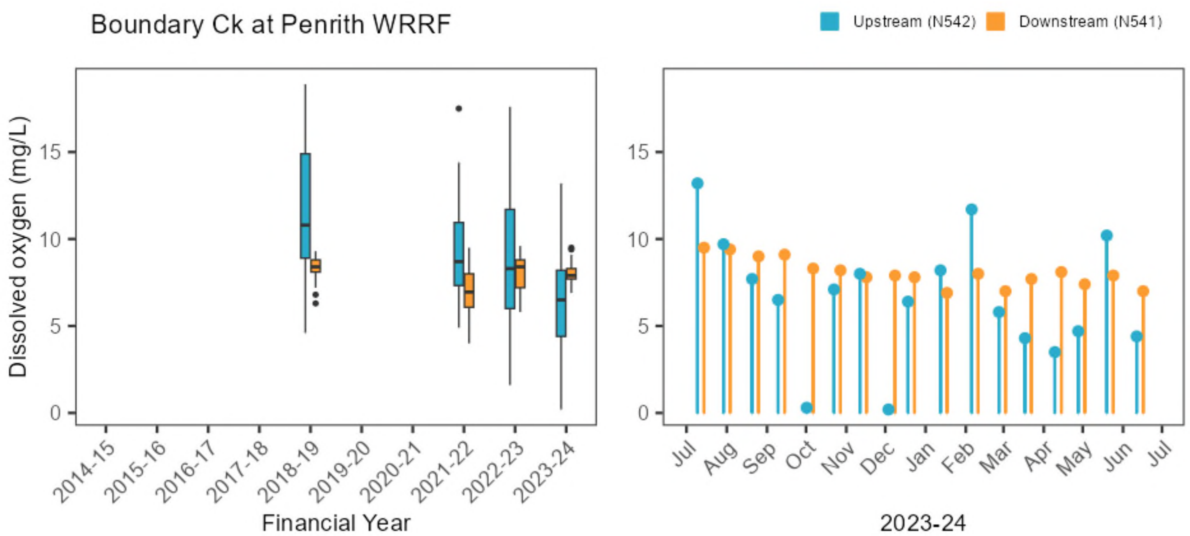
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Dissolved oxygen (mg/L)
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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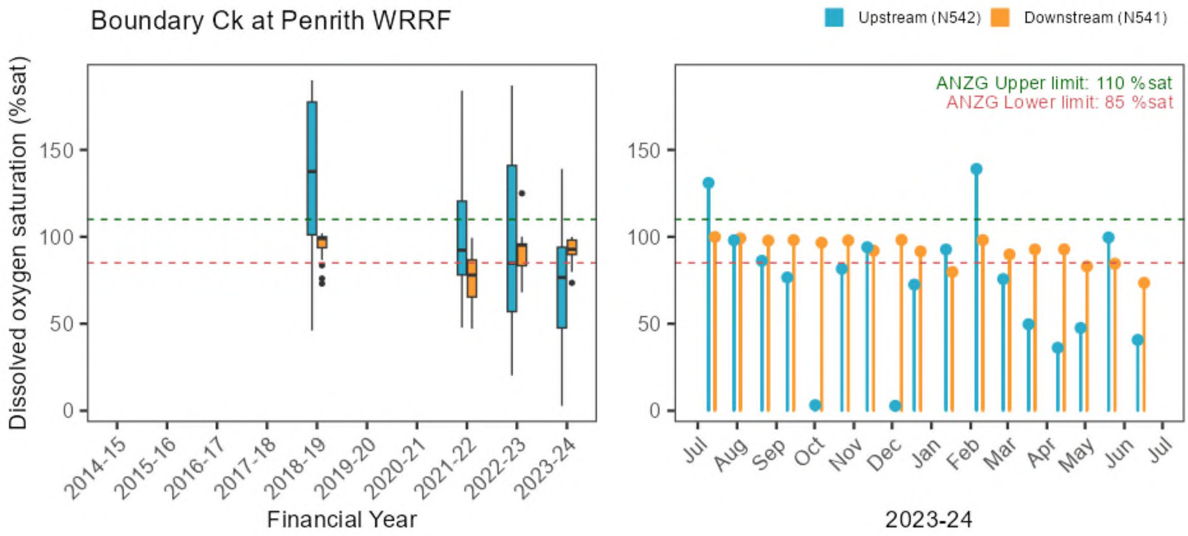
May
Jun
Jul
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Dissolved oxygen saturation (%sat)
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
0
50
100
150
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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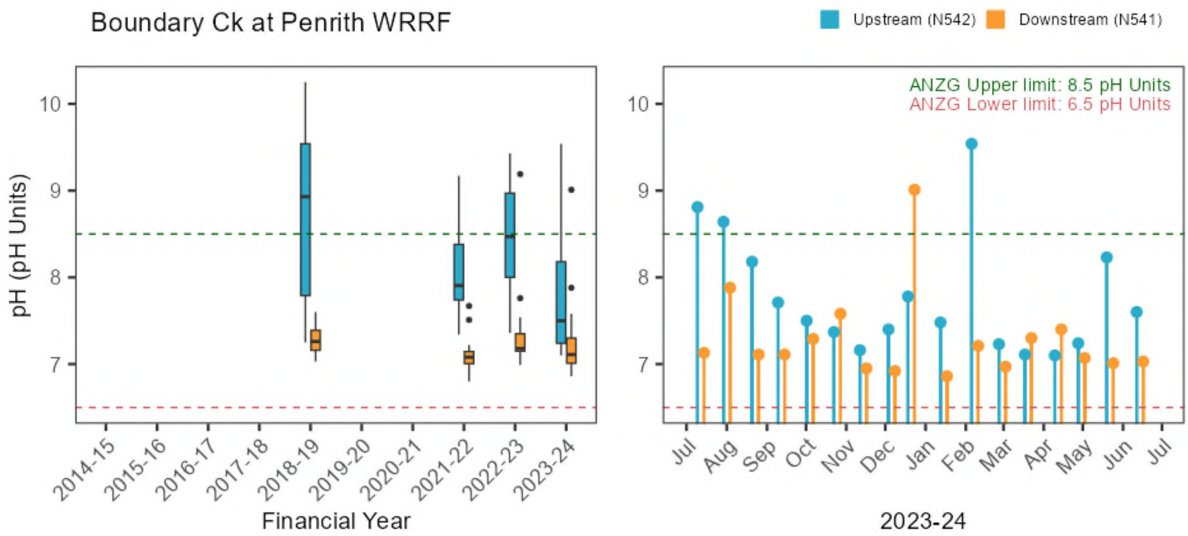
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
pH (pH Units)
ANZG Upper limit: 8.5 pH Units
ANZG Lower limit: 6.5 pH Units
7
8
9
10
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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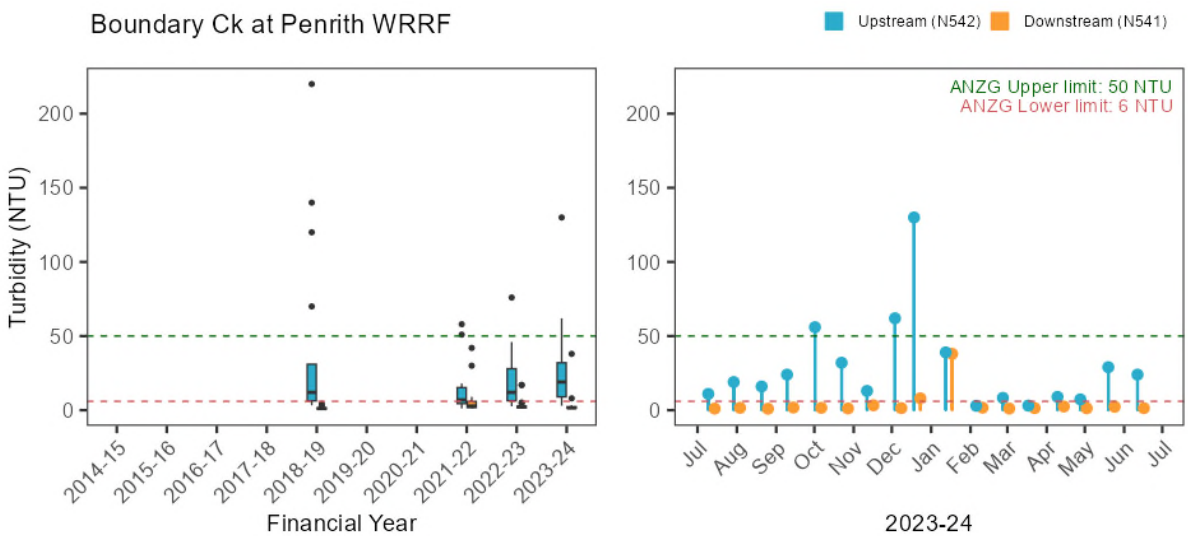
2023-24


Boundary Ck at Penrith WRRF
Upstream (N542)
Downstream (N541)
Turbidity (NTU)
ANZG Upper limit: 50 NTU
ANZG Lower limit: 6 NTU
0
50
100
150
200
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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2023-24

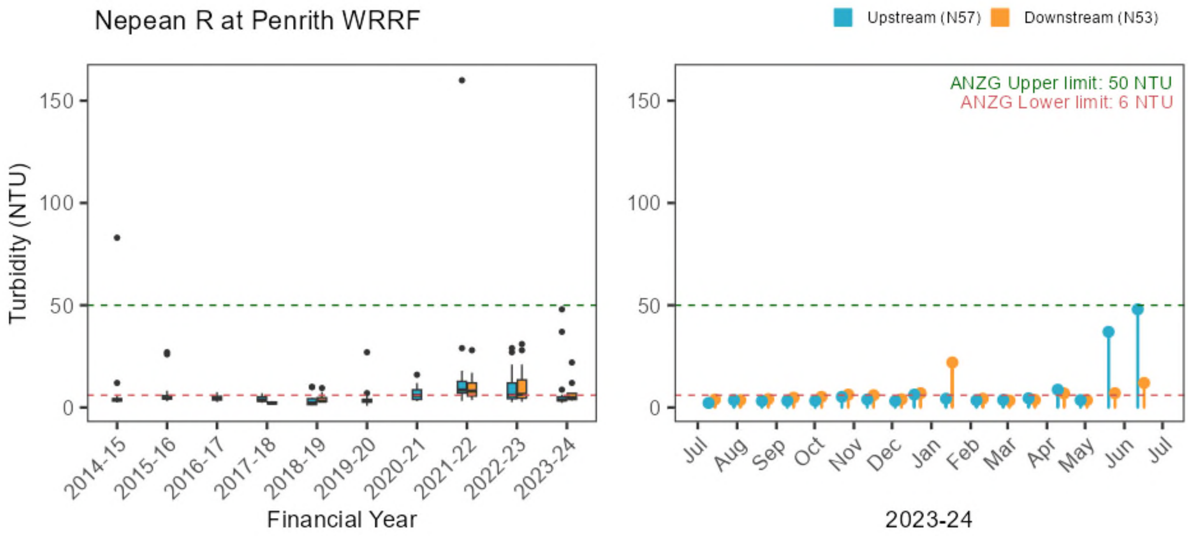


Figure 4-21 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Penrith WRRF

Ecosystem Receptor – Phytoplankton

Table 4-24 Gate 1 analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Penrith WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (N542)	→
Downstream tributary (N541)	→
Upstream river (N57)	→
Downstream river (N53)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

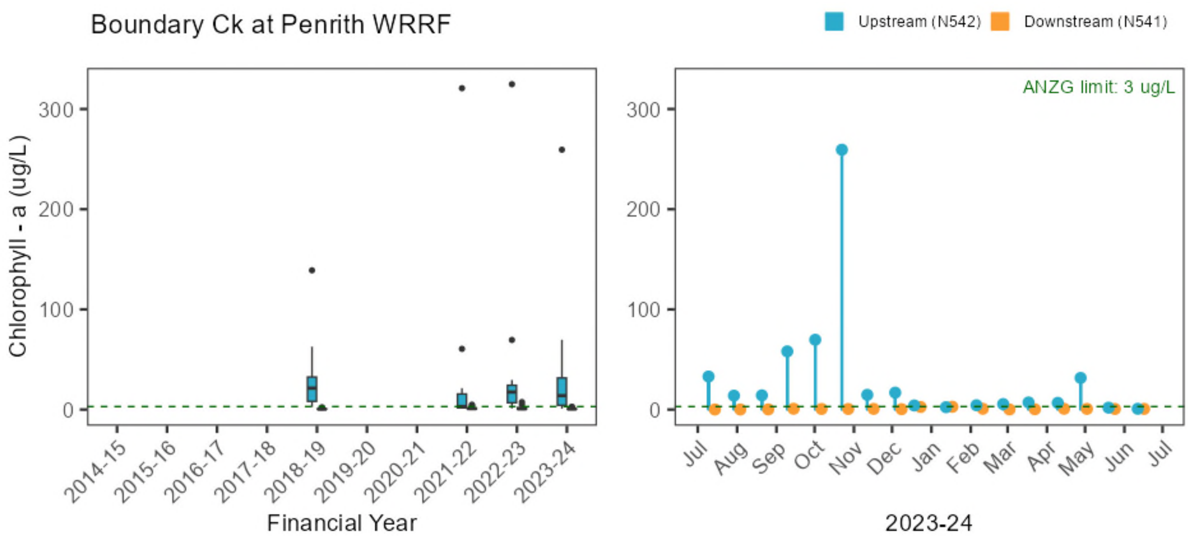
Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary current year (N542 vs N541)	U
Upstream vs downstream river (N57 vs N53)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

Chlorophyll-a concentrations were steady in 2023-24 compared to the previous five to nine years at both the upstream/downstream Boundary Creek and Nepean River monitoring sites.

In the 2023-24 period, the median chlorophyll-a concentrations exceeded the ANZG (2018) guidelines at the upstream control site of Boundary Creek (N542) and both upstream/ downstream Nepean River sites. At N542 chlorophyll-a reached a peak of 259.4 µg/L in late October 2023 taking an advantage of elevated nutrients from the first sewer overflow incident.

Statistical analysis confirmed that chlorophyll-a in 2023-24 was significantly higher at the upstream Boundary Creek site (N542) in comparison to downstream site (N541). The flow from Penrith WRRF might have had a positive influence by diluting or displacing phytoplankton. There was no such significant difference found between the upstream and downstream Nepean River sites. This indicates that the discharge from Penrith WRRF has not had a negative impact on the ecosystem receptor (chlorophyll-a) immediately downstream creek or river site.



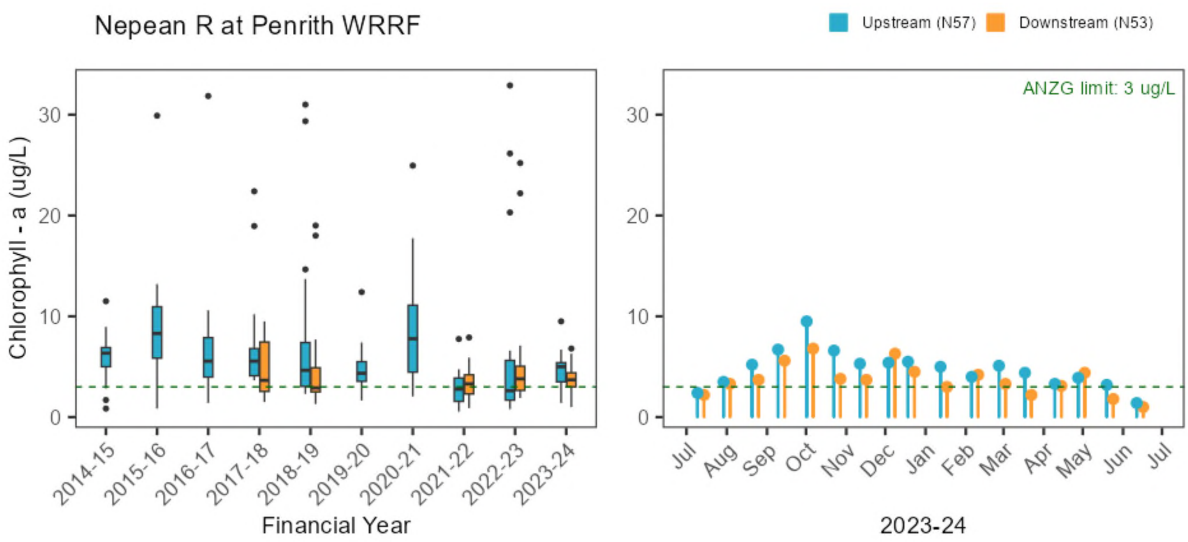


Figure 4-22 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Penrith WRRF

Ecosystem Receptor – Macroinvertebrates

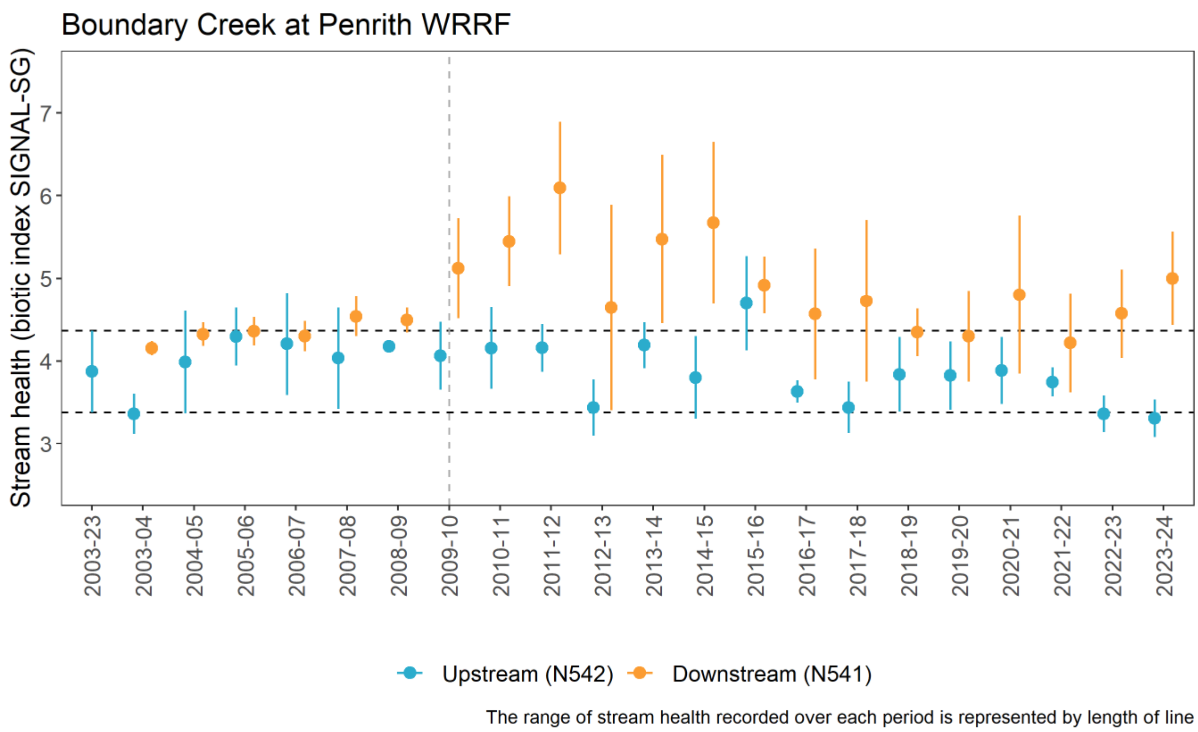
The SIGNAL-SG plot for Boundary Creek suggests that downstream stream health was substantially higher in comparison to the upstream site, as indicated by the significant statistical outcome. The SIGNAL-SG plot and statistical outcome for the Nepean River suggest that downstream stream health was similar in comparison to the upstream site.

This indicates that the treated discharge from the Penrith WRRF did not have a measurable negative impact on stream health of either Boundary Creek or the Nepean River during 2023-24, and this was consistent with the outcome from previous years.

Table 4-25 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Penrith WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (N542 vs N541)	U
Upstream vs downstream river (N57A vs N53)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)



Grey line indicates an intervention year (commissioning of the St Marys AWTP)

Figure 4-23 Stream health of Boundary Creek upstream and downstream of Penrith WRRF.

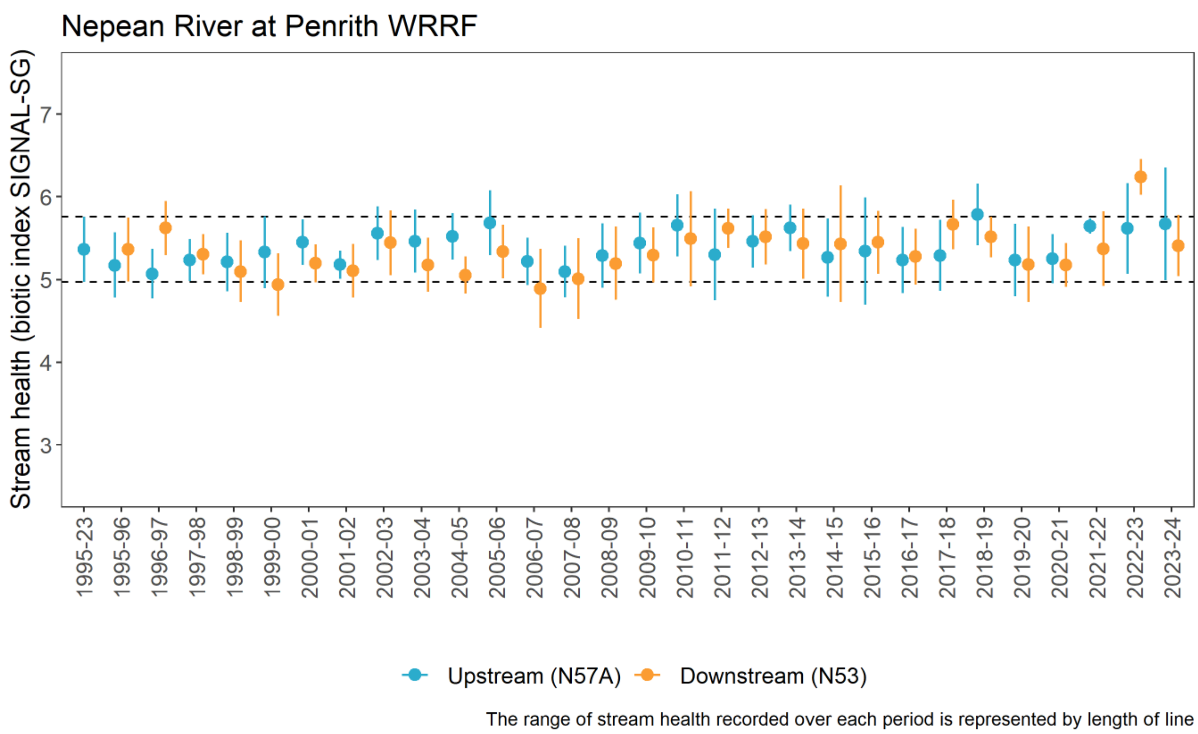


Figure 4-24 Stream health of the Nepean River upstream and downstream of the confluence of Boundary Creek near Penrith WRRF

Gate 2 – Synthesis of impact of Penrith WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as Chlorophyll-a		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Ammonia nitrogen	→	U	D	U	-	U	-	Increased nutrients and ammonia concentrations in upstream catchment instigated adverse ecosystem health impact on phytoplankton and macroinvertebrates of control site. Further analysis (Gate 3) to be carried out if this continues in future years.
Oxidised nitrogen		D	-					
Total nitrogen	↗	-	-					
Filterable total phosphorus		U	-					
Total phosphorus	↗	U	-					
Conductivity		U	-					
Dissolved oxygen		D	-					
Dissolved oxygen saturation		-	-					
pH		-	-					
Temperature		-	-					
Turbidity		U	-					

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
D	Downstream impact ($p<0.05$)	U	Upstream impact ($p<0.05$)	-	No difference ($p>0.05$)
(orange)	EPL limit exceedance	(grey)	Analyte Not monitored		

4.1.5. Winmalee WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Winmalee WRRF in 2023-24 were within EPL limits. There were increasing trends in total phosphorus and aluminium concentrations in the treated discharge, and decreasing trends in total nitrogen, copper and iron concentrations in comparison to the last nine years.
- Nutrient concentrations (oxidised and total nitrogen) increased significantly at the upstream Nepean River site in 2023-24 compared to last eight years.
- At the downstream Winmalee lagoon site, total and filterable phosphorus increased significantly in 2023-24 compared to eight years. Downstream concentrations of these nutrients were also significantly higher than the upstream Nepean River site, indicating a link with the increased phosphorus concentration in the Winmalee WRRF discharge during the PRP800 major upgrade.
- Chlorophyll-a concentrations remained stable and there was no significant difference between upstream and downstream site in 2023-24.
- Stream health analysis (as indicated by macroinvertebrates) suggested a localised ecosystem impact in the unnamed creek into which Winmalee WRRF discharges but shows signs of recovery three kilometres downstream. There was no evidence the localised impact extends to the Nepean River system to which this creek flows.

Pressure – Wastewater discharge

Table 4-26 Gate 1 Analysis outcome summary – Winmalee WRRF

Analytes / Winmalee WRRF	Nutrients			Conventional analytes						Trace Metals				Other
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc	Diazinon
Concentration	→	↘	↗	→	→	→		→	→	↗	↘	↘	→	→
Load														

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge from Winmalee WRRF were within EPL limits. Statistical analysis identified significantly increasing trends in total phosphorus and aluminium concentrations and significant decreasing trends in total nitrogen, copper and iron concentrations during the 2023-24 reporting period compared to the previous nine years.

Winmalee WRRF has undergone a $50M upgrade to fulfil the requirements of the Pollution Reduction Program (PRP) 800 under Environment Protection Licence (EPL) 1963. The upgrade involved the construction of a membrane bioreactor to increase biological process capability and facilitate a reduction in nutrient concentrations being discharged from Winmalee WRRF. The membrane bioreactor was completed in October 2023 and commissioned September 2024.

The increasing trend in total phosphorus and aluminium concentrations at Winmalee WRRF is a result of the reduced treatment capacity associated with plant upgrades and extreme wet weather events during membrane bioreactor pre-commissioning period between April 2023 and November 2023. Under PRP 800, increased alum chemical dosing was required to meet the 50 percentile EPL limit for total phosphorus whilst the facility was functioning under reduced process capacity.

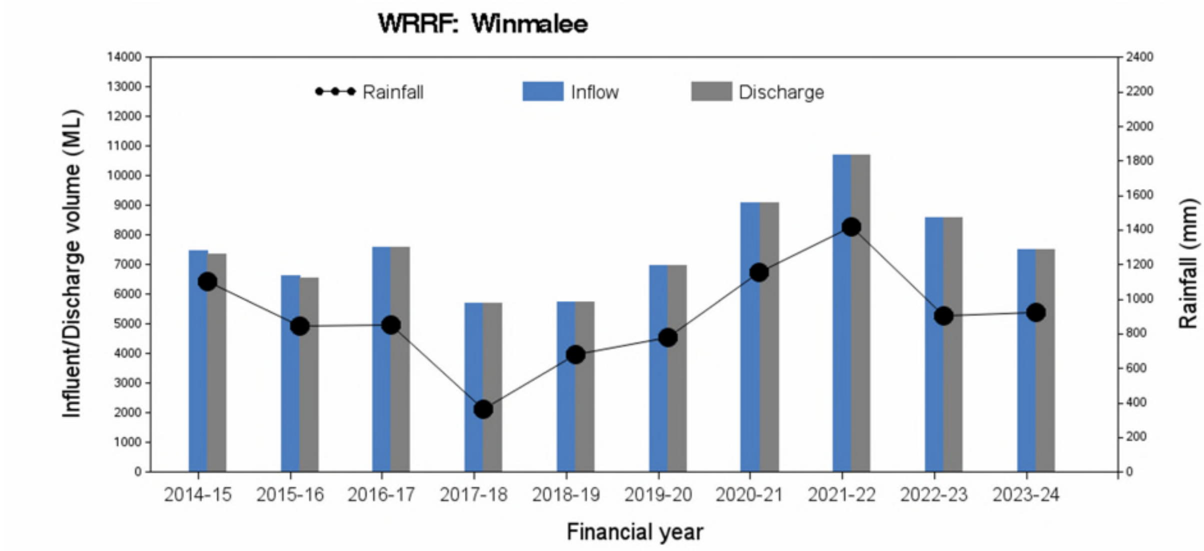
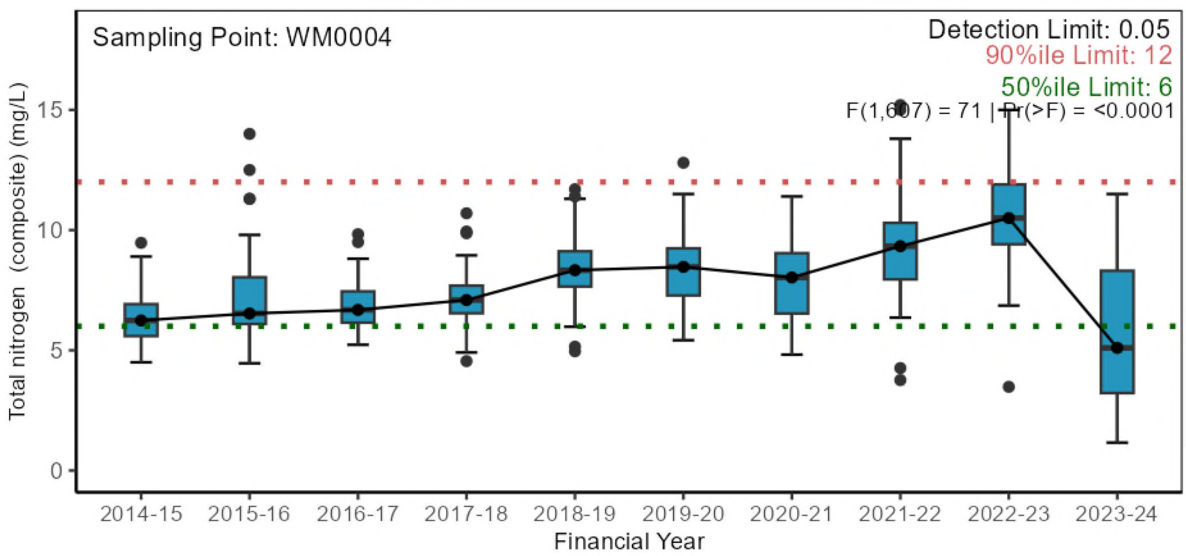
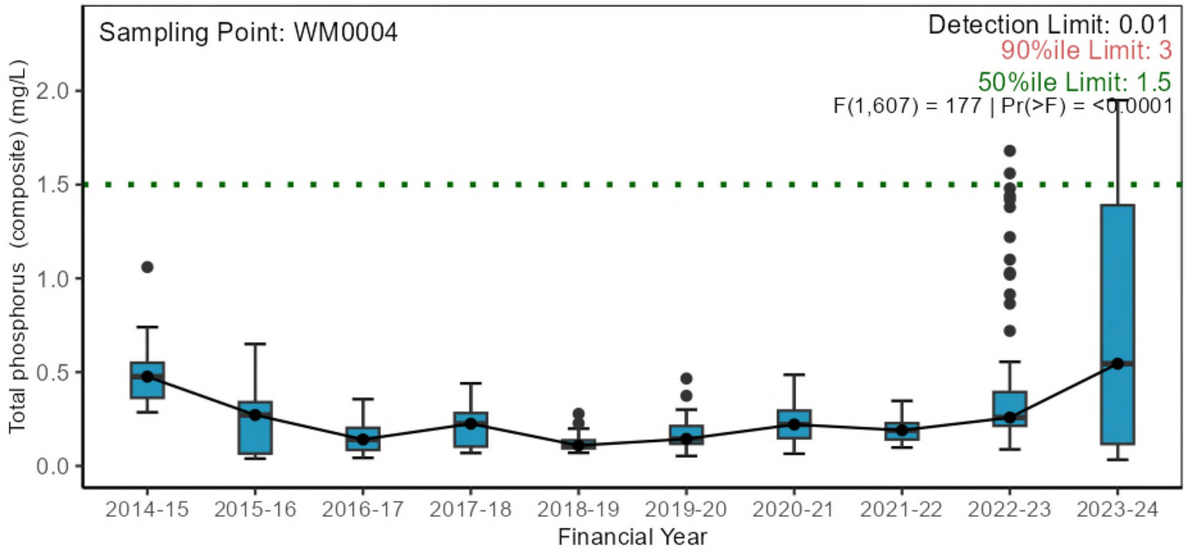
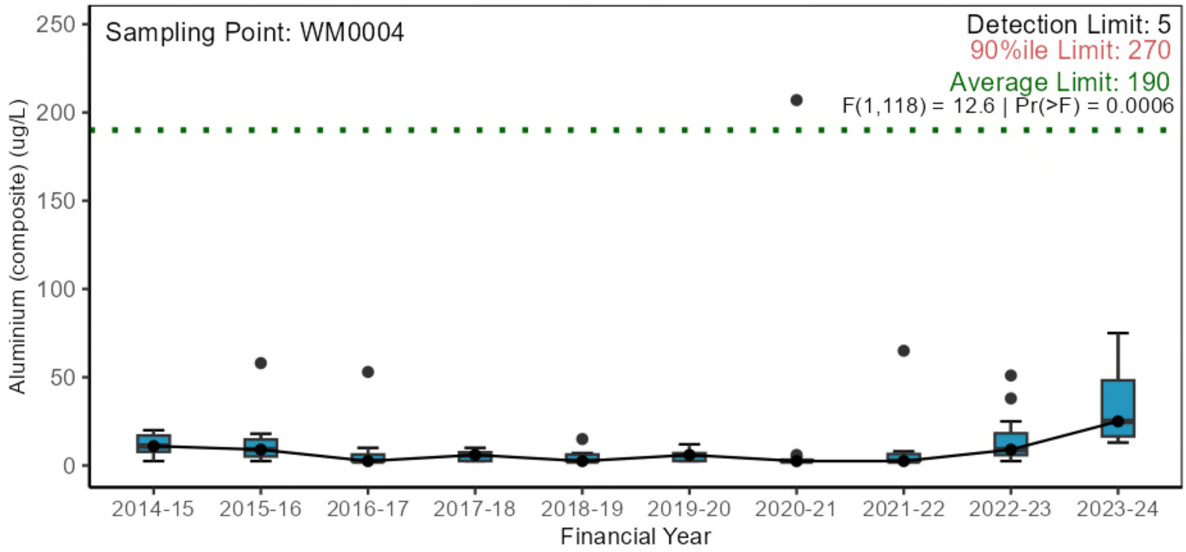
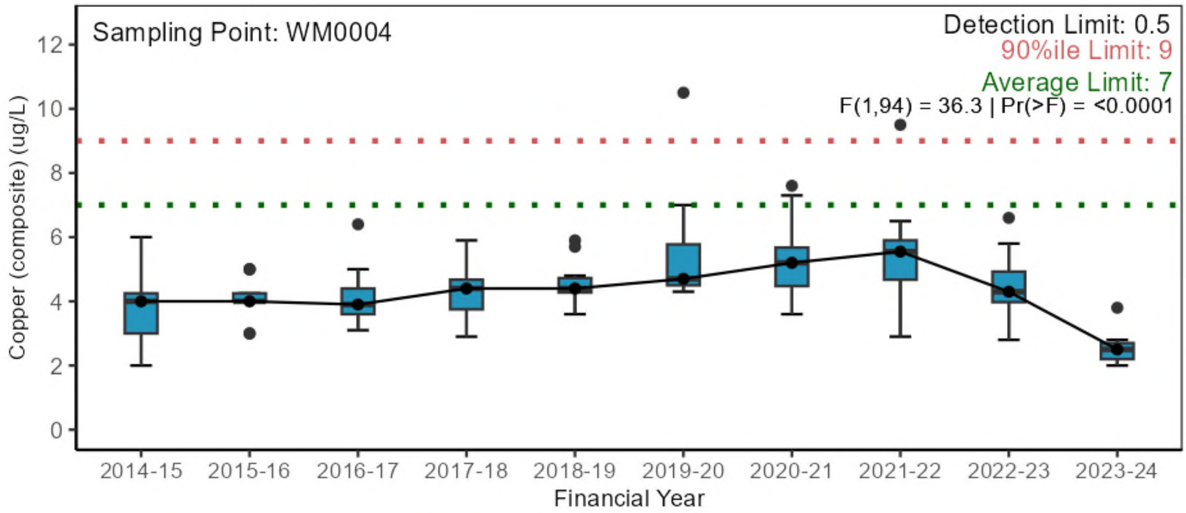


Figure 4-25 Winmalee WRRF inflow and discharge volume with catchment rainfall

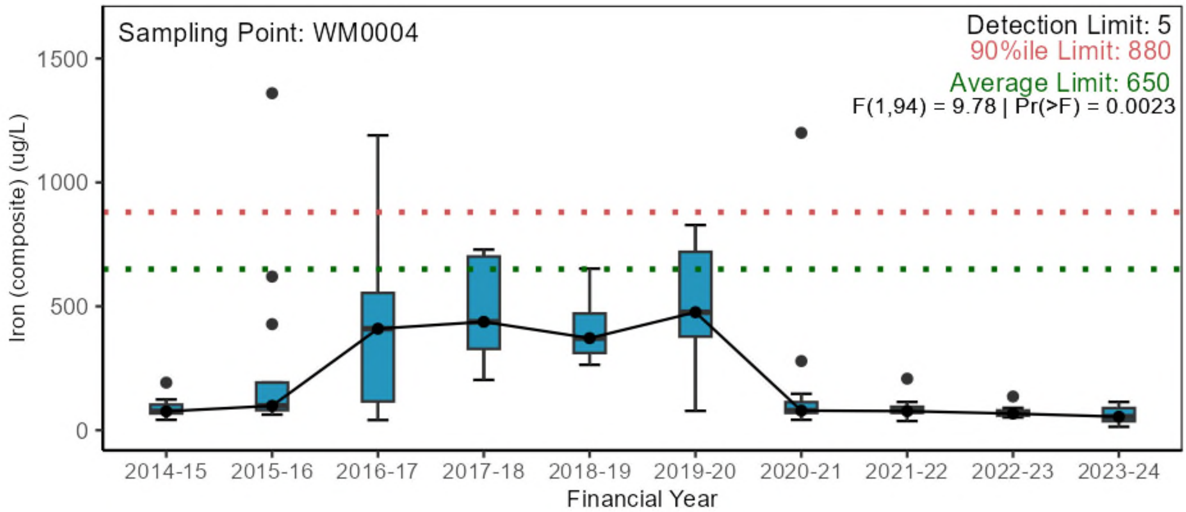



Sampling Point: WM0004
Detection Limit: 0.01
90%ile Limit: 3
50%ile Limit: 1.5
F(1,607) = 177 | Pr(>F) = <0.0001
Total phosphorus (composite) (mg/L)
2.0
1.5
1.0
0.5
0.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: WM0004
Detection Limit: 5
90%ile Limit: 270
Average Limit: 190
F(1,118) = 12.6 | Pr(>F) = 0.0006
Aluminium (composite) (ug/L)
250
200
150
100
50
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Statistical test excludes data prior to 2016-17 due to method detection limit change.



Statistical test excludes data prior to 2016-17 due to method detection limit change.

Figure 4-26 Winmalee WRRF treated discharge and reuse quality exceptions plots

Stressor – Water quality

Table 4-27 Gate 1 analysis outcome summary for water quality – upstream and downstream of Winmalee WRRF

Winmalee WRRF	Analytes	Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Proxy upstream tributary (N462)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Downstream tributary (N461)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
River	Upstream river (N48A)	→	↗	↗	→	→	→	→	→	→	→	→
	Downstream river (N464)	→	→	→	↗	↗	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(shaded)	Median value outside the guideline limit in 2023-24				

NA: Statistical comparison not conducted due to only one financial year of data

Winmalee WRRF	Analytes	Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
River	Upstream vs downstream current year (N48A vs N464)	-	-	-	D	D	-	-	-	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

The unnamed creek into which Winmalee WRRF discharges starts at the WRRF. Therefore, no feasible upstream tributary monitoring site exists for the Winmalee WRRF. Data for the two downstream creek sites (N462 and N461, 0.3 and 3 km from discharge point, respectively) was limited to 2023-24 period, and not analysed statistically.

The Nepean River site at Smith Road (N48A) is about 7 km downstream from Unnamed Creek into which Winmalee WRRF discharges. This site is also influenced by local agricultural and upstream mining activities. Submerged macrophyte beds with the occasional floating macrophyte species are often present at N48A.

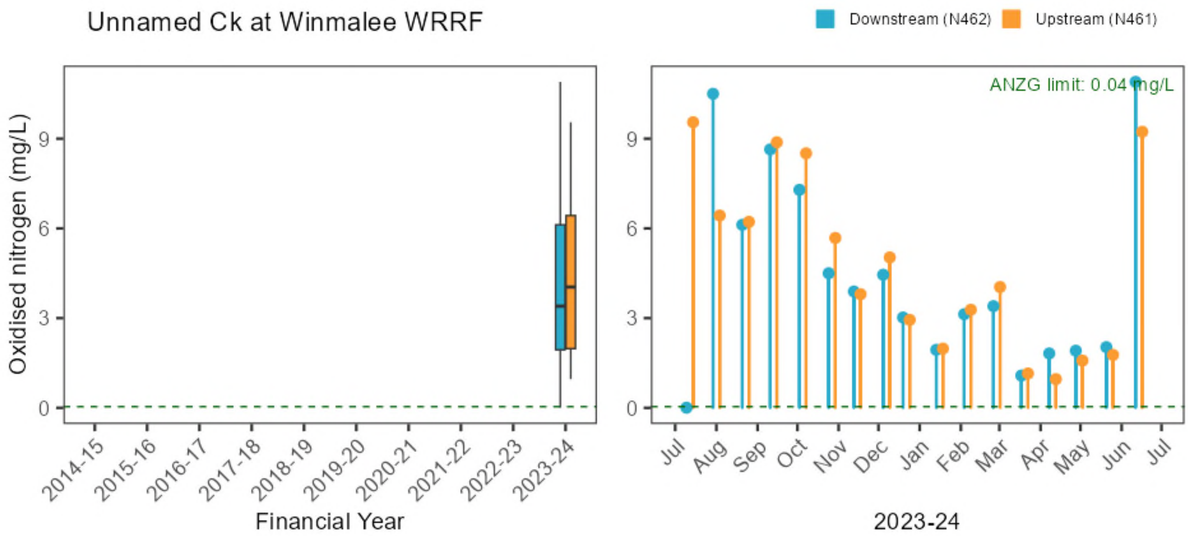
Oxidised nitrogen) and total nitrogen concentrations deteriorated significantly at the upstream control site (N48A) in 2023-24 compared to the previous nine years.

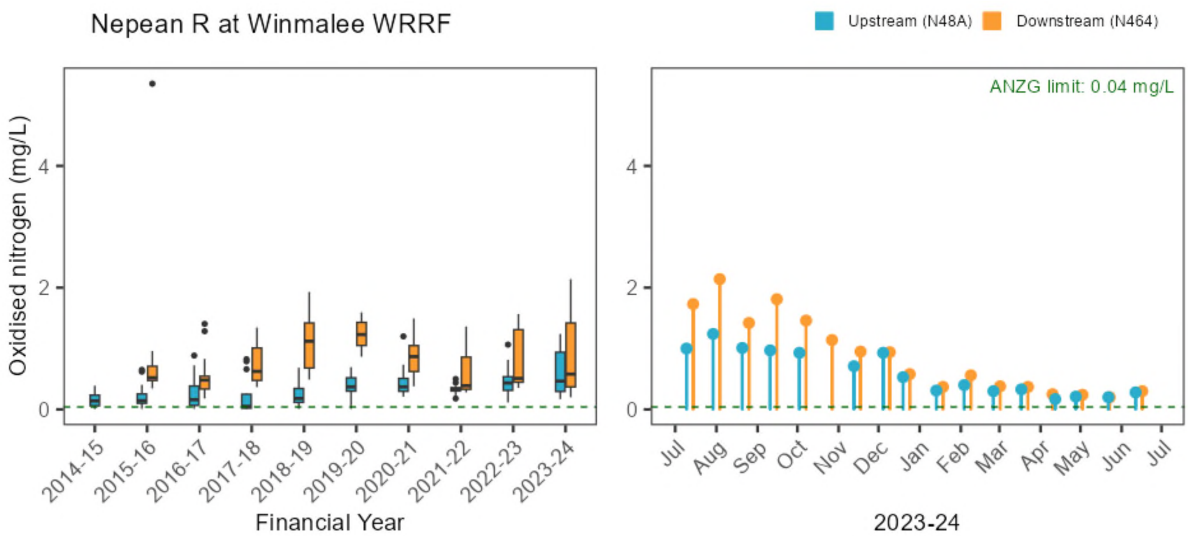
The downstream Nepean River site is located at Winmalee lagoon (N464), at the main branch of Nepean River draining downstream. Filterable total phosphorus and total phosphorus concentrations doubled at this site in 2023-24 compared to previous eight years results. This was likely due to the elevated phosphorus concentrations in the discharge from Winmalee WRRF during the first half of the year (July to November 2023) when PRP800 Bioreactor was offline.

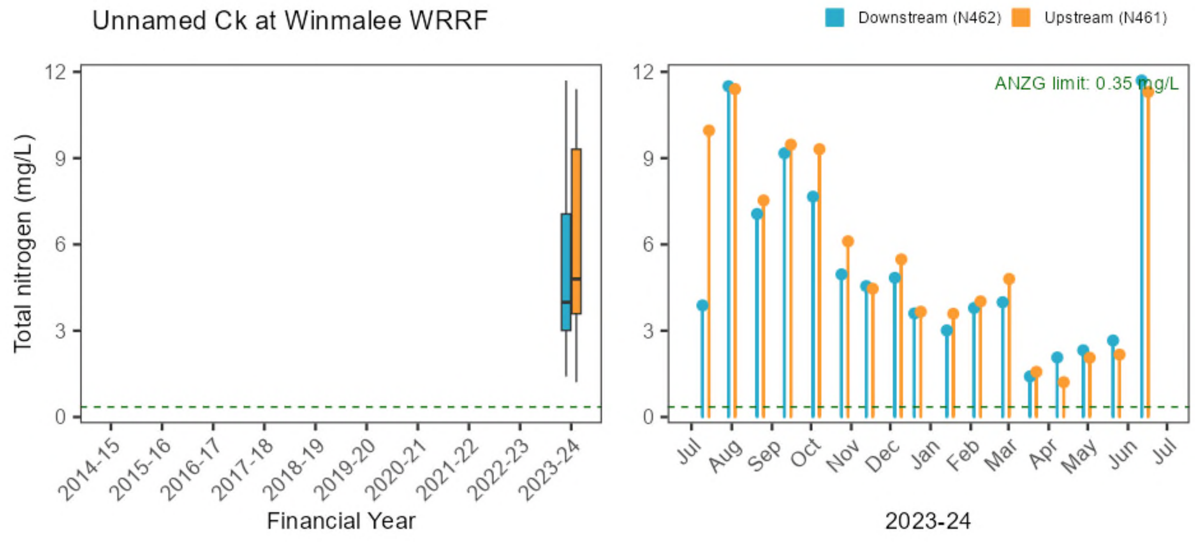
In 2023-24, the median oxidised nitrogen, total nitrogen and total phosphorus concentrations exceeded the respective ANZG (2018) guidelines at both the upstream and downstream sites in the unnamed tributary. The median oxidised and total nitrogen concentrations in the Nepean River and Winmalee lagoon exceeded the respective ANZG (2018) guideline at both sites. The total phosphorus concentration also exceeded the guideline at downstream lagoon site (N464).

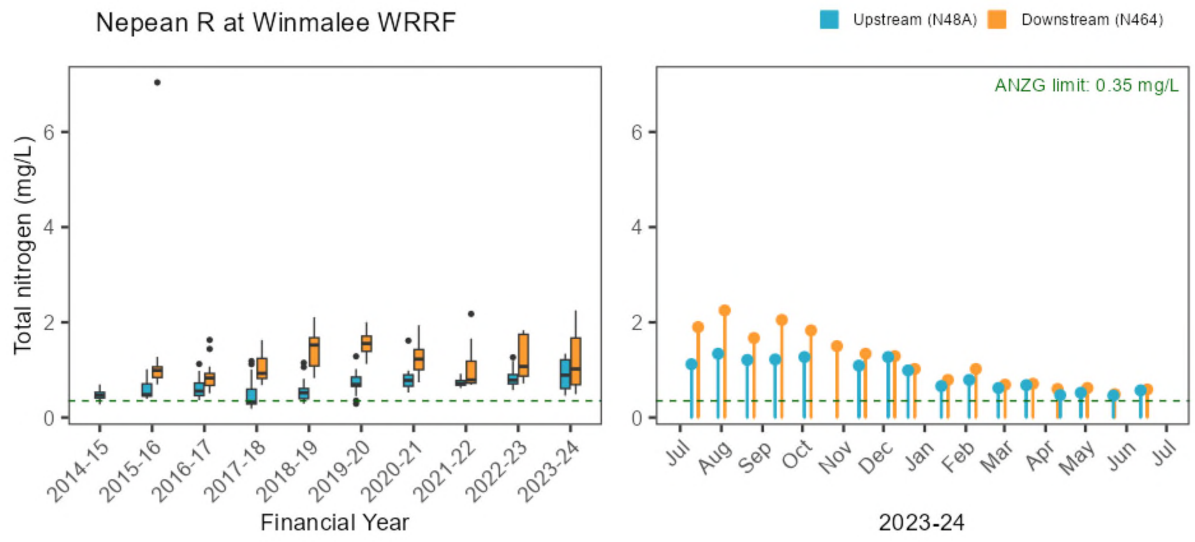
The median turbidity was less than the lower guideline at both unnamed tributary (N462 and N461) and river/lagoon sites (N48A and N464).

Filterable and total phosphorus concentrations at the downstream river site were significantly higher in comparison to upstream concentrations in 2023-24 indicating a link with the increased phosphorus concentration in the Winmalee WRRF discharge during the PRP800 major upgrade.






Unnamed Ck at Winmalee WRRF
Downstream (N462)
Upstream (N461)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
0
3
6
9
12
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Nepean R at Winmalee WRRF
Upstream (N48A)
Downstream (N464)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
0
2
4
6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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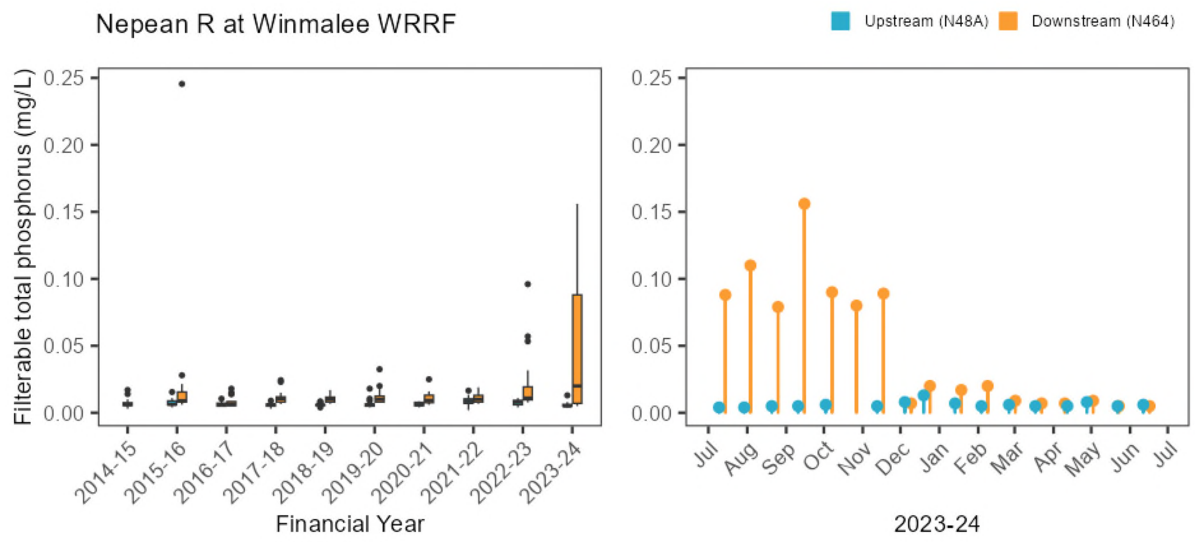
Jul
2023-24


Nepean R at Winmalee WRRF
Upstream (N48A)
Downstream (N464)
Filterable total phosphorus (mg/L)
0.00
0.05
0.10
0.15
0.20
0.25
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

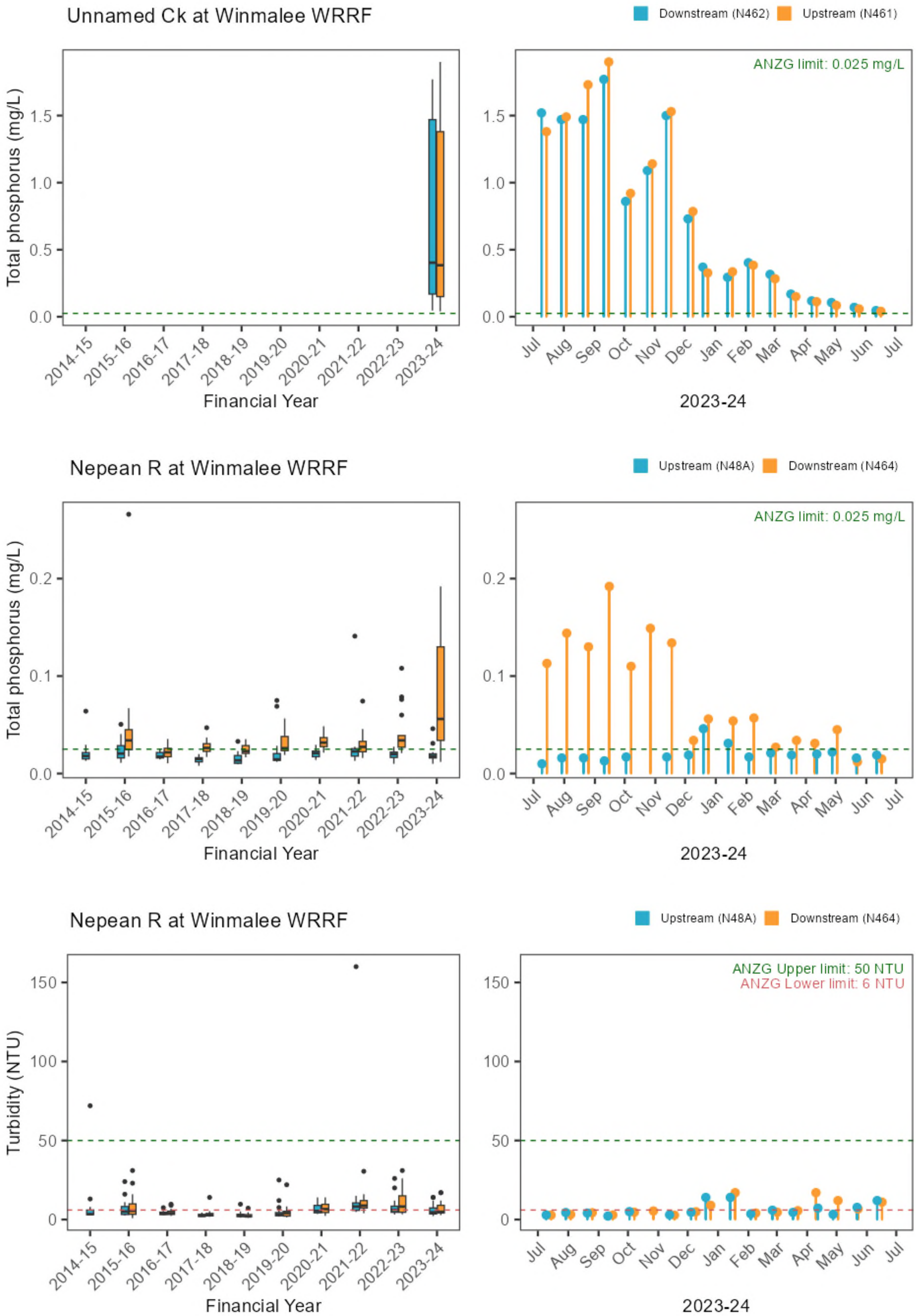


Figure 4-27 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Winmalee WRRF

Ecosystem Receptor – Phytoplankton

Table 4-28 Gate 1 analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Winmalee WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Proxy upstream tributary (N461)	NA
Downstream tributary (N462)	NA
Upstream river (N48A)	→
Downstream river (N464)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(orange)	Median value outside the guideline limit in 2023-24				

NA - Statistical comparison not conducted due to only one financial year of data

Statistical comparison (paired sites current year)	Chlorophyll-a
Proxy upstream vs downstream tributary (N461 vs N462)	NA
Upstream vs downstream river (N48A vs N464)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

Chlorophyll-a concentrations were statistically steady in 2023-24 compared to the previous nine years at both upstream/downstream monitoring sites in the Nepean River/lagoon.

In the 2023-24 period, the median chlorophyll-a concentration exceeded the ANZG (2018) guideline at both the Nepean River and lagoon sites but was within the guideline at both unnamed creek sites.

Statistical analysis confirmed no significant difference in chlorophyll-a concentration between upstream and downstream site in 2023-24.

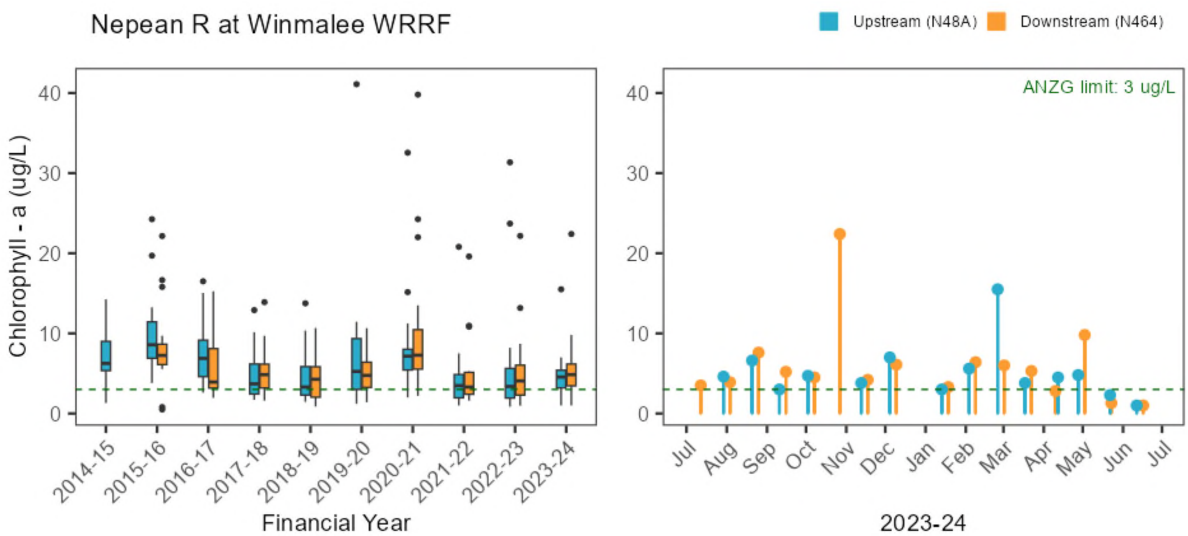


Figure 4-28 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Winmalee WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested a localised ecosystem impact in the unnamed creek into which Winmalee WRRF discharges. No macroinvertebrate stream health impacts were identified for the Nepean River downstream of the confluence of unnamed creek near Winmalee WRRF as indicated by the non-significant statistical outcome.

Table 4-29 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Winmalee WRRF

Statistical comparison (paired sites current year)	SIGNAL
Proxy upstream vs downstream tributary (N461 vs N462)	D
Upstream vs downstream river (N48 vs N44)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

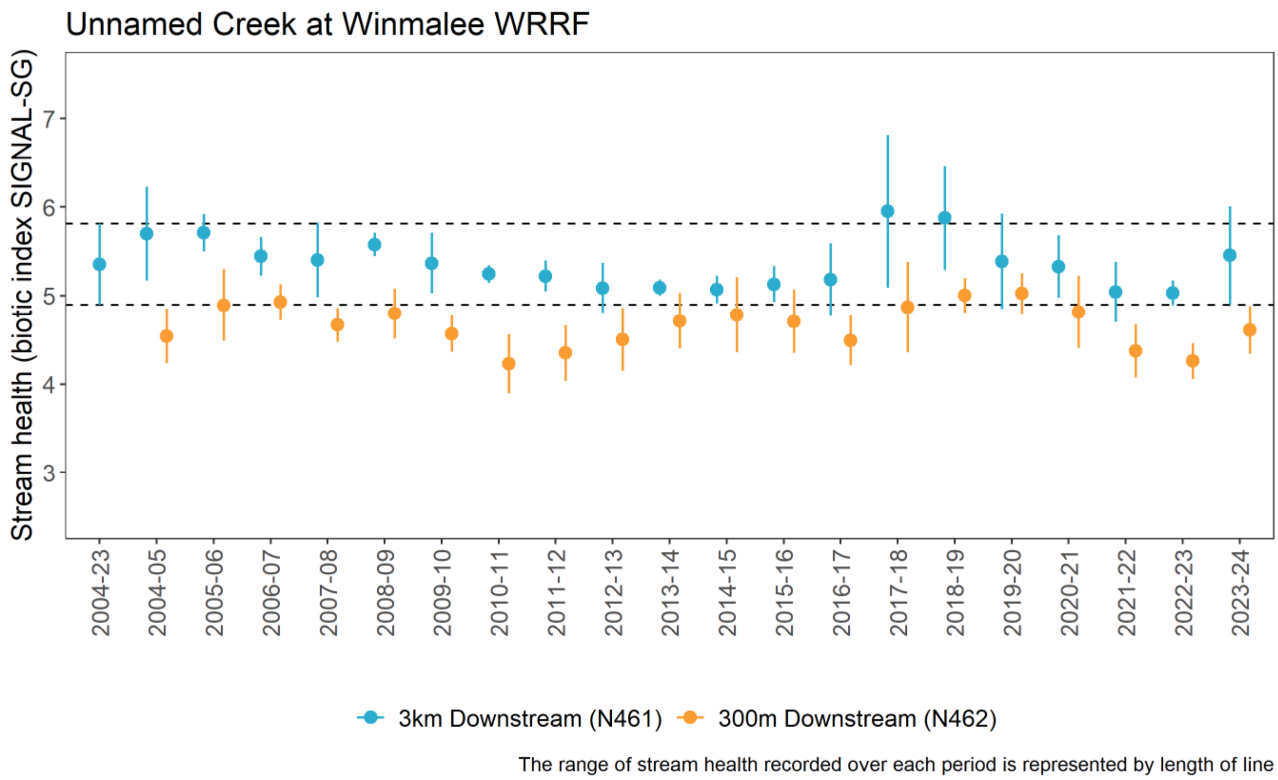


Figure 4-29 Stream health at two downstream sites on unnamed creek at Winmalee WRRF

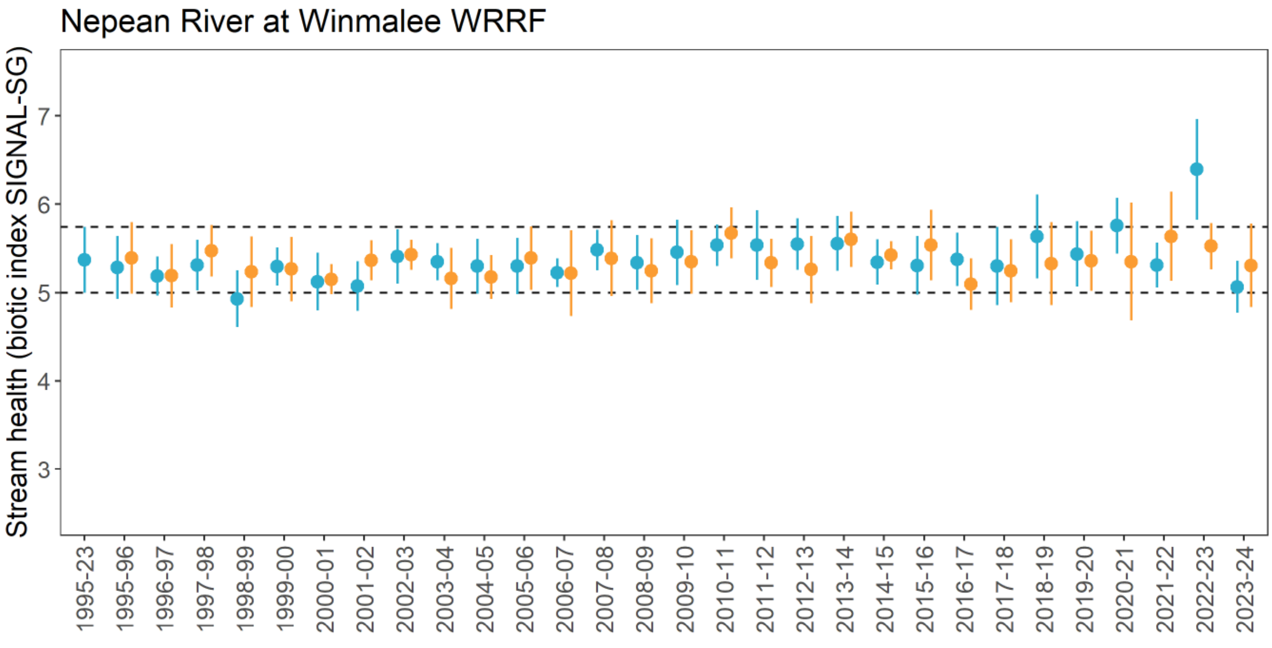


Figure 4-30 Stream health of the Nepean River upstream and downstream of Winmalee WRRF

Gate 2 – Synthesis of impact of Winmalee WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as Chlorophyll-a		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Ammonia nitrogen	→	NA	-	NA	-	D	-	Increased phosphorus concentration in Winmalee WRRF discharges triggered a subsequent increase in receiving water phosphorus. Downstream ecosystem health in terms of macroinvertebrates has deteriorated with no further evidence from Winmalee discharge impact. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		NA	-					
Total nitrogen	↘	NA	-					
Filterable total phosphorus		NA	D					
Total phosphorus	↗	NA	D					
Conductivity		NA	-					
Dissolved oxygen		NA	-					
Dissolved oxygen saturation		NA	-					
pH		NA	-					
Temperature		NA	-					
Turbidity		NA	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte Not monitored		

NA - Statistical comparison not conducted due to only one financial year of data

4.1.6. North Richmond WRRF

- Total ammonia nitrogen (90th percentile) and copper (average and 90th percentile) EPL concentration limits were exceeded in the treated discharge from North Richmond WRRF during 2023-24. All other concentration and load parameters monitored in the treated discharge were within EPL limits. Increasing trends in total ammonia nitrogen, total nitrogen, total phosphorus, total suspended solids, aluminium and copper concentrations were observed in comparison to the last nine years.
- Nutrient concentrations were steady at both upstream and downstream Redbank Creek sites compared to the previous five years. In the Hawkesbury River, upstream and downstream sites, total and filterable phosphorus concentrations increased significantly compared to last nine years. Oxidised nitrogen, total nitrogen and total phosphorus concentrations increased significantly at the downstream river site compared to last nine years.
- Nutrient concentrations were significantly higher at the downstream Redbank Creek site in comparison to upstream concentrations, indicating a possible impact from North Richmond WRRF discharge.
- Chlorophyll-a concentrations were significantly higher at the upstream Hawkesbury River site compared to previous nine years. However, no significant differences were found between the upstream and downstream creek or river sites for chlorophyll-a.
- Stream health analysis (as indicated by macroinvertebrates) suggested a localised ecosystem impact in Redbank Creek where North Richmond WRRF discharges. There was no evidence these impacts extended to the Hawkesbury River to which this creek flows.

Pressure – Wastewater discharge

Table 4-30 Gate 1 Analysis outcome summary –North Richmond WRRF

Analytes	Nutrients			Conventional analytes					Trace Metals				Other	
North Richmond WRRF	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc	Hydrogen sulfide (un-ionised)	Diazinon
Concentration	↗ (EPL limit exceedance)	↗	↗	→	→	(not required)	↗	→	↗	↗ (EPL limit exceedance)	→	→	→	→
Load	(not required)				(not required)			(not required)	(not required)	(not required)	(not required)	(not required)	(not required)	(not required)

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

The 90th percentile concentration limit for total ammonia nitrogen and the average and 90th percentile concentration limits for copper in the treated discharge from North Richmond WRRF were exceeded during the 2023-24 reporting period. All other concentration and load levels in the treated discharge were within EPL limits.

Statistical analysis identified a significantly increasing trend in the concentrations of total ammonia nitrogen, total nitrogen, total phosphorus, total suspended solids, aluminium and copper in 2023-24 compared to the previous nine years.

The concentration non compliances, as well as the increasing trends in nutrient, metal and conventional analytes were largely influenced by increased inflows to North Richmond WRRF due to catchment growth and limitations of the outdated treatment technology currently in use. North Richmond WRRF is currently not capable of treating wastewater to the revised Stage 1 EPL limits that were set in June 2020.

Municipal wastewater treatment plants are not primarily designed for targeted removal of metals. North Richmond is operating above capacity so incidental removal of aluminium and copper through coagulation, flocculation and precipitation has diminished, further leading to the observed trend increase.

To restore compliance, Sydney Water is progressing with upgrading the treatment capacity of Richmond WRRF and decommissioning North Richmond WRRF, with flows from the North Richmond catchment to be transferred to Richmond WRRF for treatment via a transfer pipeline.

The Richmond WRRF upgrade is progressing but has faced delays due to:

– Complications with confirming the road alignment of a new bridge over the Hawkesbury River by Transport for NSW. The delay occurred due to confirming how the road alignment impacted the design timeframe, undertaking re-designs of the alignment, and delayed environmental approvals for the project.

– Market capacity across the infrastructure construction sector in Sydney is constrained. As a result, Sydney Water had difficulty acquiring a suitable service provider which prolonged the tender period and delayed the design process.

The upgrade to Richmond WRRF and subsequent closure of North Richmond WRRF is expected to be complete in late 2026.

North Richmond WRRF operations continue to actively operate, maintain and optimise facility assets to ensure the highest level of treatment performance possible until the Richmond System Wastewater Upgrade Project is delivered including:

– Installation of an aerator in Pasveer ditch to improve resilience during peak flows

– Management of inflow peaks by optimising flushing cycles

– Altering sludge wasting

– Installation of online ammonia analysers for real time monitoring.

The EPA approved a licence variation on 28th June 2024, allowing North Richmond WRRF to temporarily increase the total ammonia nitrogen 50th percentile and 90th percentile concentration limits to 1.2 and 2.5 mg/L (previously 0.9 and 1.4 mg/L respectively). This licence variation will remain valid until completion of the transfer pipeline from North Richmond to Richmond WRRF. Given these interim limits, future total ammonia nitrogen concentration percentiles are expected to be compliant at North Richmond WRRF.

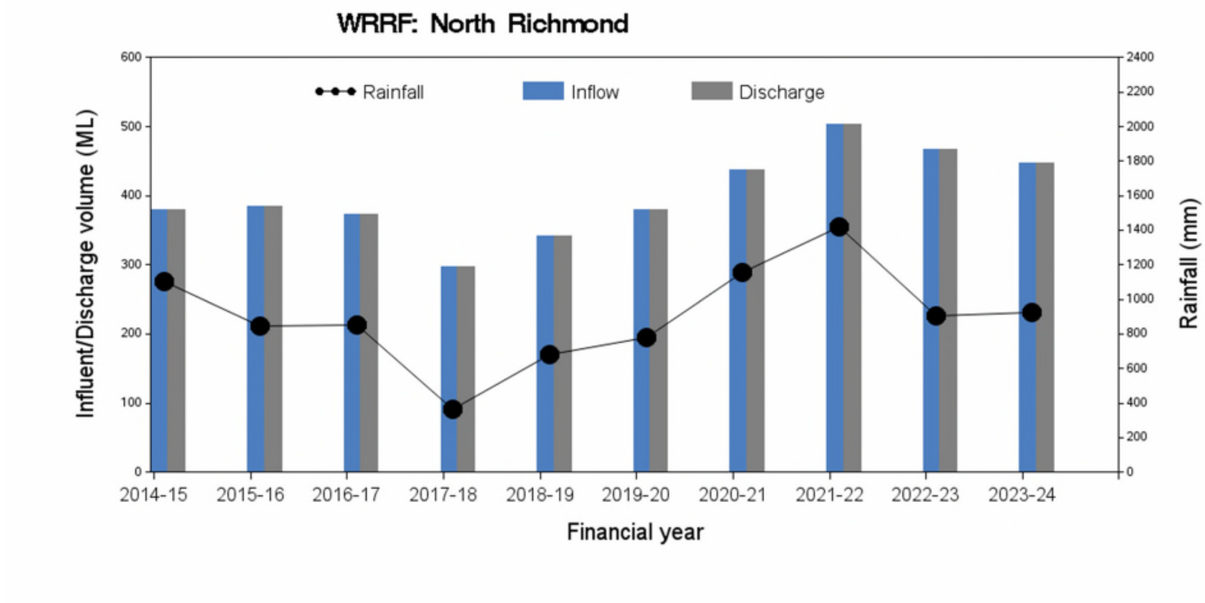
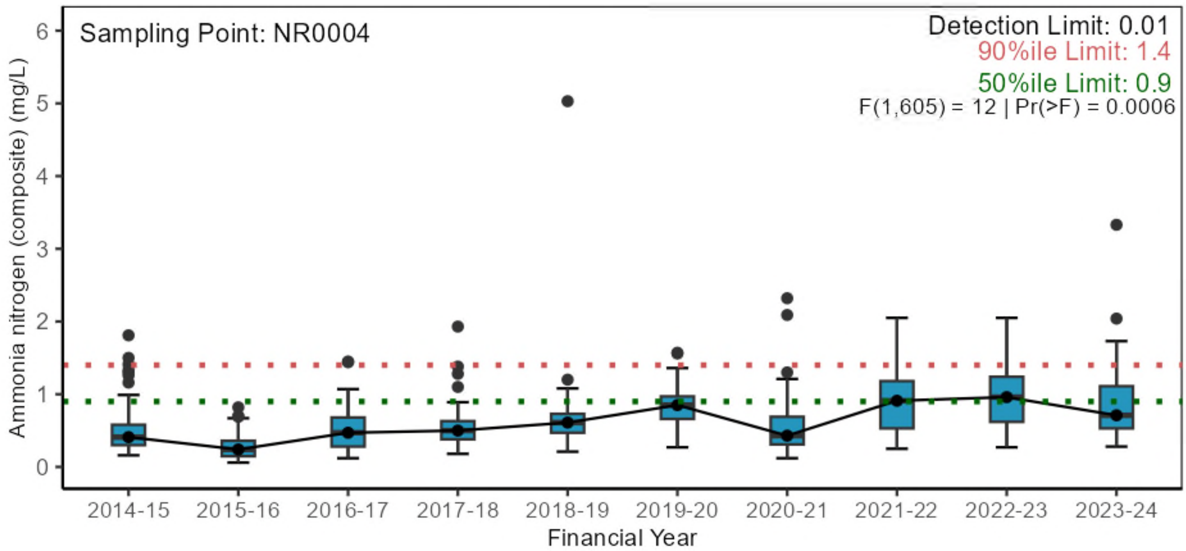
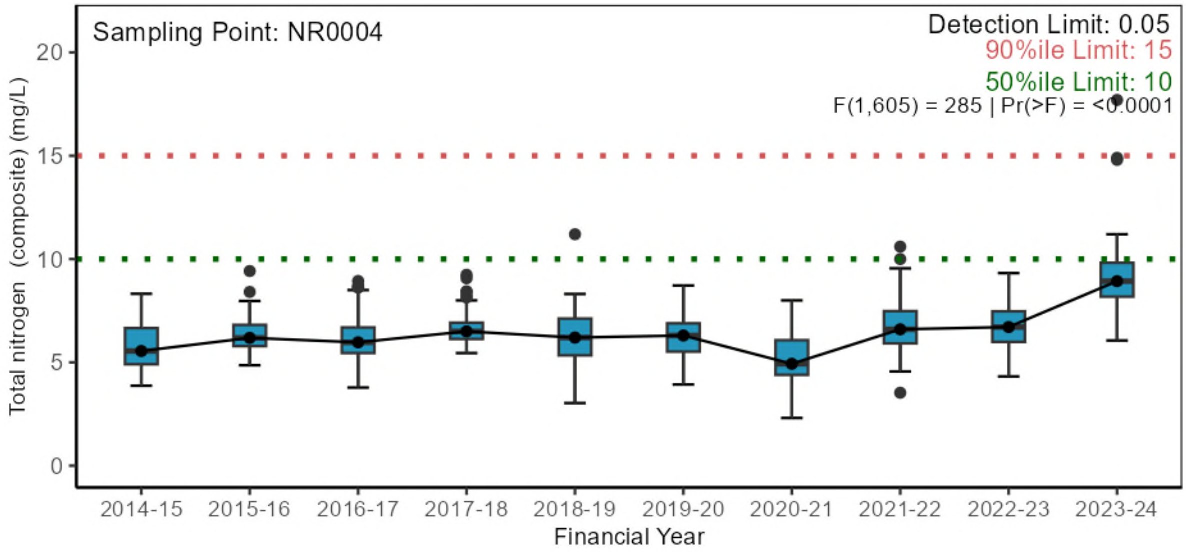
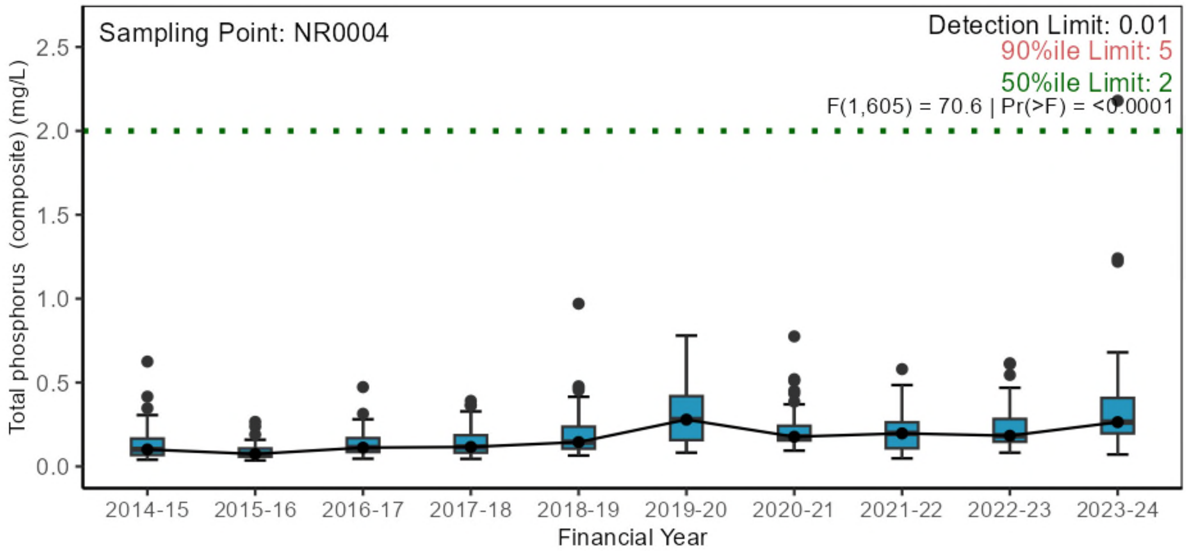


Figure 4-31 North Richmond WRRF inflow and discharge volume with catchment rainfall

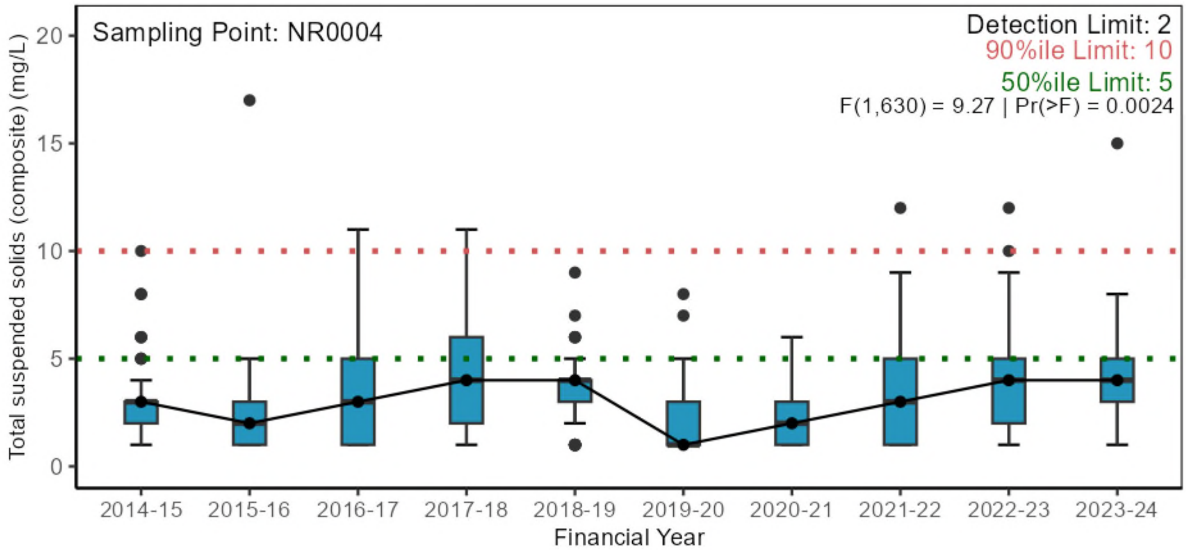


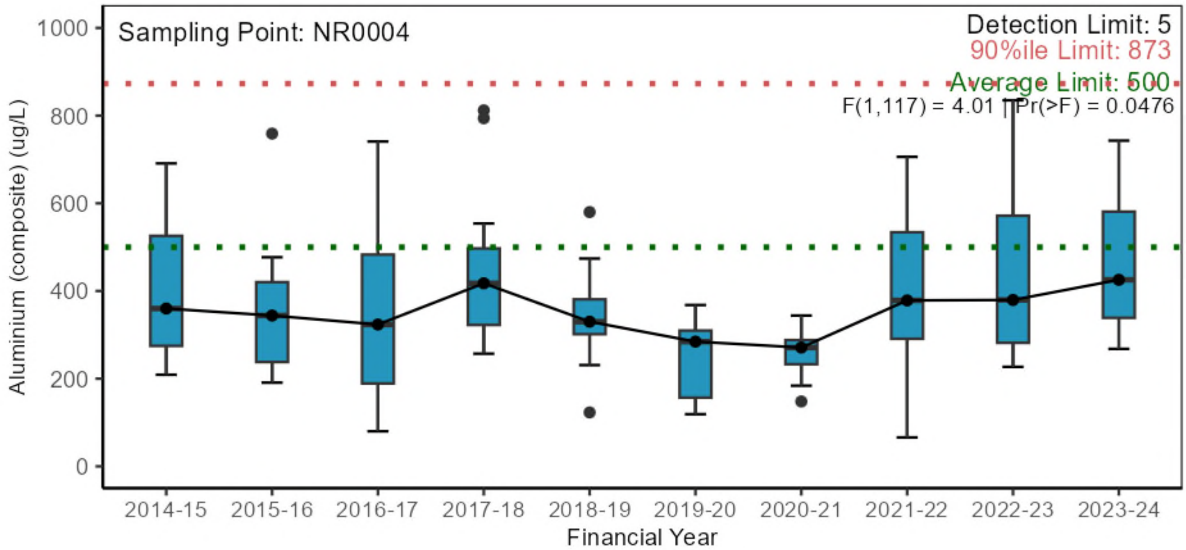


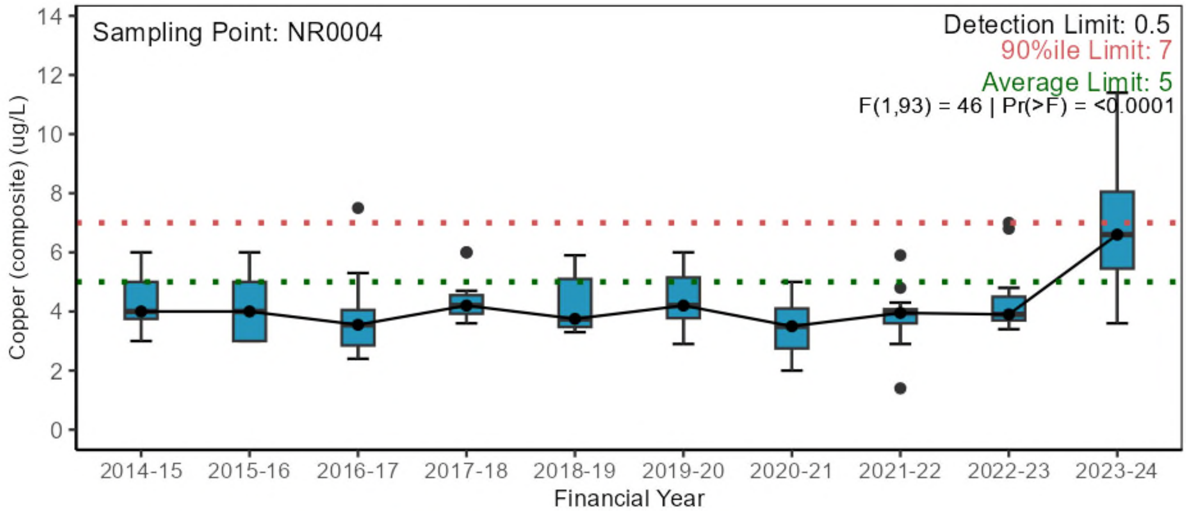
Sampling Point: NR0004
Detection Limit: 0.05
90%ile Limit: 15
50%ile Limit: 10
F(1,605) = 285 | Pr(>F) = <0.0001
Total nitrogen (composite) (mg/L)
0
5
10
15
20
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Sampling Point: NR0004
Detection Limit: 0.01
90%ile Limit: 5
50%ile Limit: 2
F(1,605) = 70.6 | Pr(>F) = <0.0001
Total phosphorus (composite) (mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: NR0004
Detection Limit: 2
90%ile Limit: 10
50%ile Limit: 5
F(1,630) = 9.27 | Pr(>F) = 0.0024
Total suspended solids (composite) (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24


Sampling Point: NR0004
Detection Limit: 5
90%ile Limit: 873
Average Limit: 500
F(1,117) = 4.01 | Pr(>F) = 0.0476
Aluminium (composite) (ug/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24



Statistical test excludes data prior to 2016-17 due to method detection limit change.

Figure 4-32 North Richmond WRRF treated discharge and reuse quality exceptions

Stressor – Water quality

Table 4-31 Gate 1 analysis outcome summary for water quality – upstream and downstream of North Richmond WRRF

North Richmond WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (N412)	→	→ (shaded)	→ (shaded)	→	→	→	↗	↗	→	→	→ (shaded)
	Downstream tributary (N411)	→	→ (shaded)	→ (shaded)	→	→ (shaded)	→	→	→	→	→	→ (shaded)
River	Upstream river (N42)	→	→ (shaded)	→ (shaded)	↗	↗ (shaded)	↗	→	→	→	→	→ (shaded)
	Downstream river (N39)	→	↗ (shaded)	↗ (shaded)	→	↗	→	→	→	→	→	→ (shaded)

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(shaded)	Median value outside the guideline limit in 2023-24				

North Richmond WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (N412 vs N411)	D	D	D	D	D	D	-	D	-	-	-
River	Upstream vs downstream current year (N42 vs N39)	-	-	-	-	-	-	-	-	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

North Richmond WRRF discharges to an unnamed watercourse flowing into Redbank Creek and then Nepean River. The upstream control site of Redbank Creek (N412) is influenced by a semi-rural residential and agricultural catchment. The further upstream catchment is predominantly Blue-Mountains National Park.

The Hawkesbury River at North Richmond (N42) is the control site for the North Richmond WRRF, located downstream of the confluence with the Grose River. The river widens and deepens from this point.

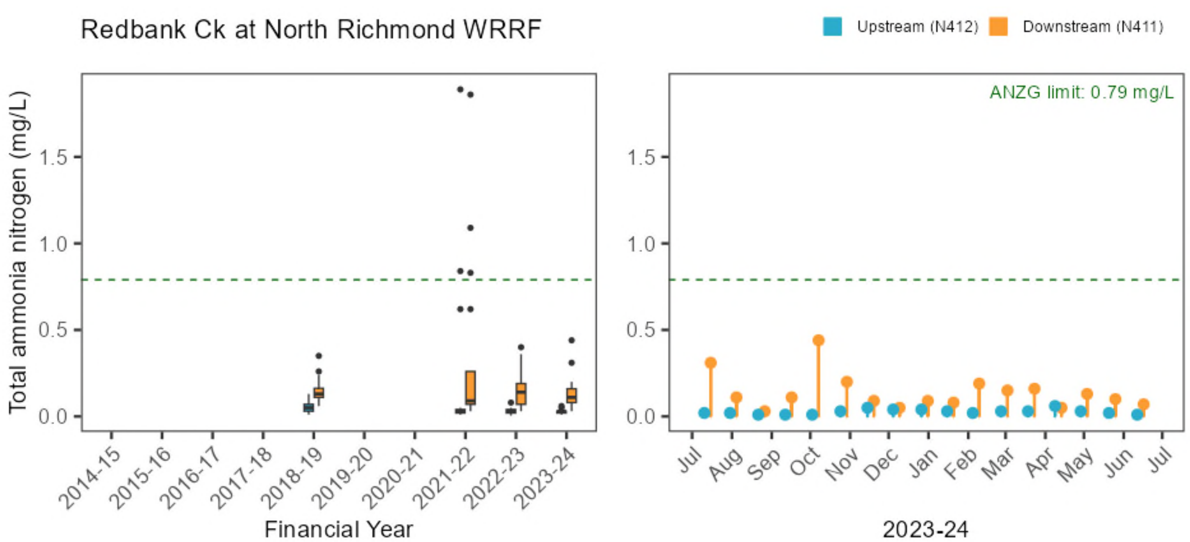
Nutrient concentrations were statistically steady in 2023-24 compared to the previous five years at both Redbank Creek sites. However, dissolved oxygen (concentration and saturation) increased significantly at the upstream control site in 2023-24 compared to previous five years. At the downstream creek site all physico-chemical analytes were statistically steady.

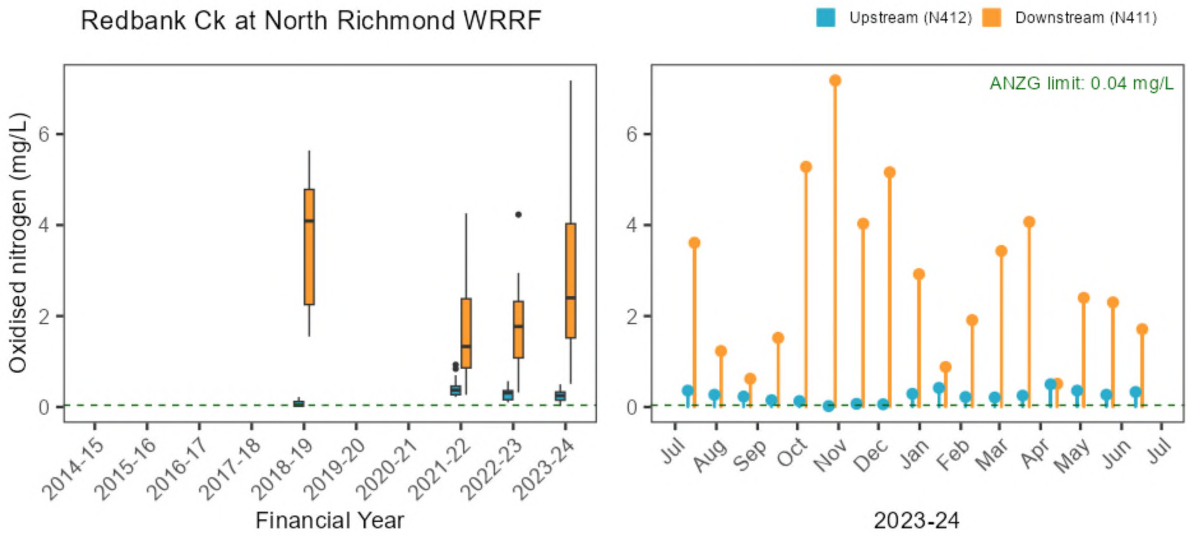
In the upstream Hawkesbury River site (N42), there was a significantly increasing trend in filterable total phosphorus, total phosphorus and conductivity in 2023-24 compared to previous nine years. Oxidised nitrogen, total nitrogen and filterable total phosphorus concentrations increased significantly at the downstream Freemans Reach site (N39), possibly due to the increasing concentrations of nitrogen and phosphorus from North Richmond WRRF.

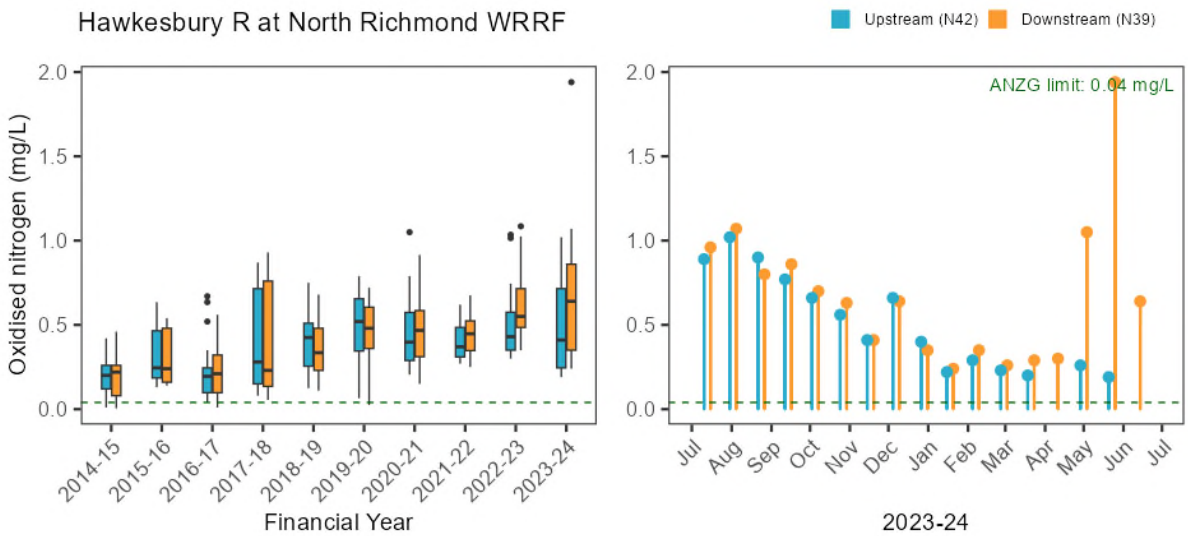
The median oxidised nitrogen, total nitrogen and turbidity levels were outside the respective ANZG (2018) guidelines in 2023-24 at all four upstream/downstream creek/river sites. The median total phosphorus exceeded the guideline at the downstream Redbank Creek site (N411) and upstream Nepean River site (N42).

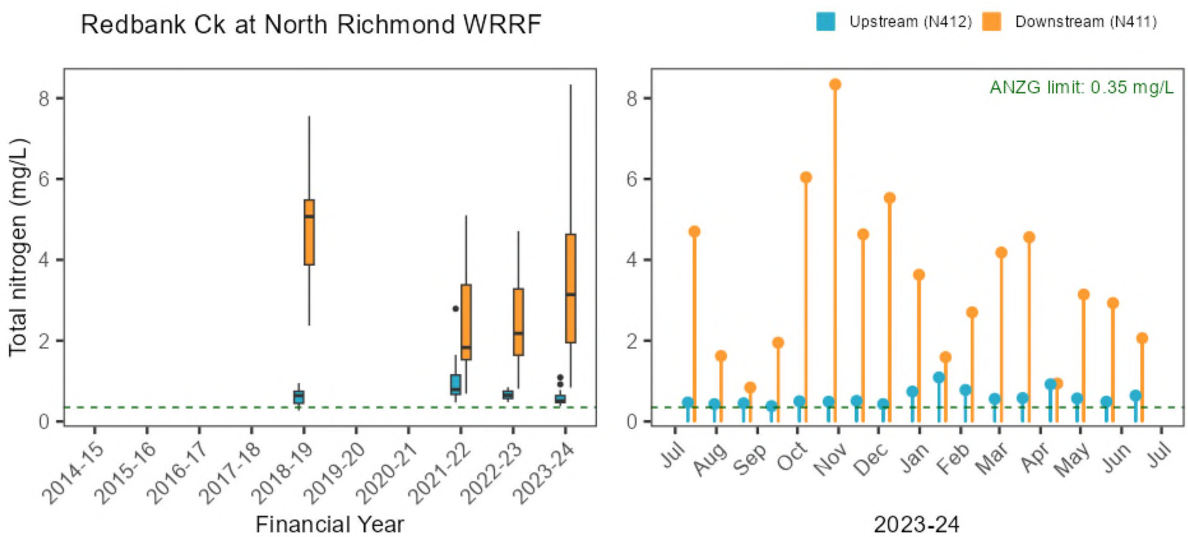
Nutrient concentrations were significantly higher at the downstream Redbank Creek site in comparison to upstream concentrations, indicating an impact from North Richmond WRRF discharge. However, dissolved oxygen saturation was significantly higher at the downstream creek site indicating a benefit from discharges.

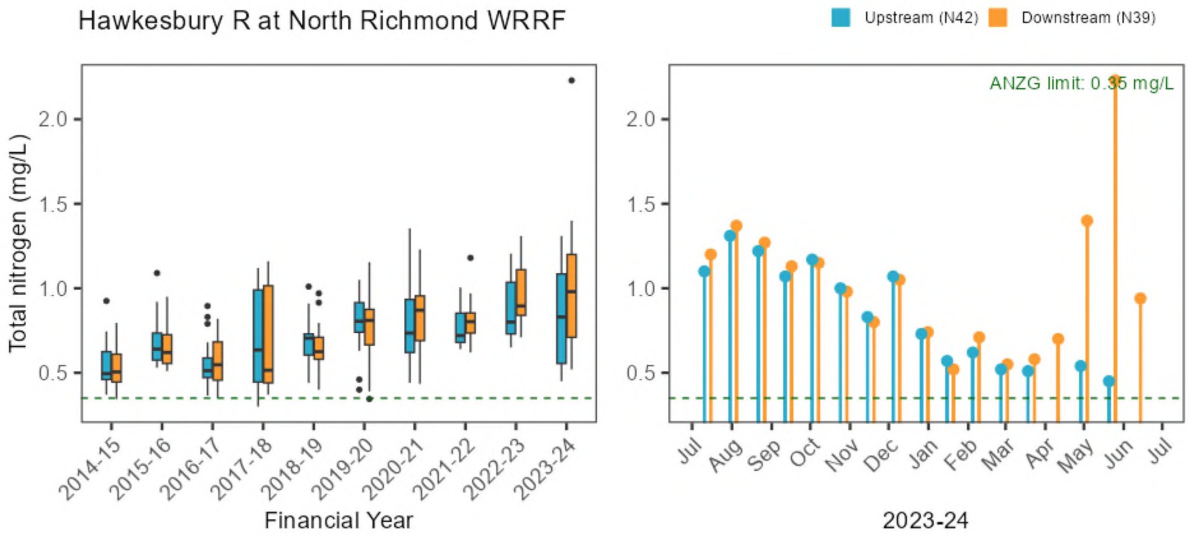
There was no significant difference identified in the concentrations/levels of any nutrients or physico-chemical analytes between upstream and downstream Hawkesbury River sites.

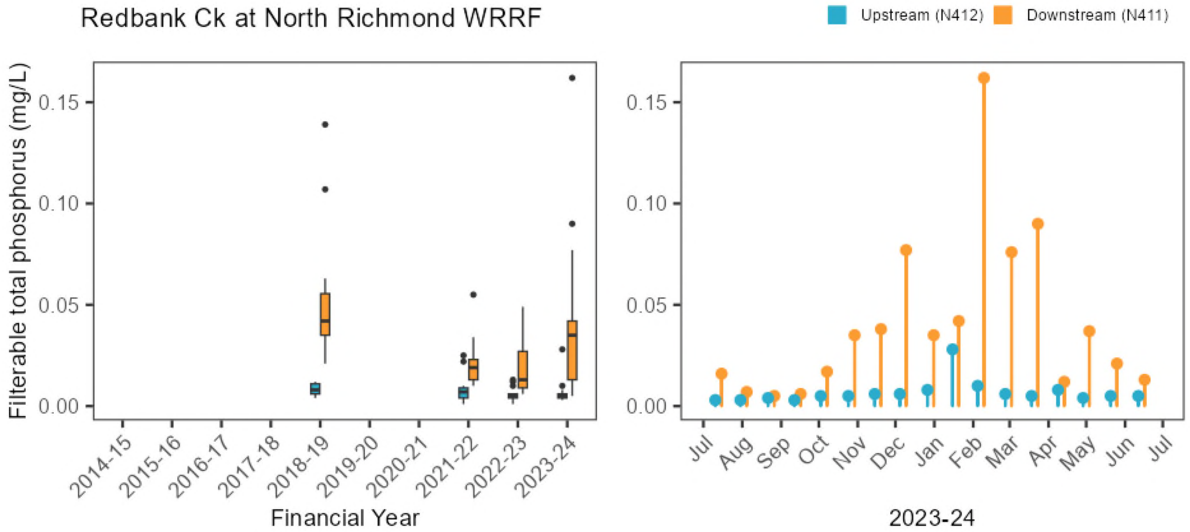


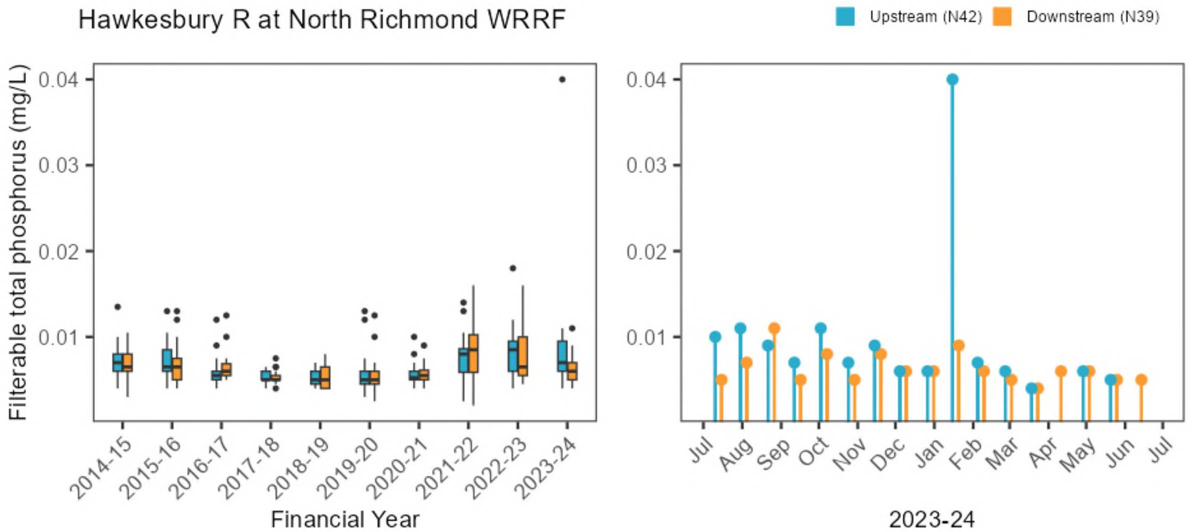

Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
Oxidised nitrogen (mg/L)
0
2
4
6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.04 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

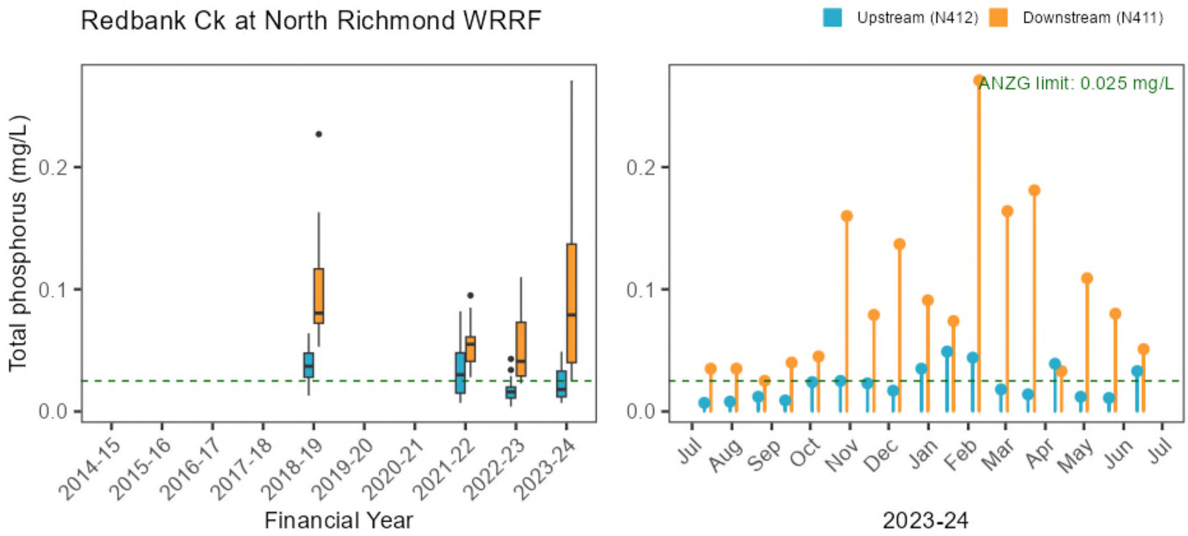

Hawkesbury R at North Richmond WRRF
Upstream (N42)
Downstream (N39)
Oxidised nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.04 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

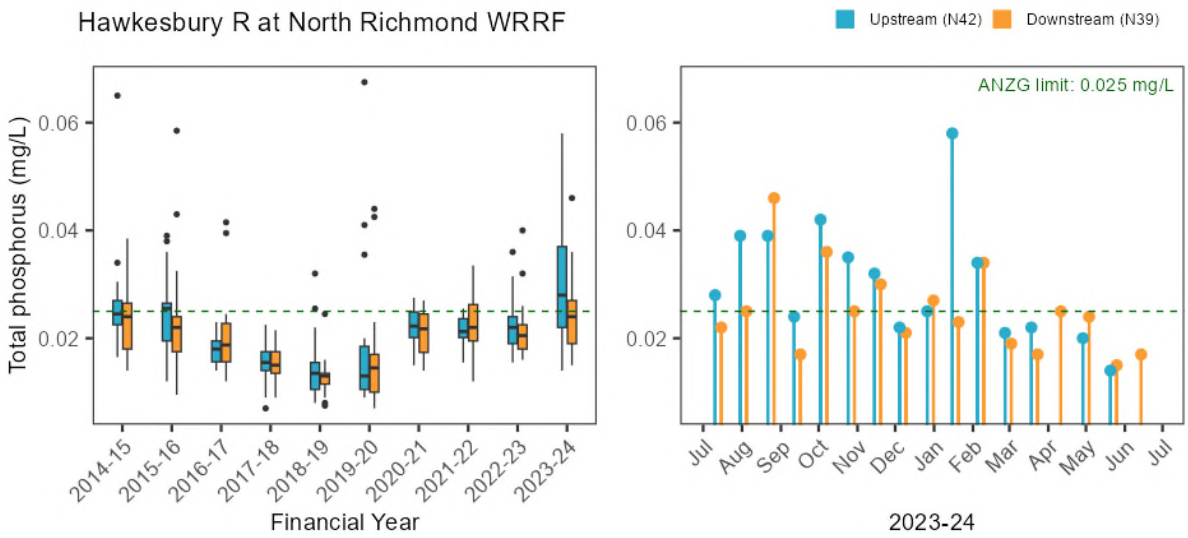

Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
Total nitrogen (mg/L)
0
2
4
6
8
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.35 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

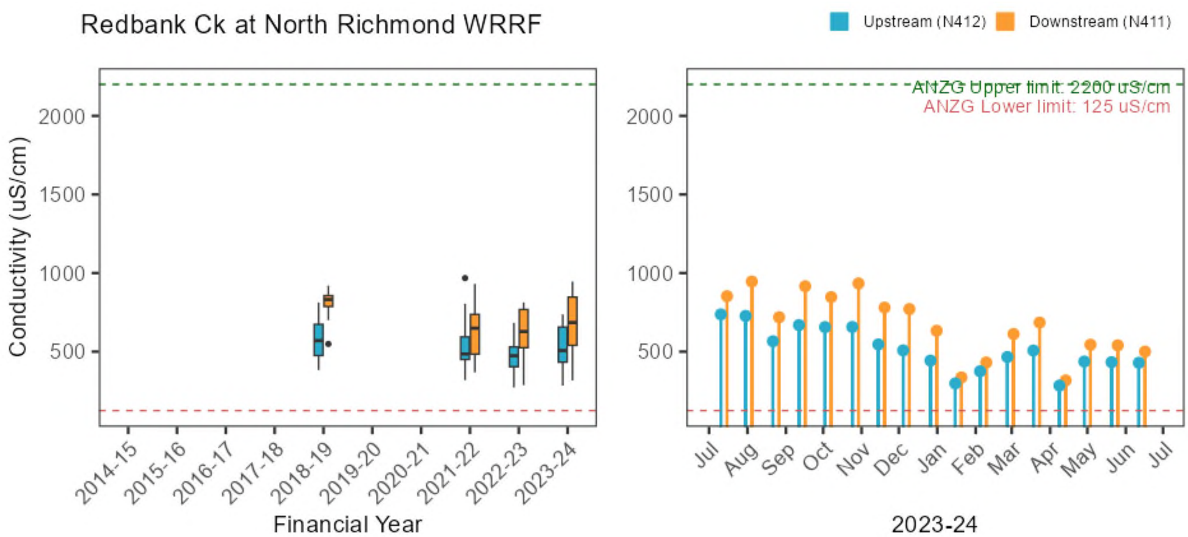

Hawkesbury R at North Richmond WRRF
Upstream (N42)
Downstream (N39)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
0.5
1.0
1.5
2.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

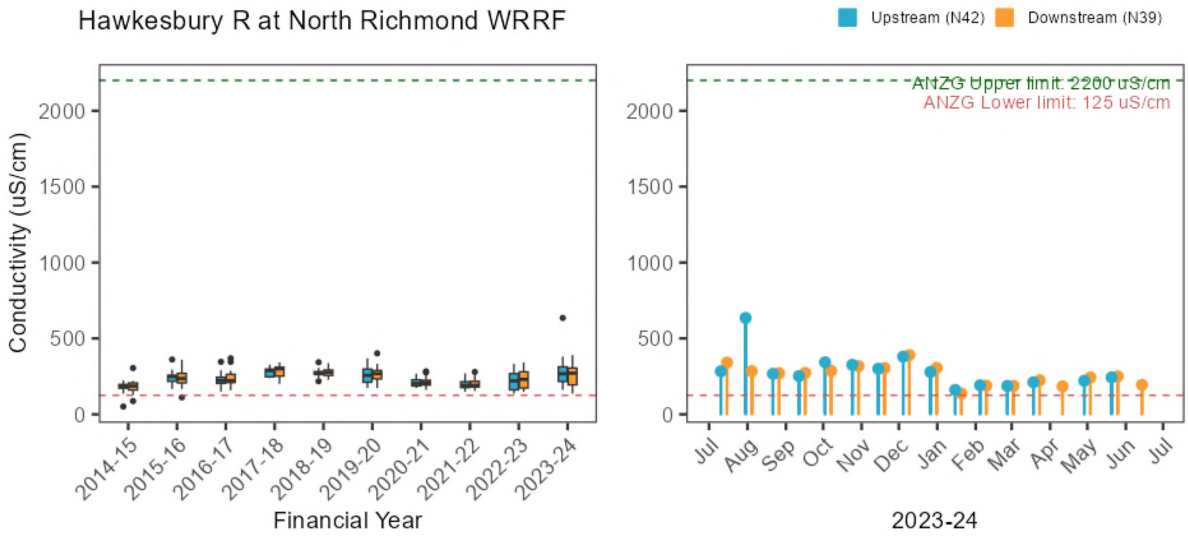

Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
Filterable total phosphorus (mg/L)
0.00
0.05
0.10
0.15
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

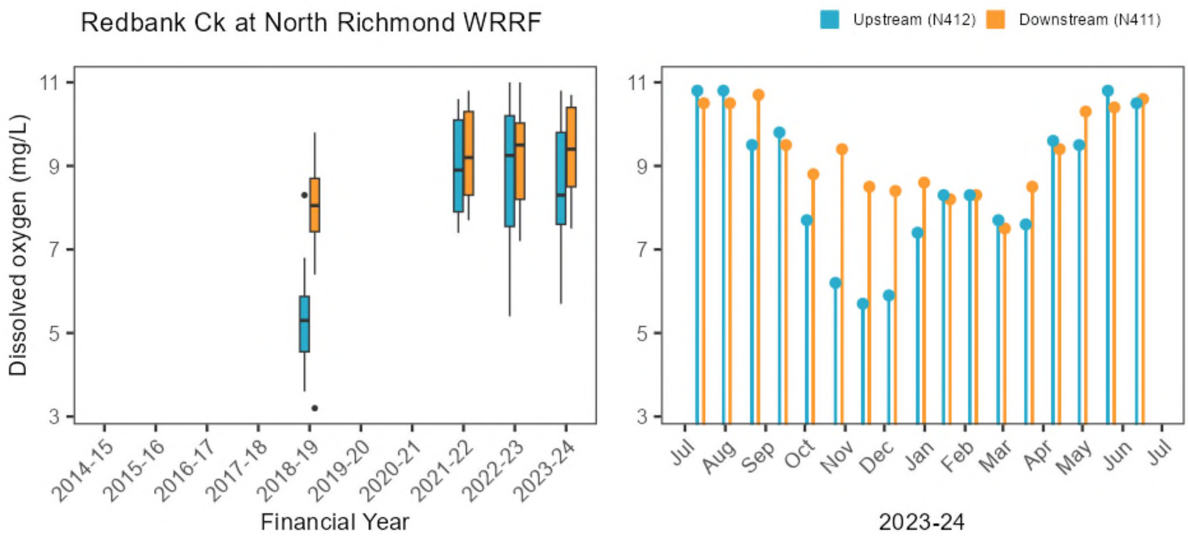

Hawkesbury R at North Richmond WRRF
Upstream (N42)
Downstream (N39)
Filterable total phosphorus (mg/L)
0.01
0.02
0.03
0.04
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

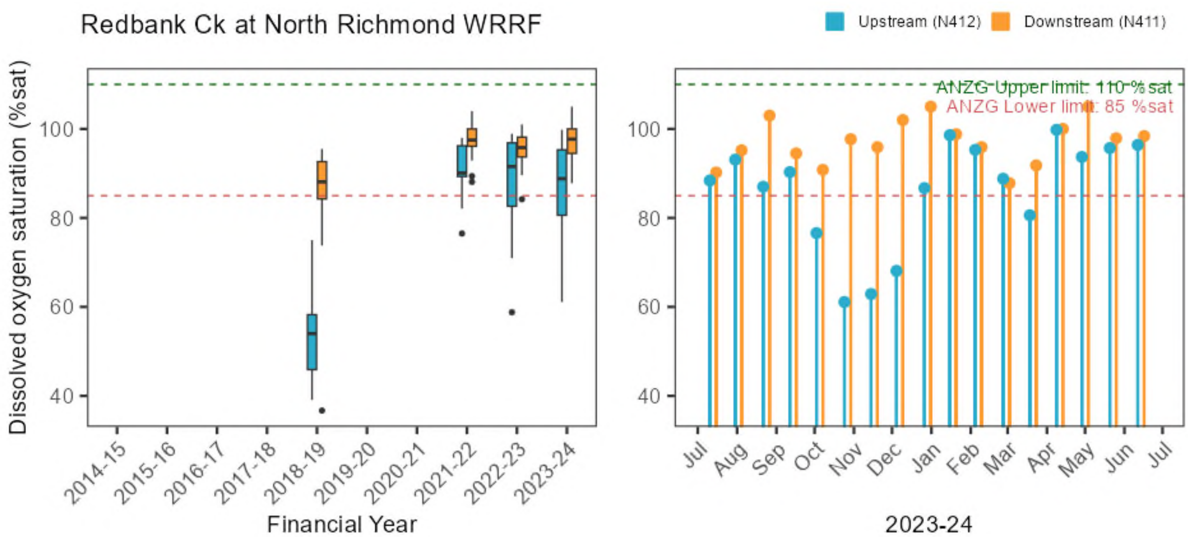

Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
0.0
0.1
0.2
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

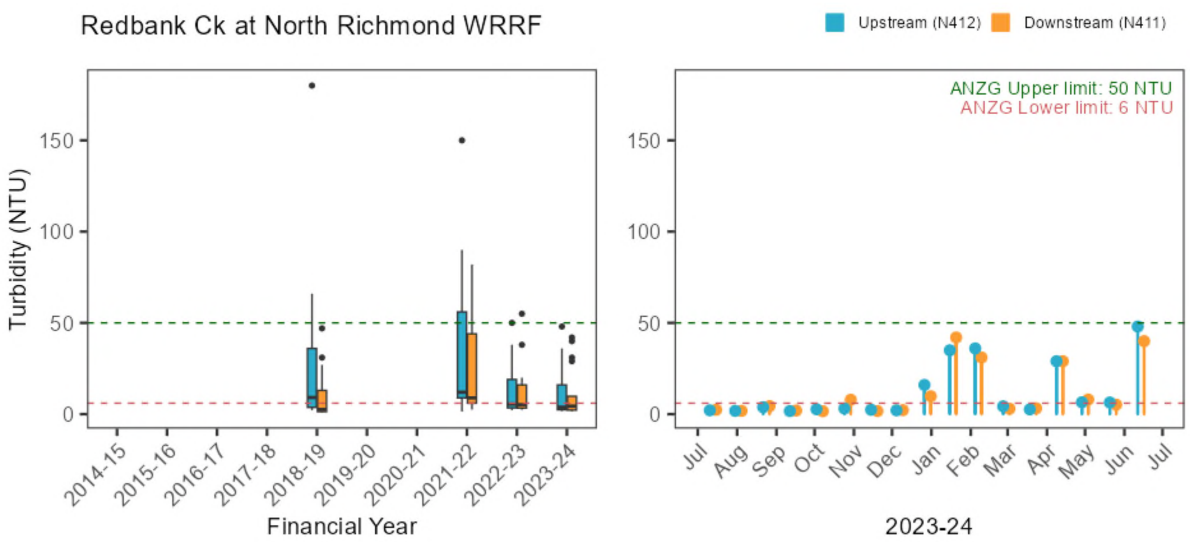

Hawkesbury R at North Richmond WRRF
Upstream (N42)
Downstream (N39)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
0.02
0.04
0.06
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Conductivity (uS/cm)
500
1000
1500
2000
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Hawkesbury R at North Richmond WRRF
Upstream (N42)
Downstream (N39)
Conductivity (uS/cm)
0
500
1000
1500
2000
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
Dissolved oxygen (mg/L)
3
5
7
9
11
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Redbank Ck at North Richmond WRRF
Upstream (N412)
Downstream (N411)
Dissolved oxygen saturation (%sat)
40
60
80
100
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24



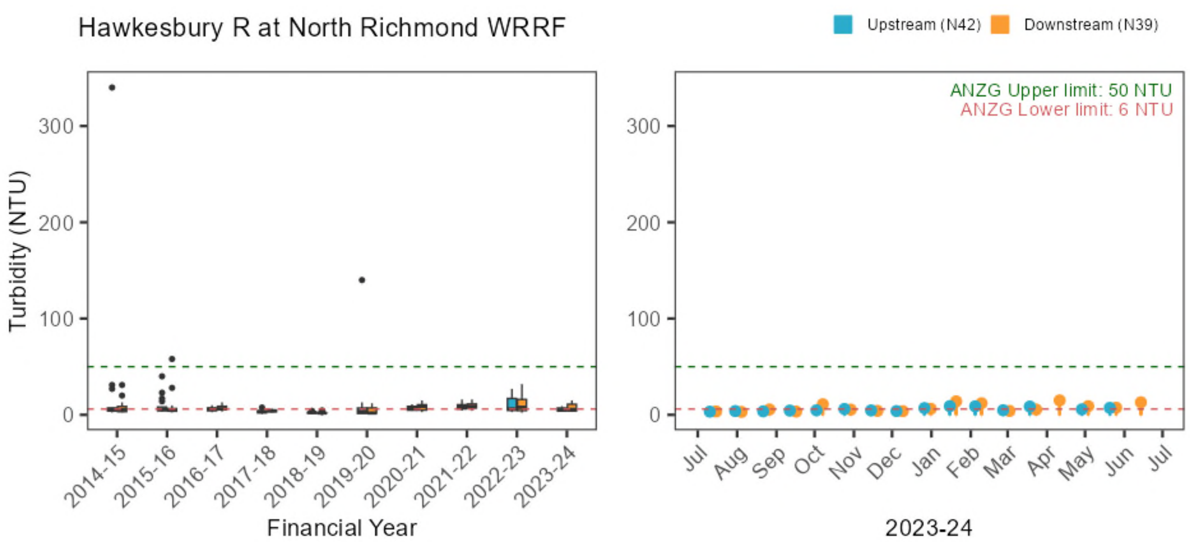


Figure 4-33 Nutrients and physico-chemical water quality exception plots, upstream and downstream of North Richmond WRRF

Ecosystem Receptor – Phytoplankton

Table 4-32 Gate 1 analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of North Richmond WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (N412)	→
Downstream tributary (N411)	→
Upstream river (N42)	↗
Downstream river (N39)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

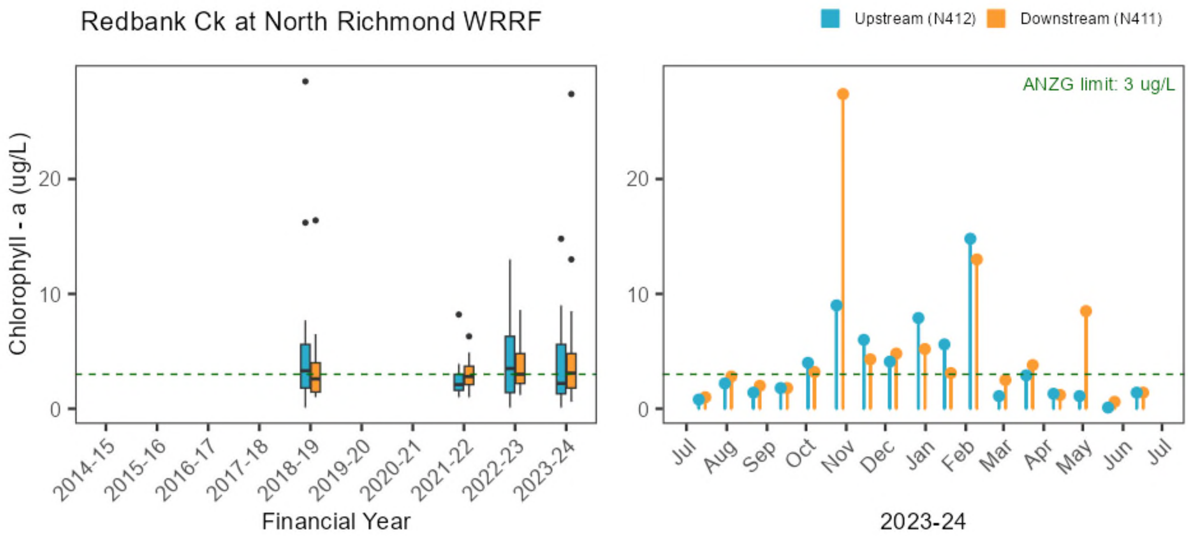
Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary current year (N412 vs N411)	-
Upstream vs downstream river (N42 vs N39)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

Chlorophyll-a concentrations were statistically steady in 2023-24 compared to the previous five years at both the upstream and downstream monitoring sites in Redbank Creek. At Nepean River upstream site (N42), the chlorophyll-a concentration has increased two folds in 2023-24 year compared to previous nine years.

In 2023-24, the median chlorophyll-a concentrations exceeded the ANZG (2018) guideline at the downstream Redbank Creek site (N411) and both the upstream and downstream Nepean River sites. At N39 chlorophyll-a reached a peak of 50.4 µg/L.

Statistical analysis confirmed no significant difference in chlorophyll-a concentration between upstream and downstream in Redbank Creek or the Hawkesbury River in 2023-24.



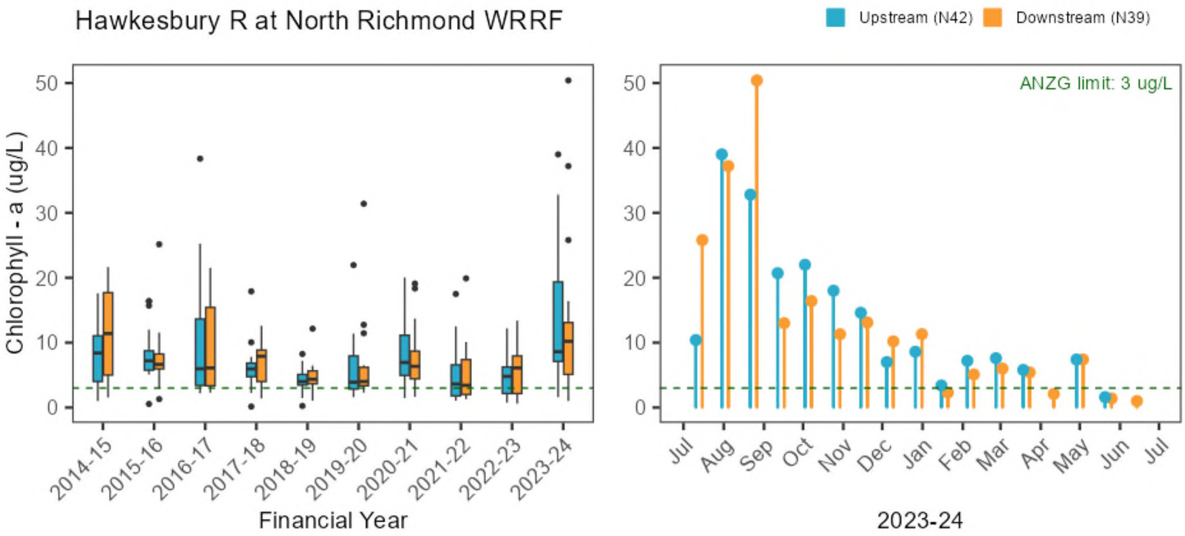


Figure 4-34 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of North Richmond WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested a localised ecosystem impact in Redbank into which North Richmond WRRF discharges. No macroinvertebrate stream health impacts were identified for the Hawkesbury River downstream of the confluence of Redbank Creek near North Richmond WRRF as indicated by the non-significant statistical outcome.

Table 4-33 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of North Richmond WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (N412 vs N411)	D
Upstream vs downstream river (N42 vs N39)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

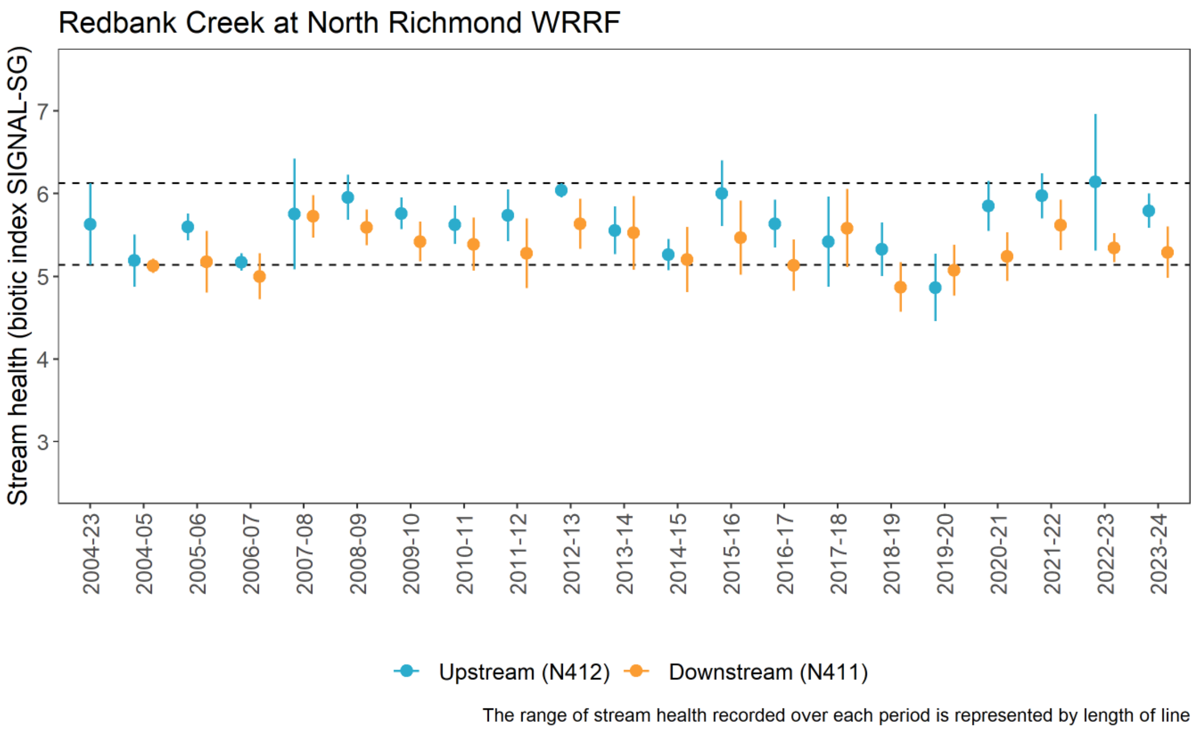


Figure 4-35 Stream health of Redbank Creek upstream and downstream of North Richmond WRRF

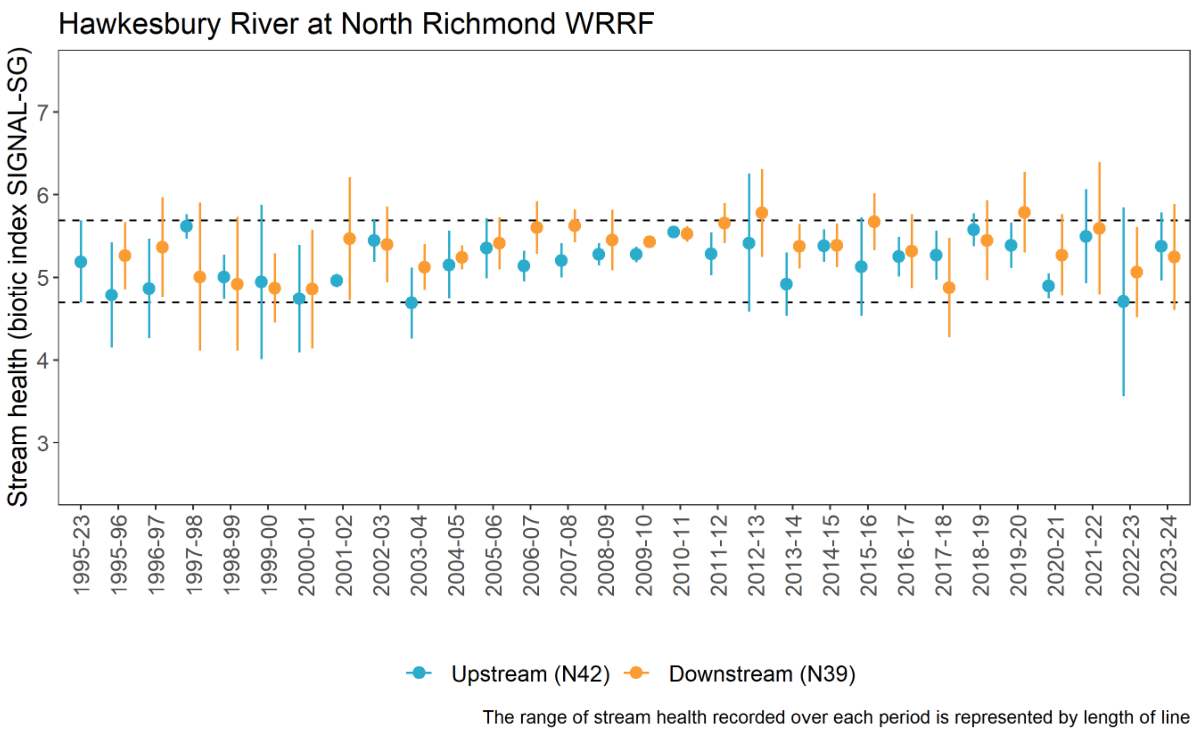


Figure 4-36 Stream health of Hawkesbury River upstream and downstream of the confluence of Redbank Creek near North Richmond WRRF

Gate 2 Synthesis of impact of North Richmond WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as chlorophyll-α		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Total ammonia nitrogen	↗	D	-	-	-	D	-	The increased nutrient concentration in the discharge from North Richmond WRRF resulted in a subsequent increase in the downstream receiving water nutrient concentrations. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D	-					
Total nitrogen	↗	D	-					
Filterable total phosphorus		D	-					
Total phosphorus	↗	D	-					
Conductivity		D	-					
Dissolved oxygen		-	-					
Dissolved oxygen saturation		D	-					
pH		-	-					
Water temperature		-	-					
Turbidity		-	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(orange)	EPL limit exceedance	(grey)	Analyte not monitored		

4.1.7. Richmond WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Richmond WRRF in 2023-24 were within the EPL limits. There was a significant increasing trend in total nitrogen concentration and a decreasing trend in total phosphorus identified in the treated discharge compared to last nine years.
- Nutrient concentrations were stable in 2023-24 compared to previous two years and no significant difference was found between upstream and downstream sites in Rickabys Creek in 2023-24.
- Chlorophyll-a was also stable compared to previous two years and no significant difference was found between upstream and downstream sites in 2023-24.
- No adverse ecological impact (as indicated by macroinvertebrates) was observed in Rickabys Creek downstream of Richmond WRRF treated discharge.

Pressure – Wastewater discharge

Table 4-34 Gate 1 Analysis outcome summary – Richmond WRRF

Analytes / Richmond WRRF	Nutrients			Conventional analytes					
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration EPA ID 16 (discharge)	→	↗	↘	→	→	→		→	→
Load EPA ID 16 (discharge)									
Concentration EPA ID 17 (reuse)	→	↗	↘	→	↗	→		→	

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge (EPA ID 16) and reuse (EPA ID 17) from Richmond WRRF were within the EPL limits during the 2023-24 period. Statistical analysis identified an increasing trend in total nitrogen and a decreasing trend in total phosphorus in the treated discharge compared to the previous nine years. Increasing trends in total nitrogen, total residual chlorine and a decreasing trend in total phosphorus concentrations was observed at the reuse monitoring point (EPA ID 17).

The increasing trend in total nitrogen concentration can be linked to high plant inflows during wet weather in the second half of 2023-24. There was a notable increase in offsite reuse during the 2023-24 reporting period compared to the previous three years with a monthly average of 48 ML supplied to University of Western Sydney's Turkey Nest Dam and Richmond Golf Course in the first half of the reporting period (July to December). During the wet months January to June 2024, the supplied average monthly reuse volume reduced to 4.5 ML. Subsequently, the volume of treated discharge to the receiving waterway (unnamed creek that flows into Rickabys Creek) increased during this period.

The increasing trend in total chlorine residual concentrations can be linked to the increased total nitrogen concentration. To keep free chlorine concentration in the recycled water supply within critical control point requirements, increased sodium hypochlorite dosing resulted in increased total residual chlorine concentrations. Sydney Water is progressing with upgrading the treatment capacity of Richmond WRRF and decommissioning North Richmond WRRF, with flows from the North Richmond catchment to be transferred to Richmond WRRF for treatment via a transfer pipeline (expected completion late 2026).

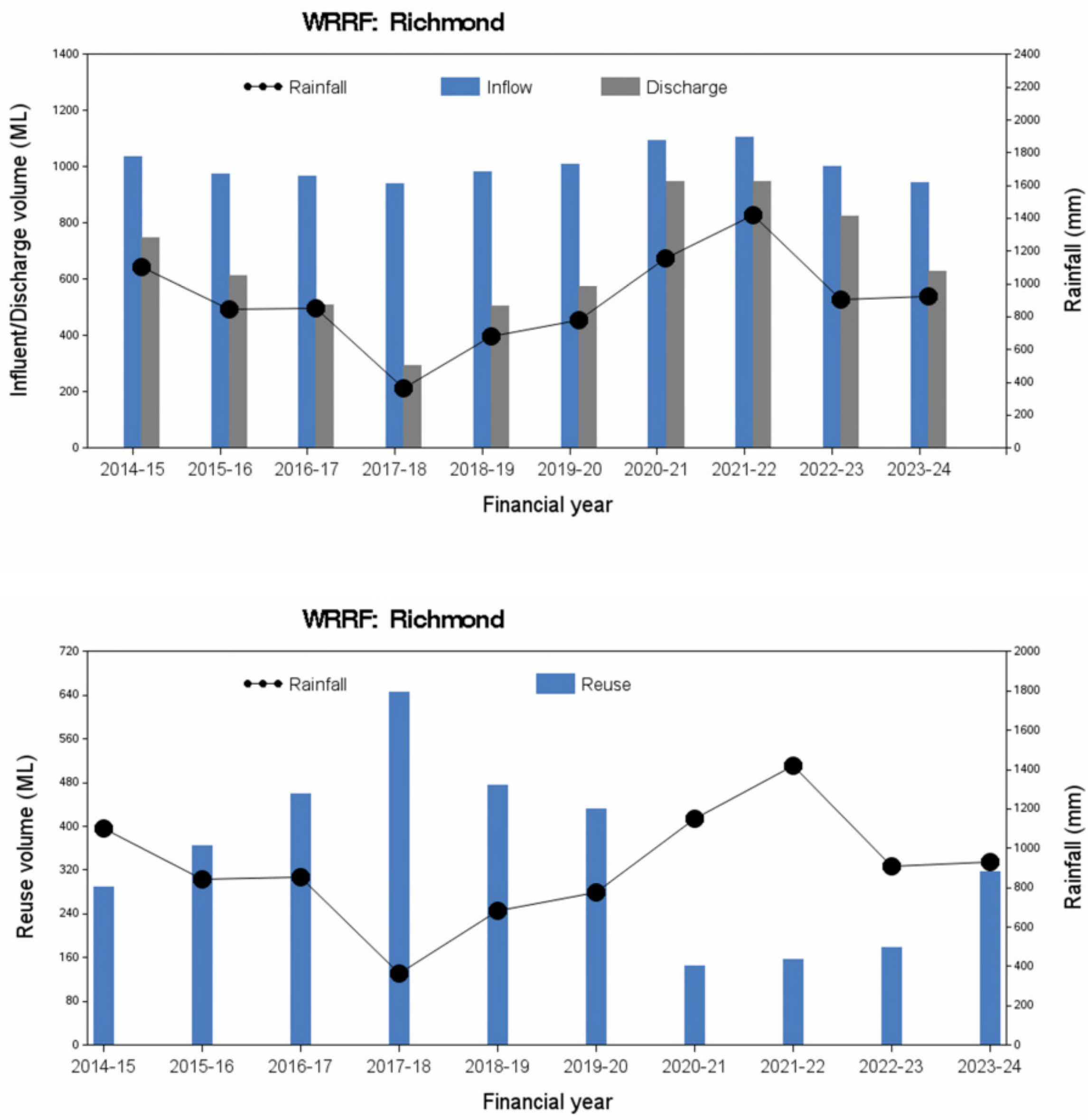
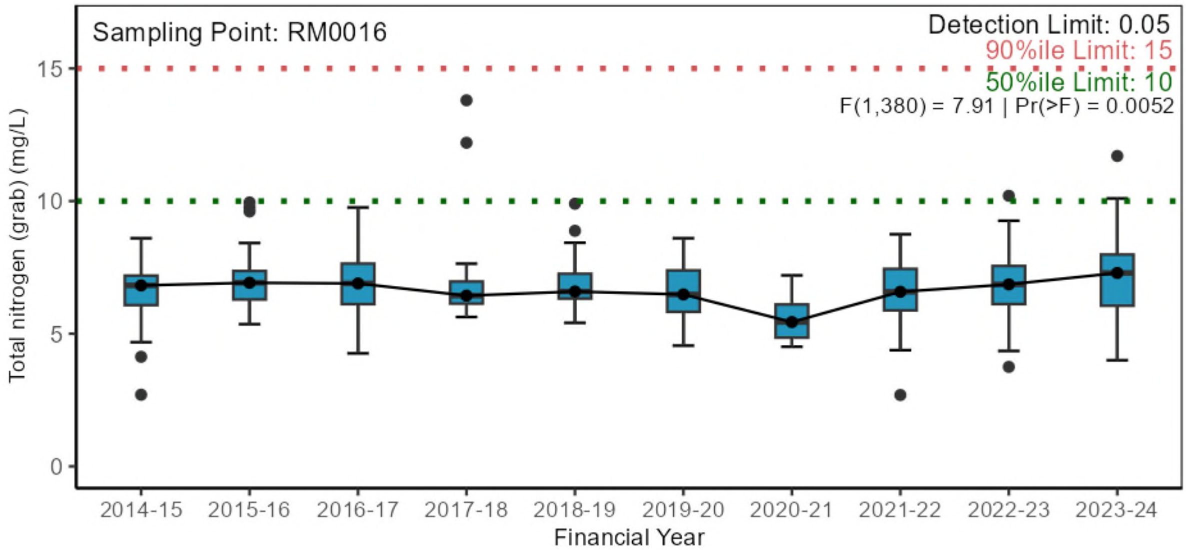
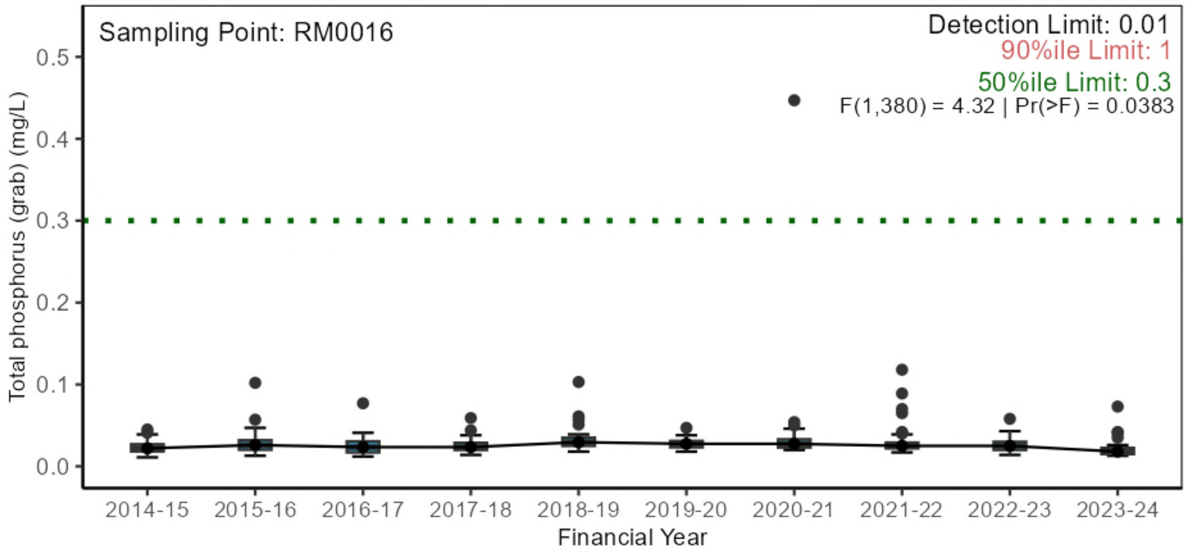


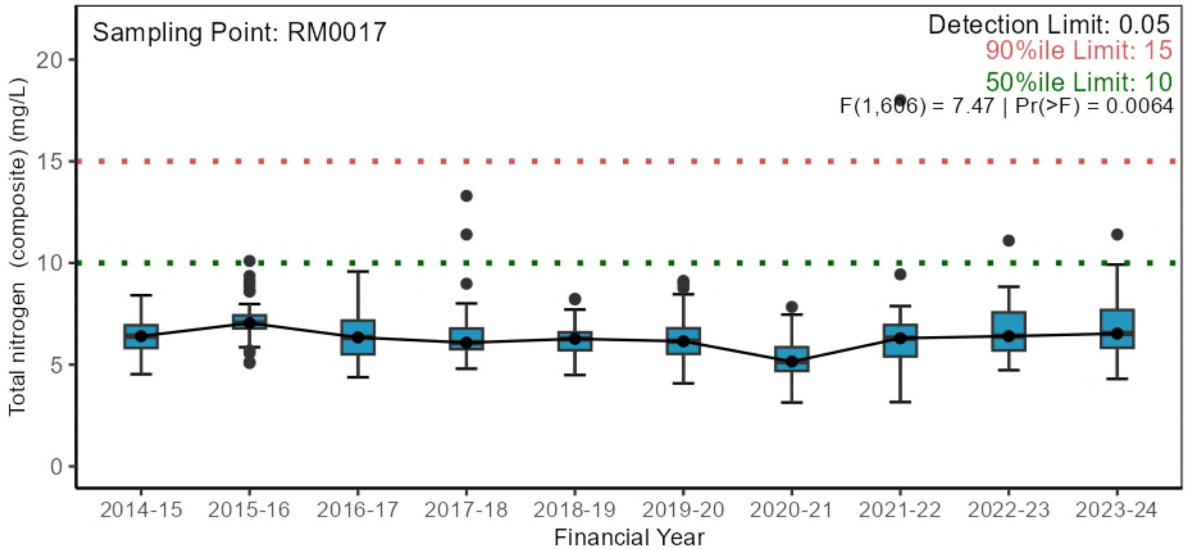
Figure 4-37 Richmond WRRF inflow, discharge and reuse volume with catchment rainfall

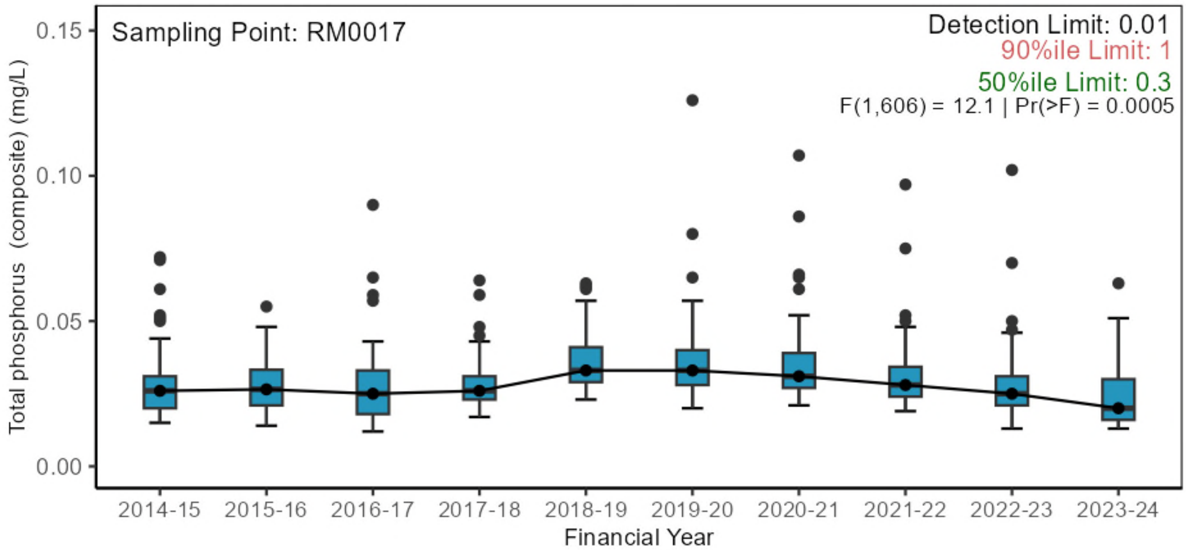


Sampling Point: RM0016
Detection Limit: 0.05
90%ile Limit: 15
50%ile Limit: 10
F(1,380) = 7.91 | Pr(>F) = 0.0052
Total nitrogen (grab) (mg/L)
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Sampling Point: RM0016
Detection Limit: 0.01
90%ile Limit: 1
50%ile Limit: 0.3
F(1,380) = 4.32 | Pr(>F) = 0.0383
Total phosphorus (grab) (mg/L)
0.5
0.4
0.3
0.2
0.1
0.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: RM0017
Detection Limit: 0.05
90%ile Limit: 15
50%ile Limit: 10
F(1,606) = 7.47 | Pr(>F) = 0.0064
Total nitrogen (composite) (mg/L)
20
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: RM0017
Detection Limit: 0.01
90%ile Limit: 1
50%ile Limit: 0.3
F(1,606) = 12.1 | Pr(>F) = 0.0005
Total phosphorus (composite) (mg/L)
0.15
0.10
0.05
0.00
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year

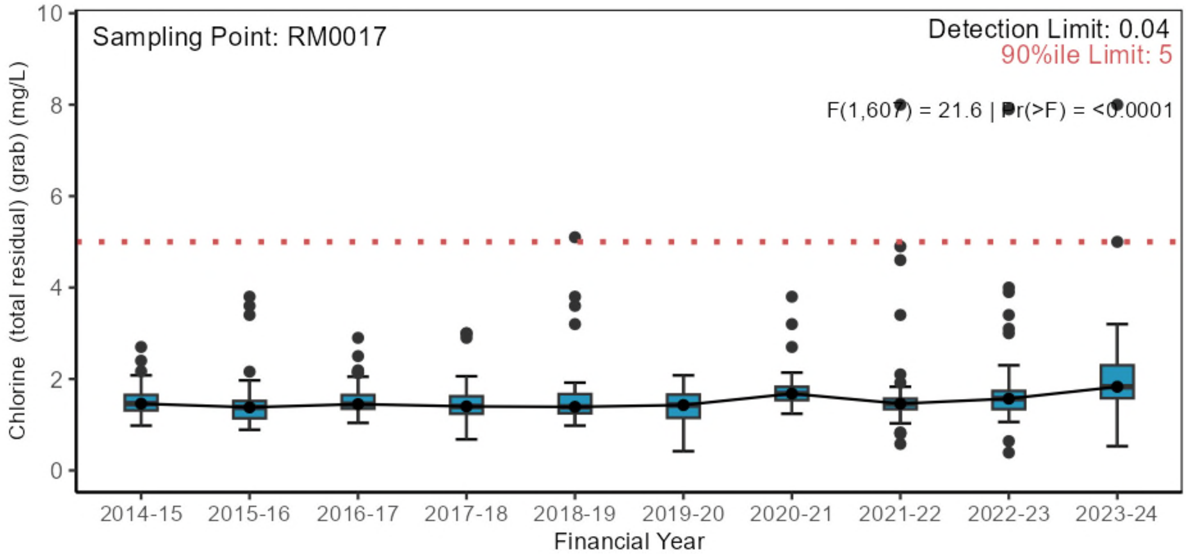


Figure 4-38 Richmond WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-35 Gate 1 Analysis outcome summary – water quality upstream and downstream of Richmond WRRF discharge point

Richmond WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (N389)	→	**→**	**→**	→	**→**	→	→	**→**	→	→	→
	Downstream tributary (N388)	→	**→**	**→**	→	**→**	↗	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(shaded)	Median value outside the guideline limit in 2023-24				

Richmond WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (N389 vs N388)	-	-	-	-	-	-	D	D	-	-	-

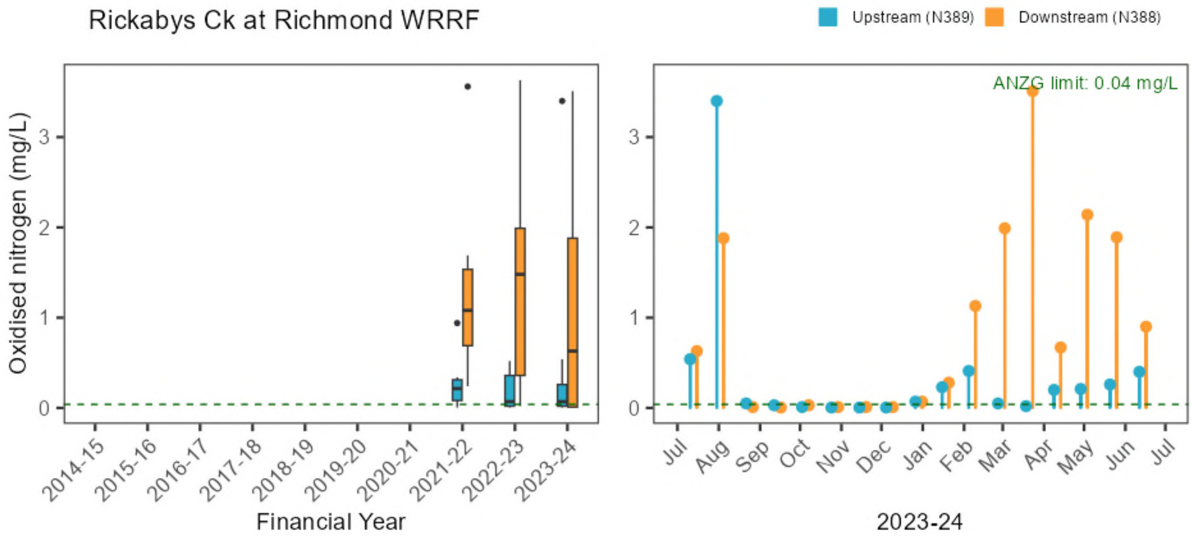
D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

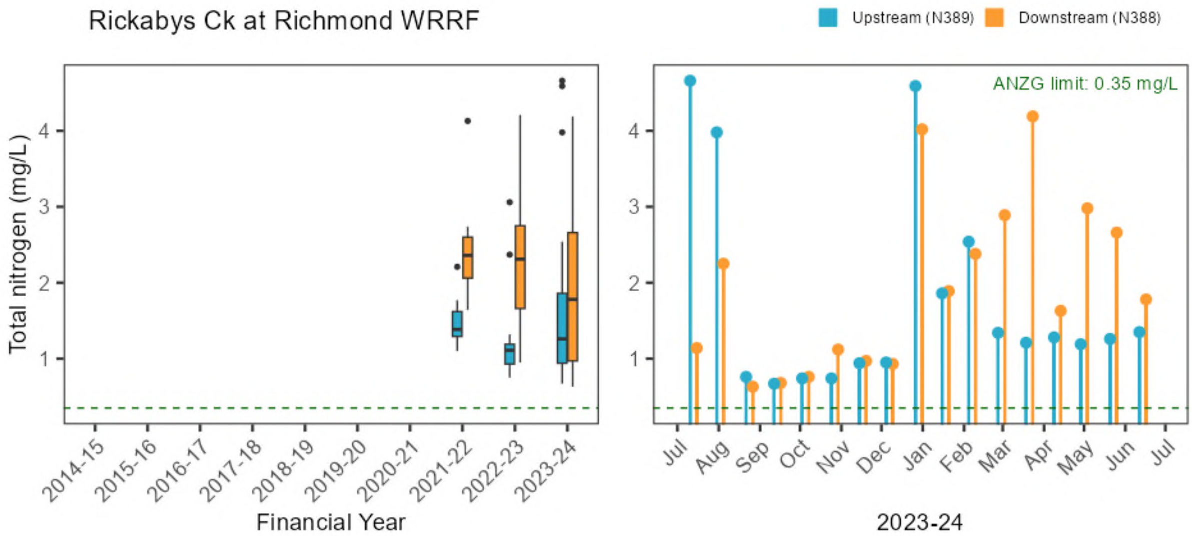
The Richmond WRRF discharges a small volume of treated effluent in an unnamed tributary that flows into Rickabys Creek (627 ML in 2023-24). The upstream catchment of Rickabys Creek is predominantly agricultural and semi-rural housing.

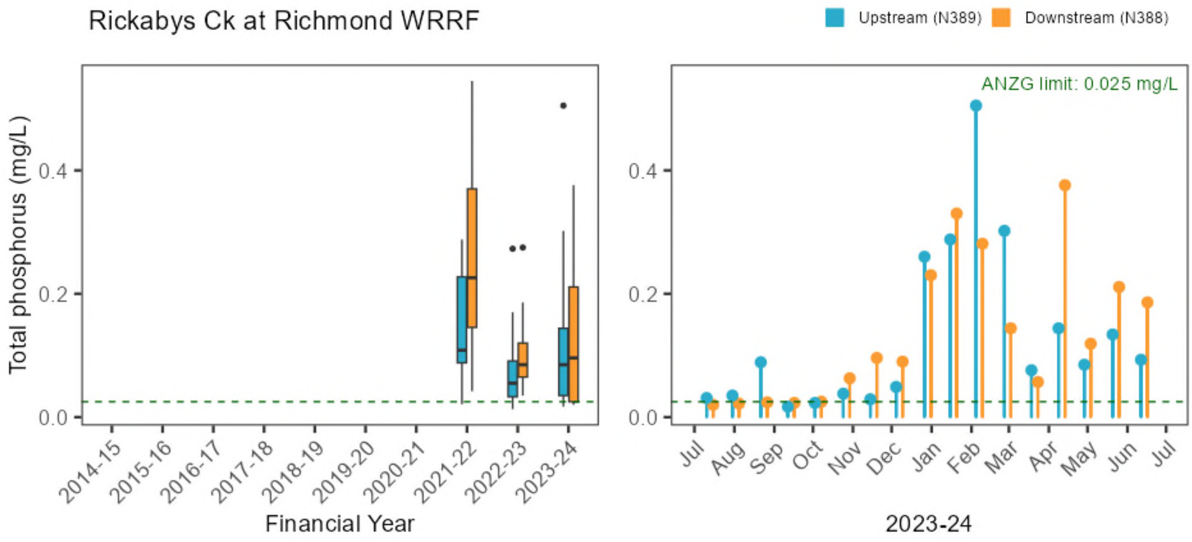
Statistical analysis confirmed that nutrient concentrations were steady in 2023-24 compared to previous two years at both Rickabys Creek sites (i.e. upstream (N389) and downstream (N388) of the tributary inflow). Conductivity significantly increased at the downstream site in 2023-24 compared to the previous two years (2021-23). At the upstream site all physico-chemical analytes were statistically steady in 2023-24 compared to previous two years.

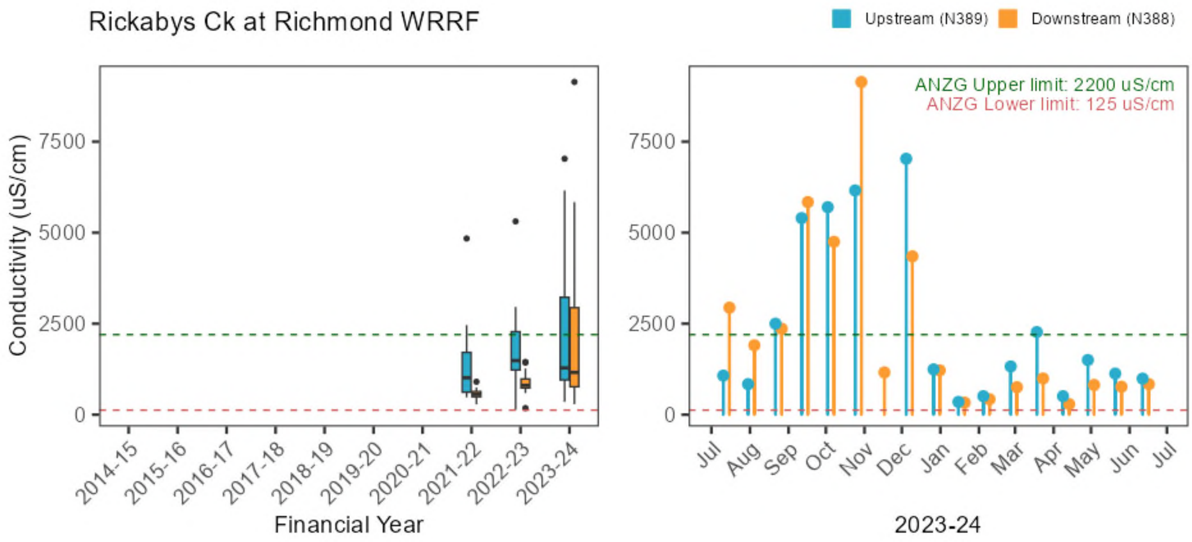
In the 2023-24 period, the median concentrations of oxidised nitrogen, total nitrogen and total phosphorus exceeded the respective ANZG (2018) guidelines at both upstream and downstream sites. Dissolved oxygen saturation was low at the upstream site (N389) with the median level lower than the ANZG (2018) guideline value.

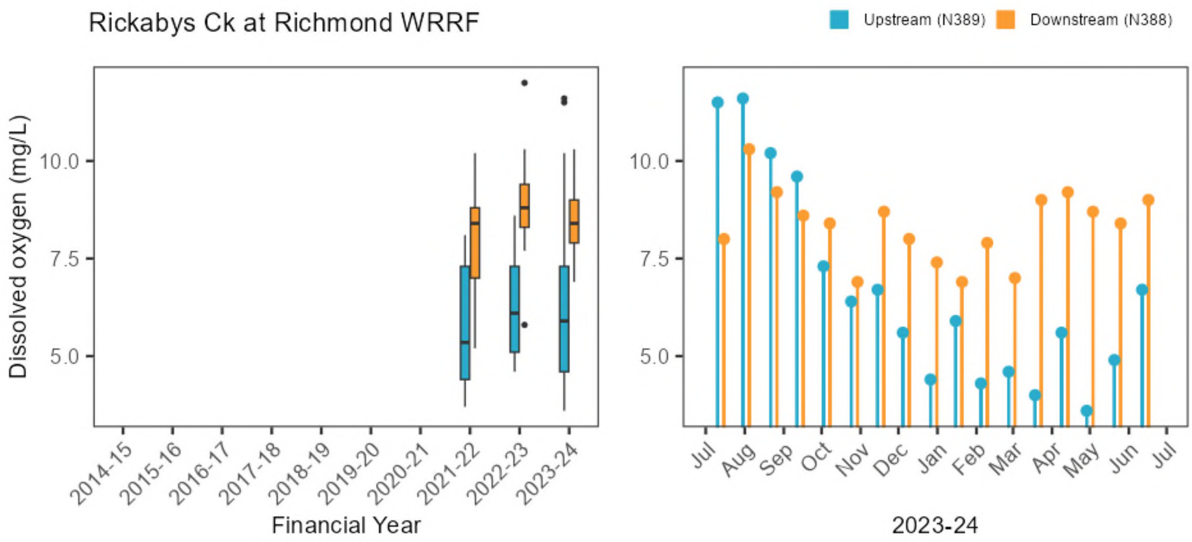
There was no statistically significant difference found in nutrients concentrations between the upstream and downstream sites indicating no influence from Richmond WRRF treated discharge. Dissolved oxygen concentration and saturation were significantly higher at the downstream Rickabys Creek site indicating a benefit from the Richmond WRRF discharge.






Rickabys Ck at Richmond WRRF
Upstream (N389)
Downstream (N388)
Total phosphorus (mg/L)
0.0
0.2
0.4
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.025 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Rickabys Ck at Richmond WRRF
Upstream (N389)
Downstream (N388)
Conductivity (uS/cm)
0
2500
5000
7500
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Rickabys Ck at Richmond WRRF
Upstream (N389)
Downstream (N388)
Dissolved oxygen (mg/L)
5.0
7.5
10.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

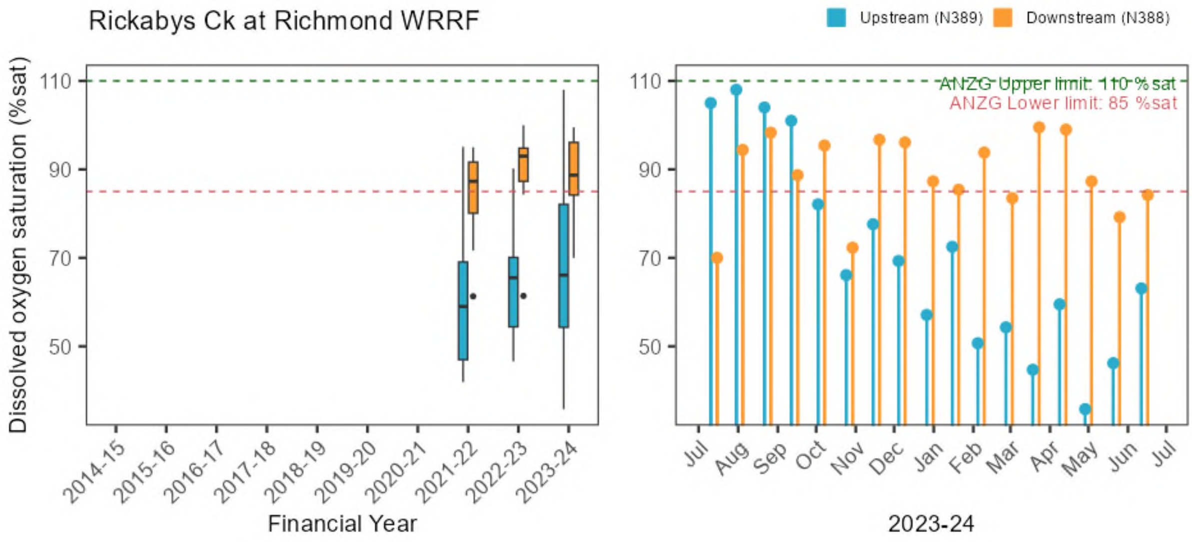


Figure 4-39 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Richmond WRRF

Ecosystem Receptor – Phytoplankton

Table 4-36 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Richmond WRRF discharge

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (N389)	→
Downstream tributary (N388)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (N389vs N388)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there were no significantly increasing/decreasing temporal trends identified for chlorophyll-a at the upstream or downstream Rickabys Creek sites compared to previous two years.

In the 2023-24 period, the median chlorophyll-a concentration exceeded the respective ANZG (2018) guidelines at both sites.

Statistical analysis also confirmed that in 2023-24 there was no significant difference found in chlorophyll-a concentration between the upstream and downstream site. However, at the upstream site, chlorophyll-a concentration was elevated in summer months, reaching a maximum of 91.1 µg/L on 29 February 2024.

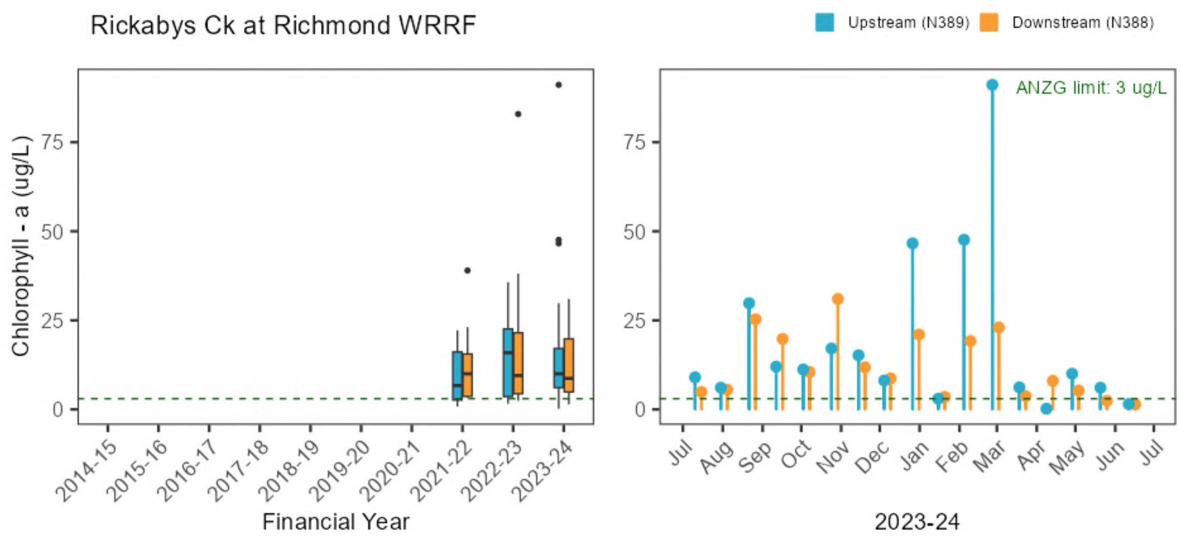


Figure 4-40 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Richmond WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested no localised ecosystem impacts in Rickabys Creek into which Richmond WRRF discharges. A SIGNAL-SG plot will be presented in future reports once more than two years of data is available for visualisation.

Table 4-37 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Richmond WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (N389 vs N388)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

Gate 2 – Synthesis of impact of Richmond WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as Chlorophyll-a	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Ammonia nitrogen	→	-	-	-	Increased nitrogen or decreased phosphorus in limited volume of Richmond discharges has no subsequent impact in downstream receiving water quality. Ecosystem health as chlorophyll-a or macroinvertebrates maintained at downstream site, no further analysis (Gate 3) to be carried out.
Oxidised nitrogen		-			
Total nitrogen	↗	-			
Filterable total phosphorus		-			
Total phosphorus	↘	-			
Conductivity		-			
Dissolved oxygen		D			
Dissolved oxygen saturation		D			
pH		-			
Temperature		-			
Turbidity		-			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.8. St Marys WRRF

- Copper exceeded the 90th percentile and average concentration limits in St Marys WRRF treated discharge during 2023-24. The South Creek bubble load limit for total phosphorus (combined St Marys, Quakers Hill and Riverstone WRRF discharge load) was also exceeded. All other parameters (concentrations and loads) were within EPL limits. There were increasing trends in total nitrogen, total phosphorus, copper and nickel concentrations in the treated discharge and a decreasing trend in ammonia nitrogen concentration compared to the last nine years.
- Nutrient concentrations at both the upstream and downstream South Creek sites were steady in 2023-24 compared to the previous five years.
- Oxidised and total nitrogen concentrations at the downstream South Creek site were significantly higher than the upstream site. This indicates a possible link with the increased concentrations in St Marys WRRF treated discharge.
- Chlorophyll-a concentrations remained stable compared to the previous five years and no significant difference was found in 2023-24 between upstream and downstream sites.
- Stream health, as indicated by macroinvertebrates, was impacted at the upstream South Creek site. Stream health at downstream South Creek site improved with no adverse ecological impact observed from the St Marys WRRF discharge.

Pressure – Wastewater discharge

Table 4-38 Gate 1 Analysis outcome summary – St Marys WRRF

Analytes / St Marys WRRF	Nutrients			Conventional analytes					
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration	↘ (within EPL limit)	↗ (within EPL limit)	↗ (within EPL limit)	→ (within EPL limit)	→ (within EPL limit)	→ (within EPL limit)	(not required)	→ (within EPL limit)	→ (within EPL limit)
Load	(not required)	(within EPL limit)	(EPL limit exceedance)	(within EPL limit)	(not required)	(not required)	(within EPL limit)	(within EPL limit)	(not required)

Analytes / St Marys WRRF	Trace Metals										Other		
	Aluminium	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Selenium	Zinc	Diazinon	Hydrogen sulfide (un-ionised)	Pesticides and PCBs
Concentration	→ (within EPL limit)	(not required)	(not required)	↗ (EPL limit exceedance)	→ (within EPL limit)	(not required)	(not required)	↗ (within EPL limit)	(not required)	→ (within EPL limit)	→ (within EPL limit)	→ (within EPL limit)	(not required)
Load	(not required)	(within EPL limit)	(within EPL limit)	(within EPL limit)	(not required)	(within EPL limit)	(within EPL limit)	(not required)	(within EPL limit)	(within EPL limit)	(not required)	(not required)	(within EPL limit)

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

The 90th percentile and average concentration limits for copper in the treated discharge from St Marys WRRF were exceeded during the 2023-24 reporting period. All other concentration values in the St Marys WRRF treated discharge were within EPL limits. The South Creek bubble load limit (combined St Marys, Quakers Hill and Riverstone WRRF discharge load) for total phosphorus was also exceeded during the 2023-24 reporting period. All other load values in the St Marys WRRF discharge were within EPL limits.

Statistical analysis identified significantly increasing trends in the concentrations of total nitrogen, total phosphorus, copper and nickel during 2023-24 compared to the previous nine years. Ammonia nitrogen concentration was observed to have a decreasing trend.

St Marys WRRF has been progressively amplified and upgraded over the past three years. This has resulted in improvements in key pollutant effluent parameters, including ammonia. More recently, significant technology changes in biosolids treatment included the commissioning of a Thermal Hydrolysis Process (THP), yielding significant benefits in terms of greater biosolids optimisation, reduced infrastructure footprint, potential to act on more chemical contaminants and ability to generate renewable energy.

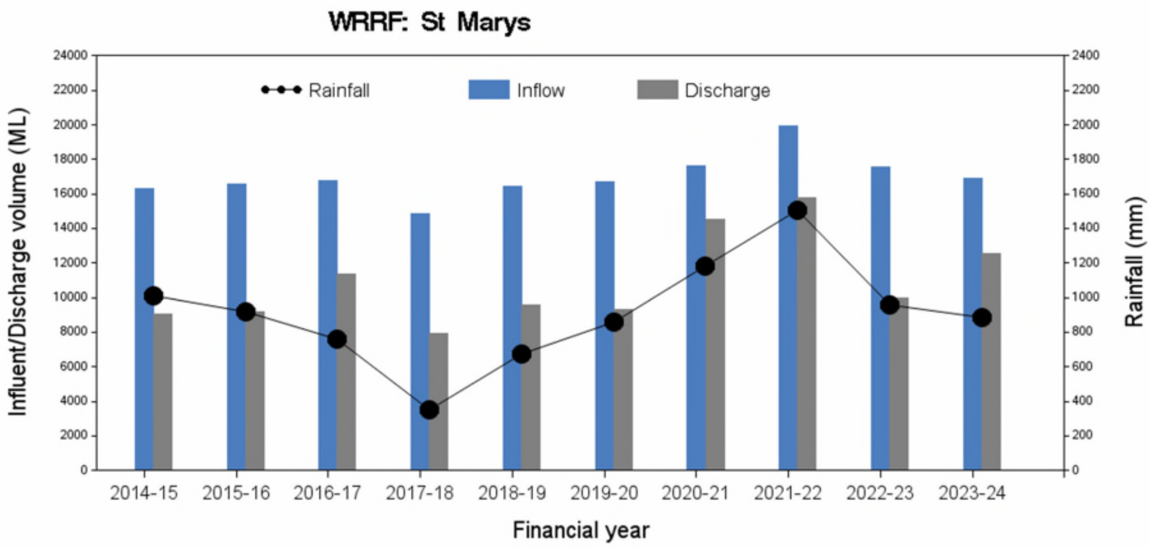
The increasing trend of total nitrogen and total phosphorus can be linked to operational changes from the Lower South Creek Treatment Upgrade Program. As part of the upgrade, two aerobic digesters have been converted into anaerobic digesters, resulting in an increase in nitrogen and phosphorus concentration returning to the process stream. As a partial remedy, methanol dosage was gradually increased to improve denitrification. Ongoing process optimisation is in progress to address this trend.

The new THP has caused significant changes to the biosolids process, affecting the movement and incidental capture of metals resulting in a transfer of mass from the biosolids stream to the liquid effluent stream. Centrate returns are reintroducing copper back into the treatment process, compounding copper concentration in the final effluent resulting in the St Marys WRRF discharge exceeding the 90th percentile and average concentration limits for copper. It can also be linked to the increasing trends in nickel concentration within the final effluent. Due to these technology changes, the copper limits under EPL 1729 are no longer able to be achieved.

The EPA granted an LVA (6 August 2024), allowing St Marys WRRF to increase the 90th percentile copper concentration limit to 50 µg/L and replace the average limit with a 50th percentile limit of 25 µg/L. In addition, the EPA added a Special Condition onto EPL 1729 (E3) requiring Sydney Water to review and assess ongoing copper discharge concentrations and concentrations in unnamed Creek and South Creek, as well as investigate source control and treatment options to reduce the impacts of copper discharged to the receiving waterways.

The South Creek Bubble total phosphorus load limit exceedance was largely due to wet weather events in the catchment between January and April 2024 with all three facilities within the South Creek Bubble operating under wet weather conditions. St Marys WRRF contributed 37.4% of the total phosphorus load from 43.7% of the total flow from the three South Creek Bubble facilities.

Sydney Water has commenced discussions with the EPA on reviewing concentration and load limit exceedances associated with rainfall events, including the initiation of environmental assessments at five WRRFs (St Marys, Hornsby Heights, West Hornsby, Quakers Hill and Wollongong).



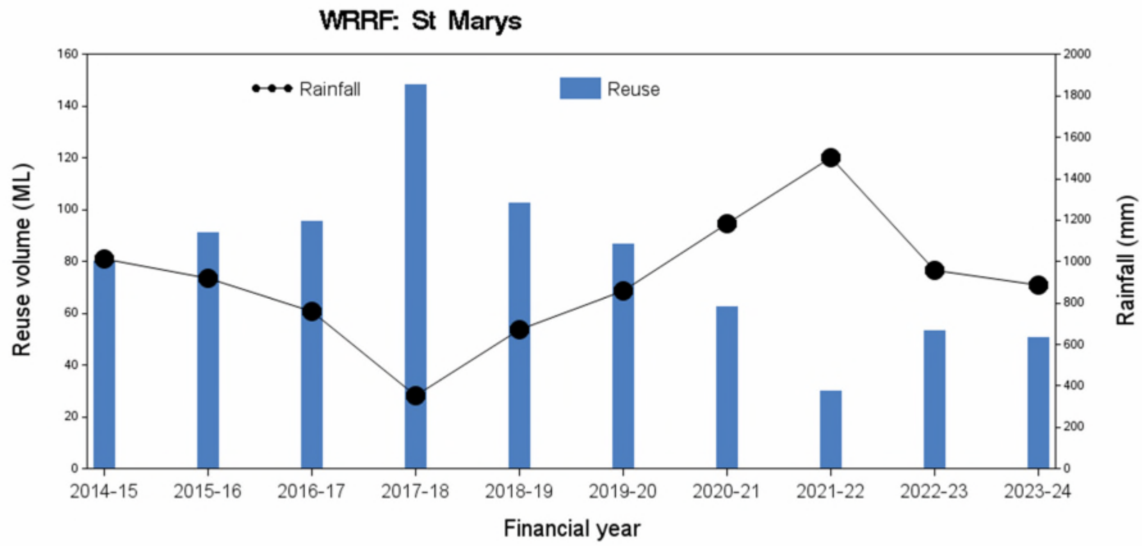
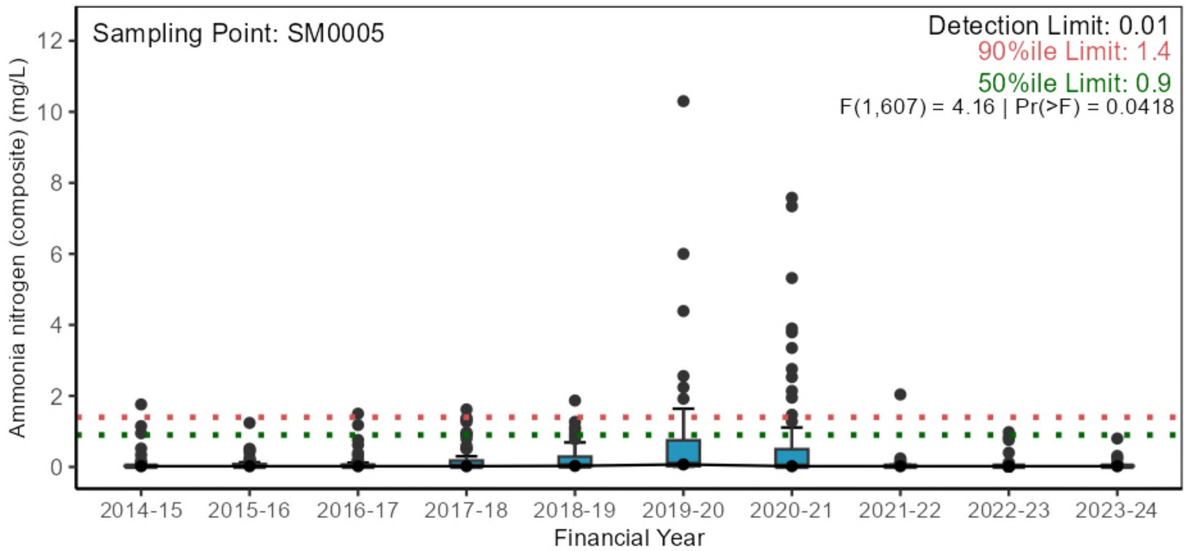
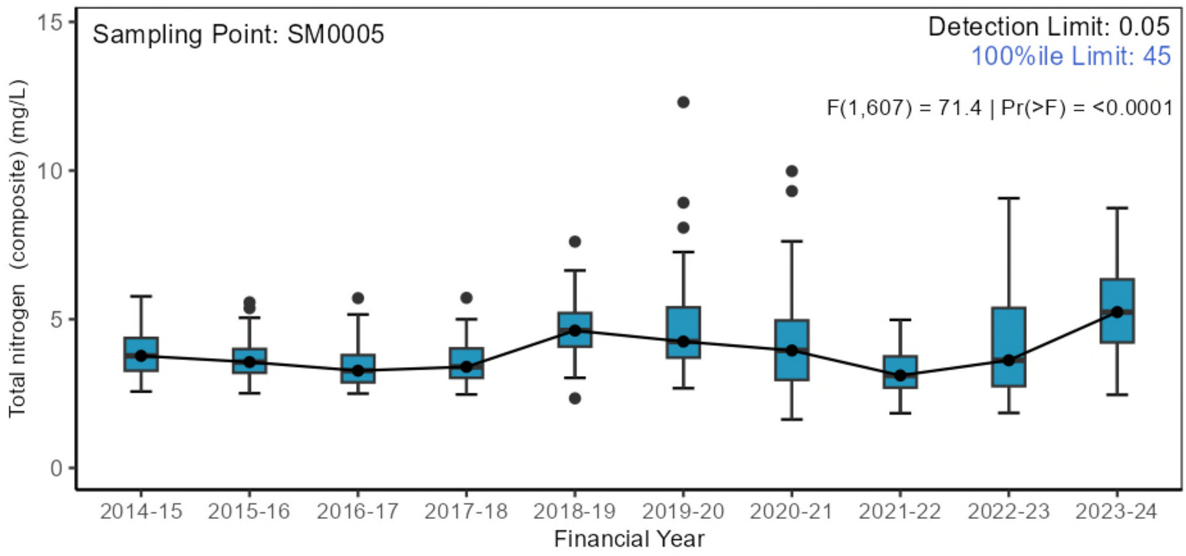
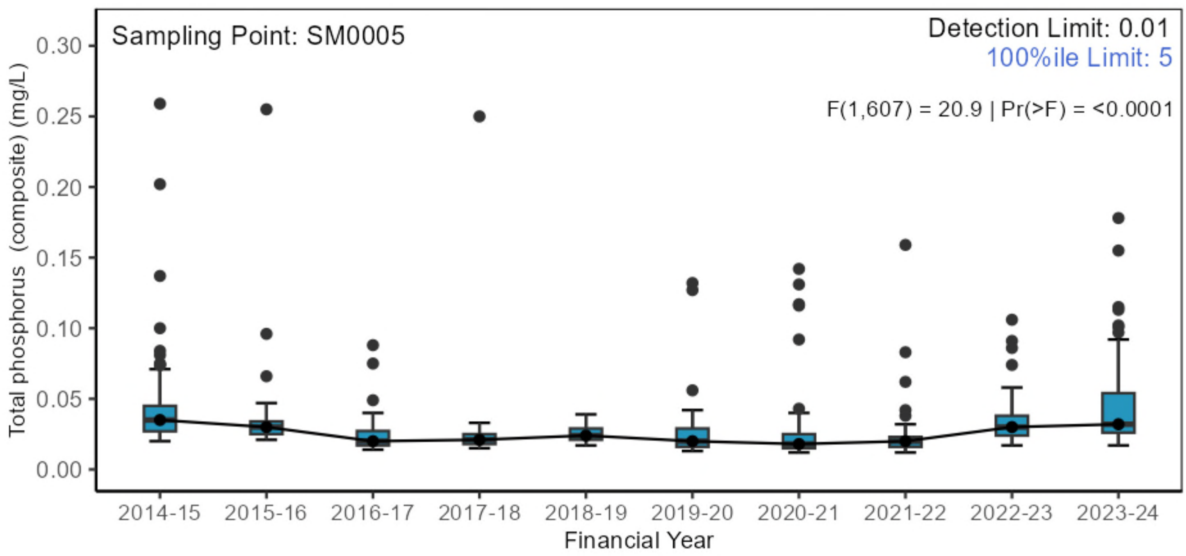
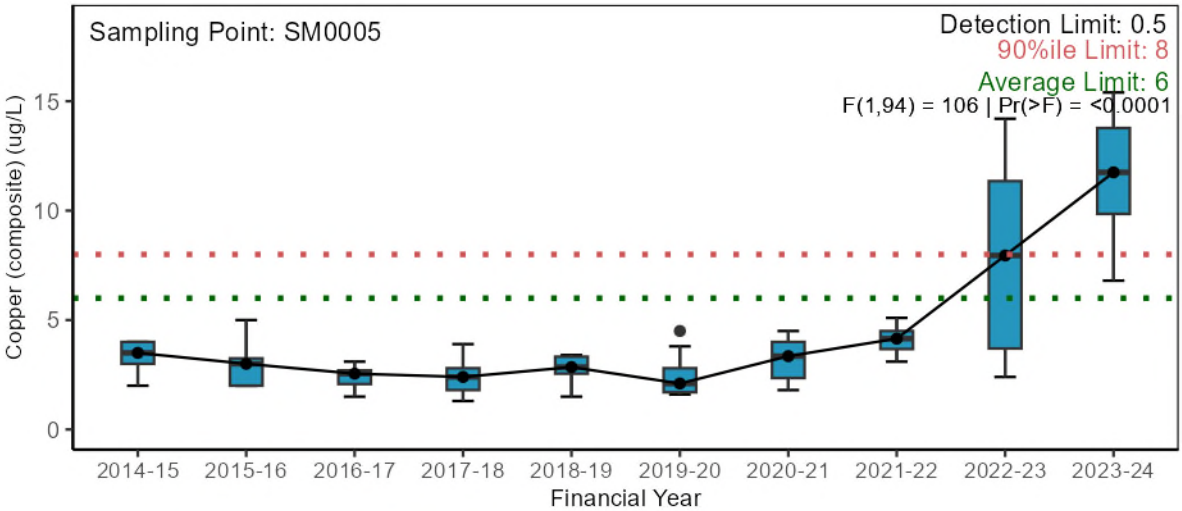


Figure 4-41 St Marys WRRF inflow, discharge and reuse volume with catchment rainfall

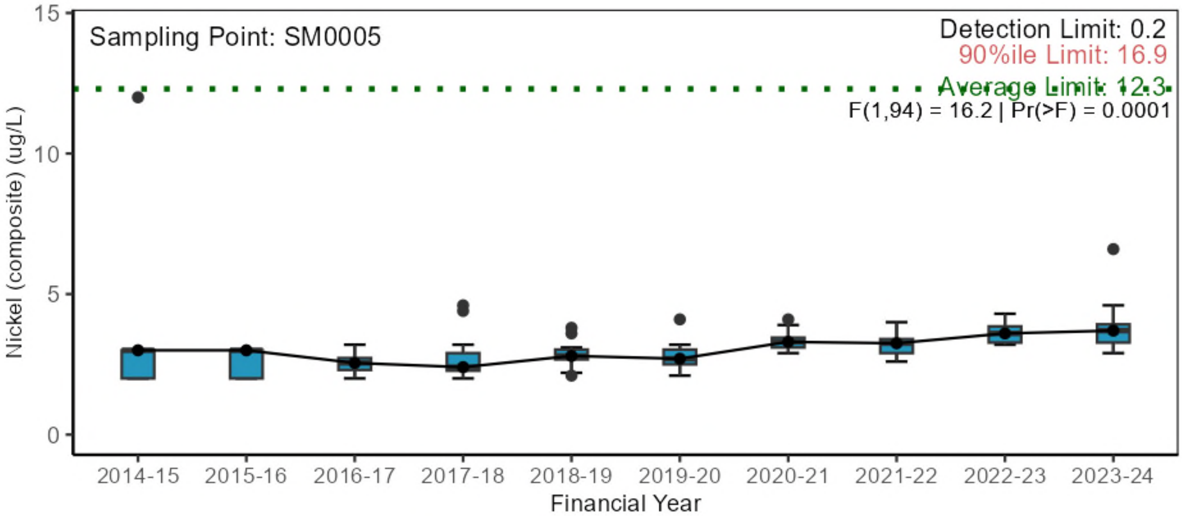



Sampling Point: SM0005
Detection Limit: 0.05
100%ile Limit: 45
F(1,607) = 71.4 | Pr(>F) = <0.0001
Total nitrogen (composite) (mg/L)
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: SM0005
Detection Limit: 0.01
100%ile Limit: 5
F(1,607) = 20.9 | Pr(>F) = <0.0001
Total phosphorus (composite) (mg/L)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Statistical test excludes data prior to 2016-17 due to method detection limit change.



Statistical test excludes data prior to 2016-17 due to method detection limit change.

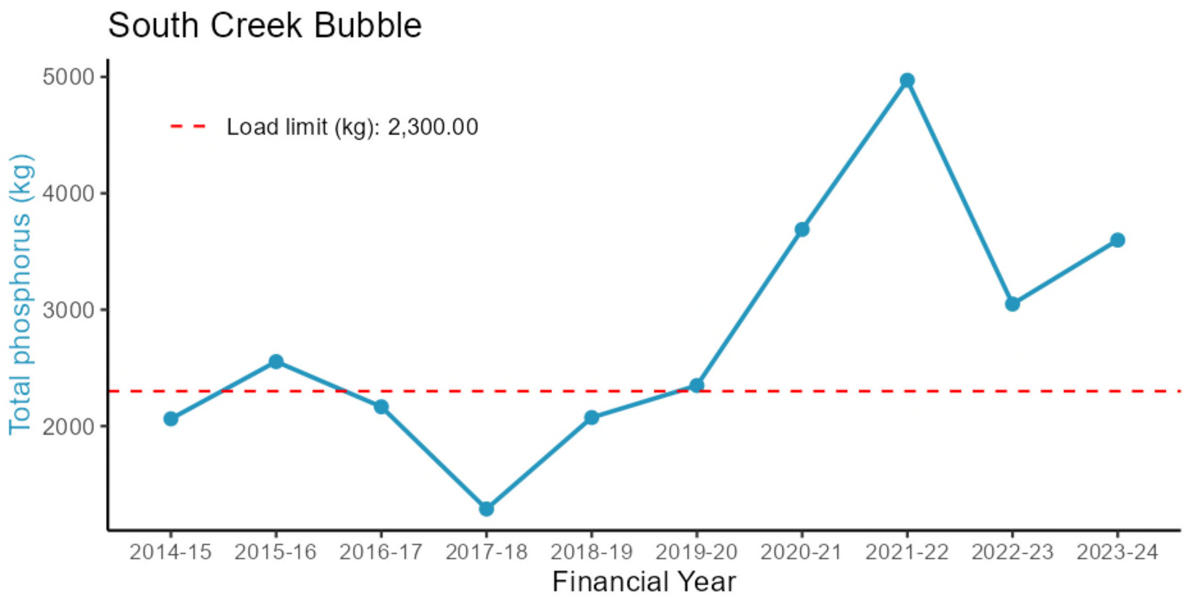


Figure 4-42 St Marys WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-39 Gate 1 Analysis outcome summary – water quality upstream and downstream of St Marys WRRF discharge point

St Marys WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NS242)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Downstream tributary (NS241)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Creek	Upstream creek (NS26)	→	→	→	→	→	→	→	↗	→	→	→
	Downstream creek (NS23A)	→	→	→	→	→	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

St Marys WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NS242 vs NS241)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
River	Upstream vs downstream current year (NS26 vs NS23A)	-	D	D	-	-	-	-	-	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

NA - Statistical comparison not conducted due to only one financial year of data

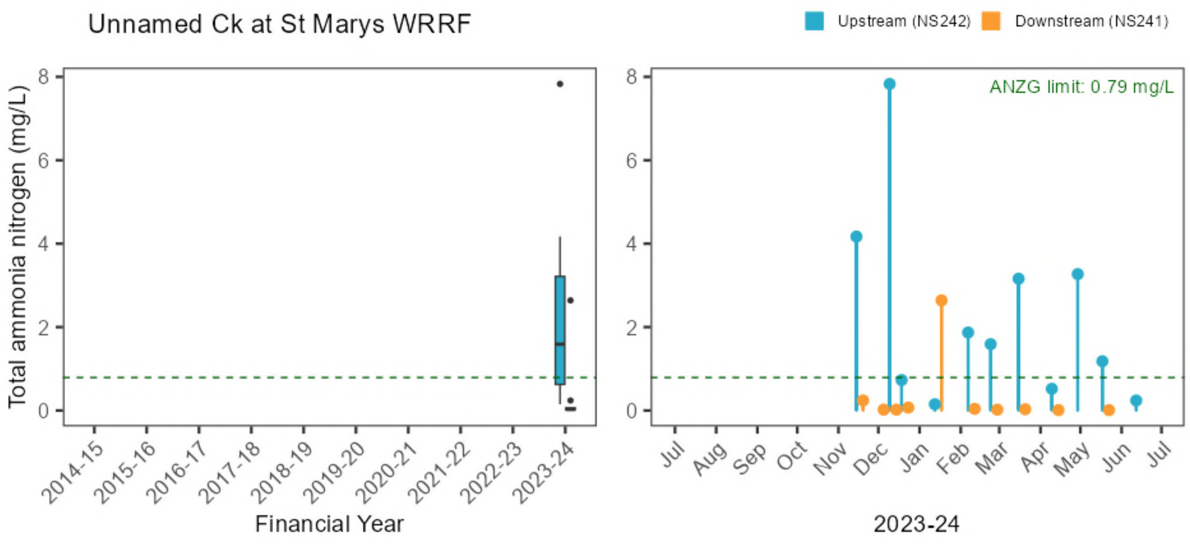
St Marys WRRF discharges into an unnamed tributary before joining South Creek and then the Hawkesbury River. The land upstream of South Creek is predominantly rural including grazing, market gardening and other intensive agriculture such as poultry farming. It also has residential and industrial land uses that have increased in recent years. Monitoring commenced at the unnamed creek upstream and downstream of St Marys WRRF discharge point from November 2023.

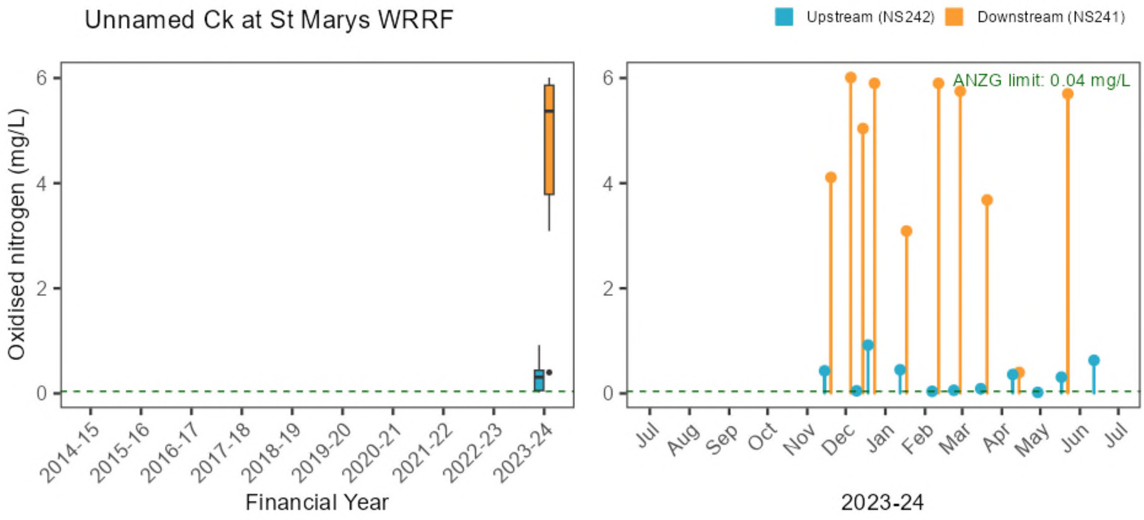
Statistical analysis confirmed that nutrient concentrations were steady in 2023-24 compared to previous five years at both South Creek sites. Dissolved oxygen saturation increased significantly at the upstream site in 2023-24 compared to the previous five years. At the downstream all physico-chemical analytes were statistically steady in 2023-24 compared to previous years.

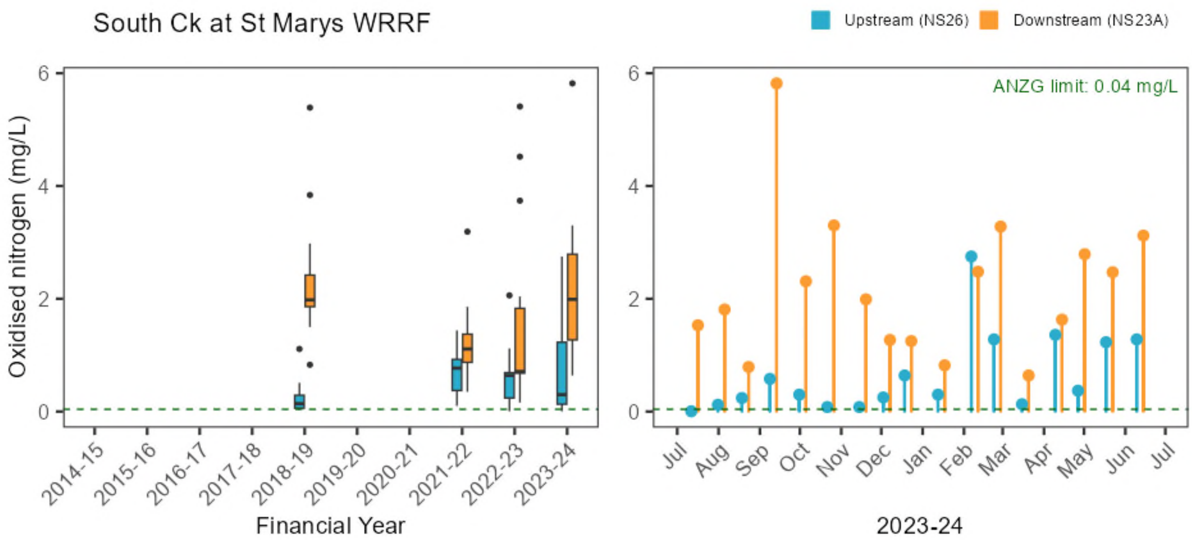
In the 2023-24 period, the median concentrations of oxidised nitrogen, total nitrogen and total phosphorus exceeded the respective ANZG (2018) guidelines at both upstream and downstream sites of unnamed creek and South Creek. Median total ammonia nitrogen concentration only exceeded the guideline at the upstream unnamed creek site.

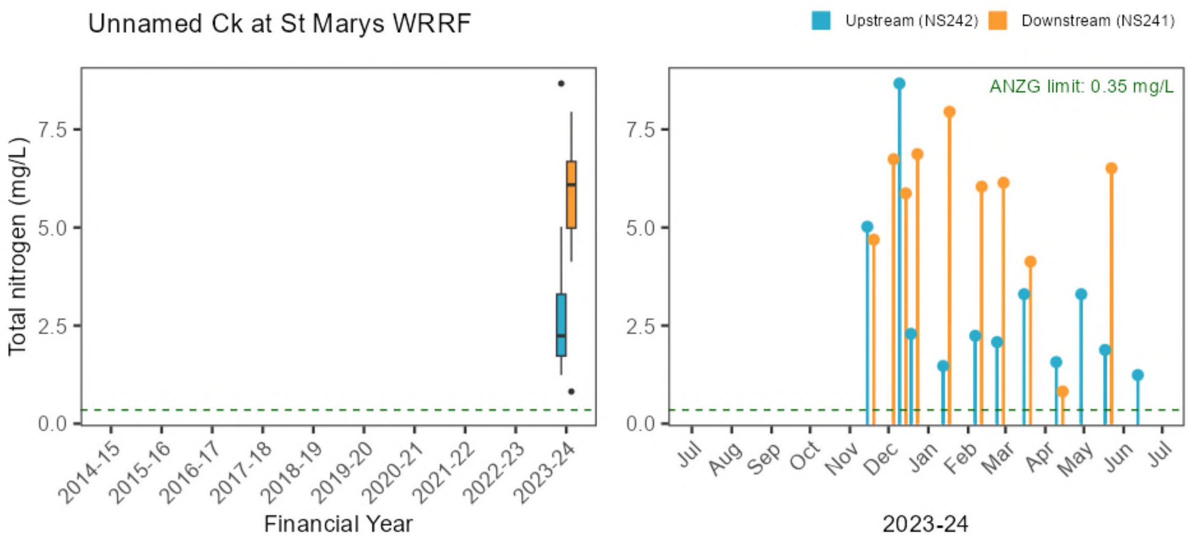
The median dissolved oxygen saturation was less than the lower guideline limit at upstream unnamed tributary and upstream South Creek site. The median turbidity was less than the lower guideline at downstream unnamed tributary and exceeded the upper guideline at upstream South Creek site.

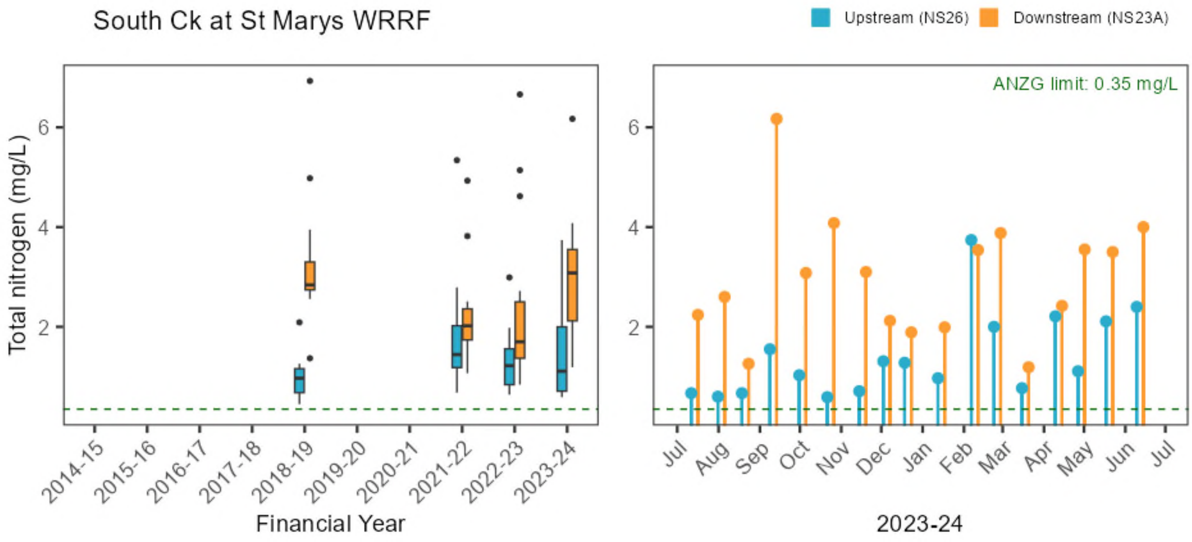
Oxidised and total nitrogen concentrations at the downstream South Creek site were significantly higher than the upstream site. This reflects the increasing trend in nitrogen concentration in St Marys WRRF treated discharges.

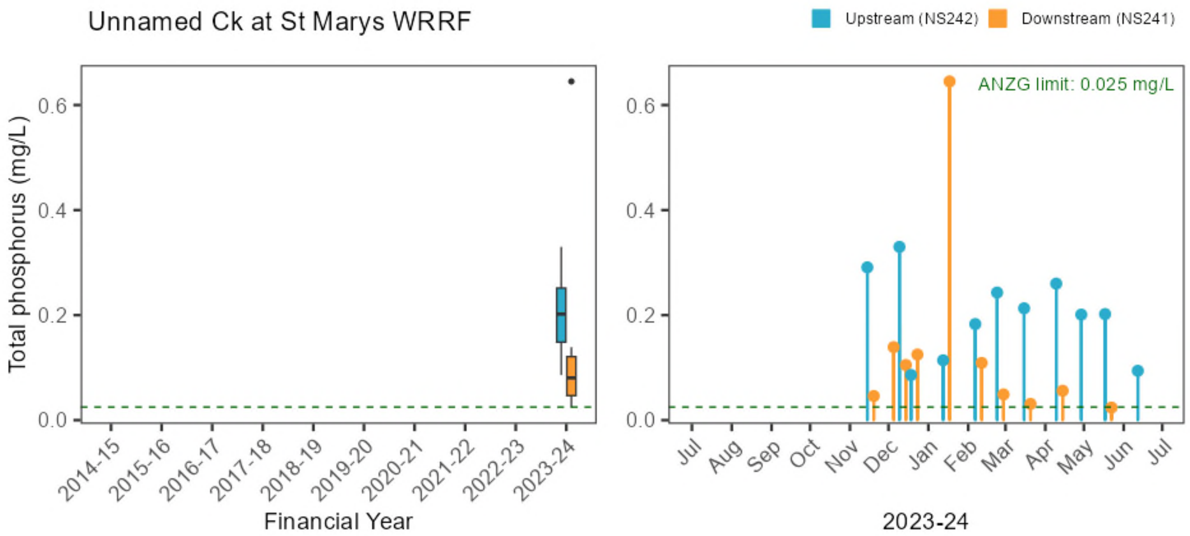



Unnamed Ck at St Marys WRRF
Upstream (NS242)
Downstream (NS241)
Oxidised nitrogen (mg/L)
ANZG limit: 0.04 mg/L
Financial Year
2023-24


South Ck at St Marys WRRF
Upstream (NS26)
Downstream (NS23A)
Oxidised nitrogen (mg/L)
ANZG limit: 0.04 mg/L
Financial Year
2023-24


Unnamed Ck at St Marys WRRF
Upstream (NS242)
Downstream (NS241)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
Financial Year
2023-24


South Ck at St Marys WRRF
Upstream (NS26)
Downstream (NS23A)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Unnamed Ck at St Marys WRRF
Upstream (NS242)
Downstream (NS241)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Jul
Aug
Sep
Oct
Nov
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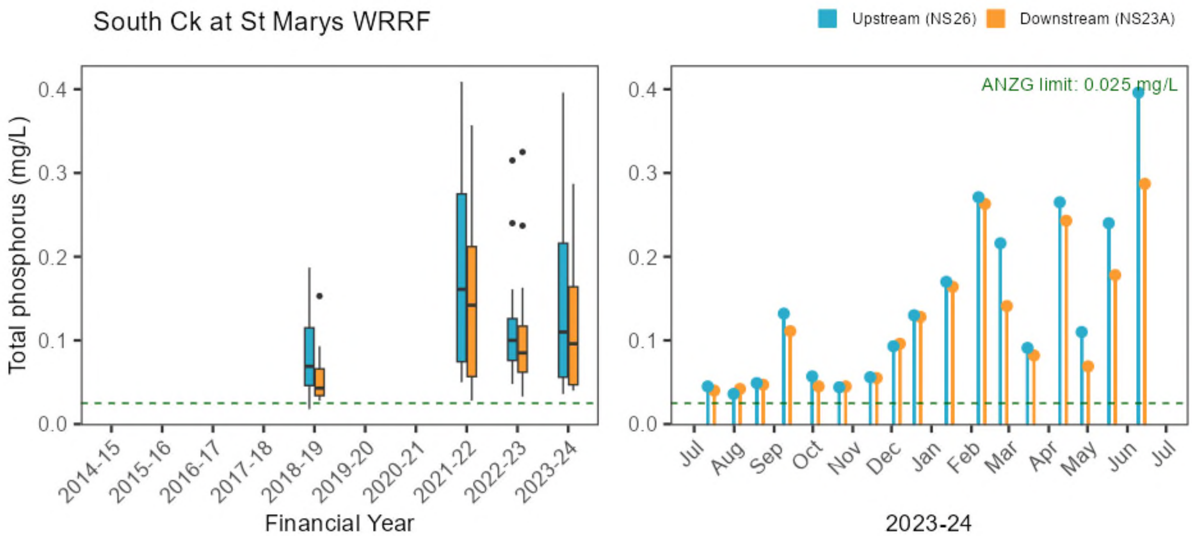
Apr
May
Jun
Jul
2023-24


South Ck at St Marys WRRF
Upstream (NS26)
Downstream (NS23A)
ANZG limit: 0.025 mg/L
Total phosphorus (mg/L)
Financial Year
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Jul
Aug
Sep
Oct
Nov
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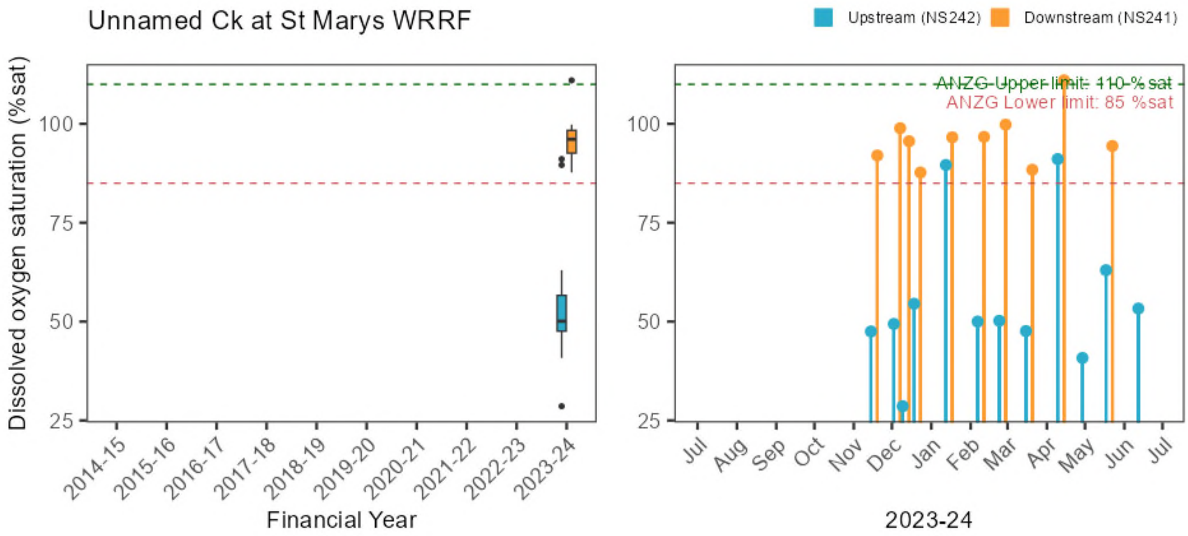
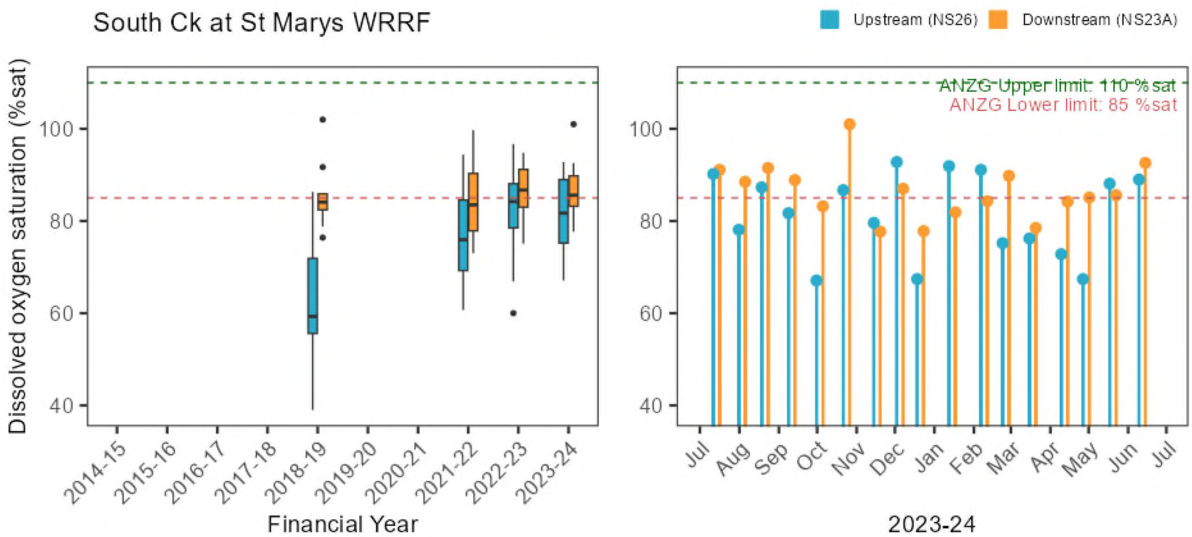
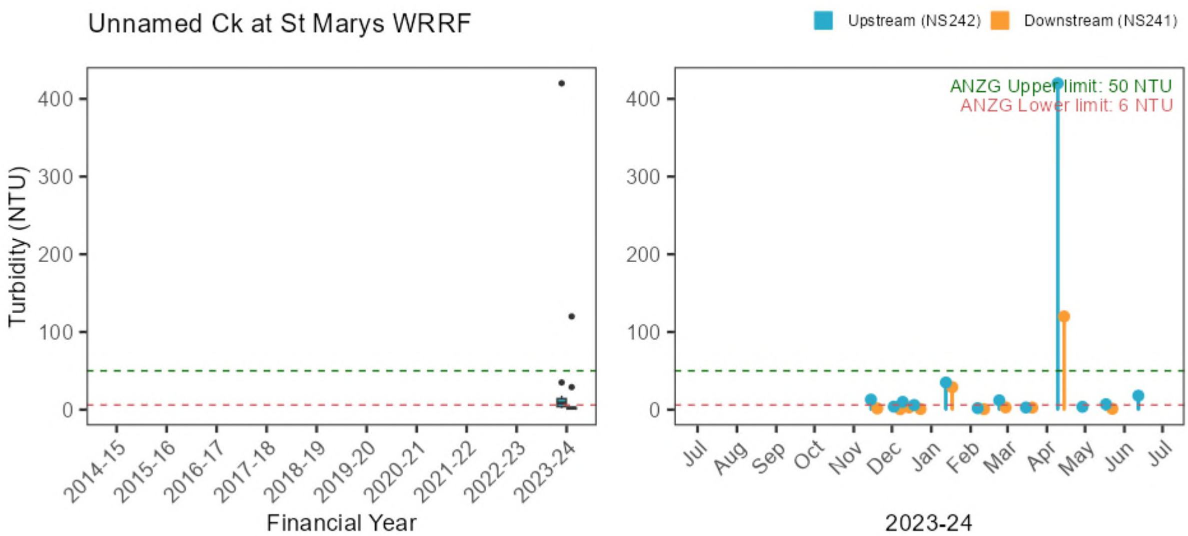
Apr
May
Jun
Jul
2023-24


Unnamed Ck at St Marys WRRF
Upstream (NS242)
Downstream (NS241)
Dissolved oxygen saturation (%sat)
Financial Year
2023-24
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat


South Ck at St Marys WRRF
Upstream (NS26)
Downstream (NS23A)
Dissolved oxygen saturation (%sat)
Financial Year
2023-24
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat


Unnamed Ck at St Marys WRRF
Upstream (NS242)
Downstream (NS241)
Turbidity (NTU)
Financial Year
2023-24
ANZG Upper limit: 50 NTU
ANZG Lower limit: 6 NTU

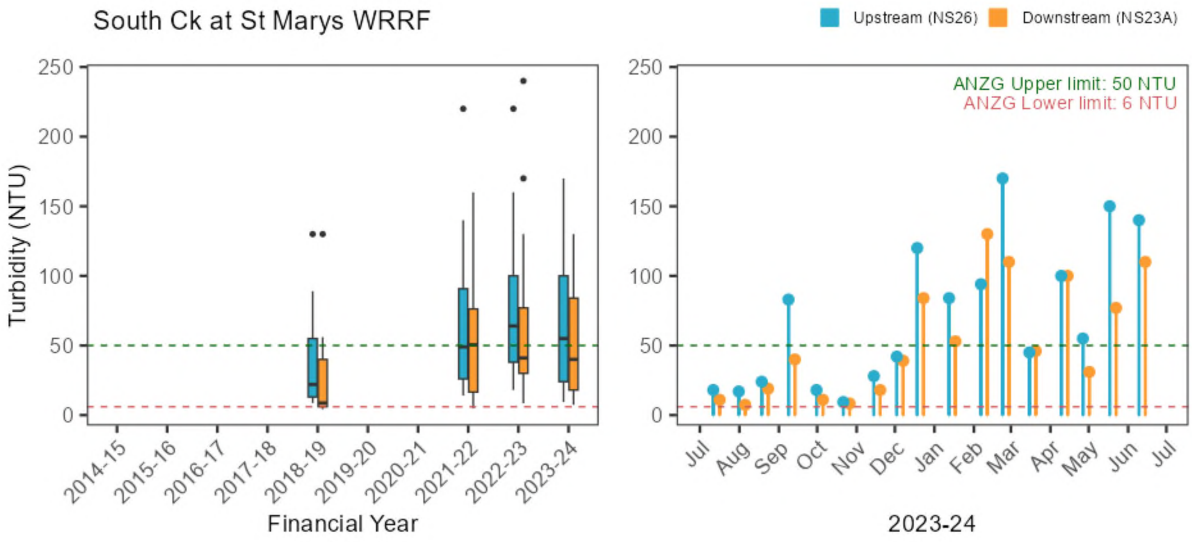


Figure 4-43 Nutrients and physico-chemical water quality exception plots, upstream and downstream of St Marys WRRF

Ecosystem Receptor – Phytoplankton

Table 4-40 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of St Marys WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NS242)	NA
Downstream tributary (NS241)	NA
Upstream creek (NS26)	→
Downstream creek (NS23A)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

NA - Statistical comparison not conducted due to only one financial year of data

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NS242 vs NS241)	NA
Upstream vs downstream creek (NS26 vs NS23A)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there was no significant increasing or decreasing trend identified in phytoplankton as chlorophyll-a at the upstream or downstream sites compared to the previous five years. In the 2023-24 period, the median chlorophyll-a concentration was lower than the ANZG (2018) guideline at both upstream and downstream site of unnamed tributary. However, chlorophyll-a exceeded the guideline at both upstream and downstream sites of South Creek.

Statistically, the upstream chlorophyll-a concentration was not significantly different (p=0.06) from the downstream concentration. However, upstream chlorophyll-a concentration was generally elevated compared to the downstream site, reaching a maximum of 45.8 µg/L (14 July 2023).

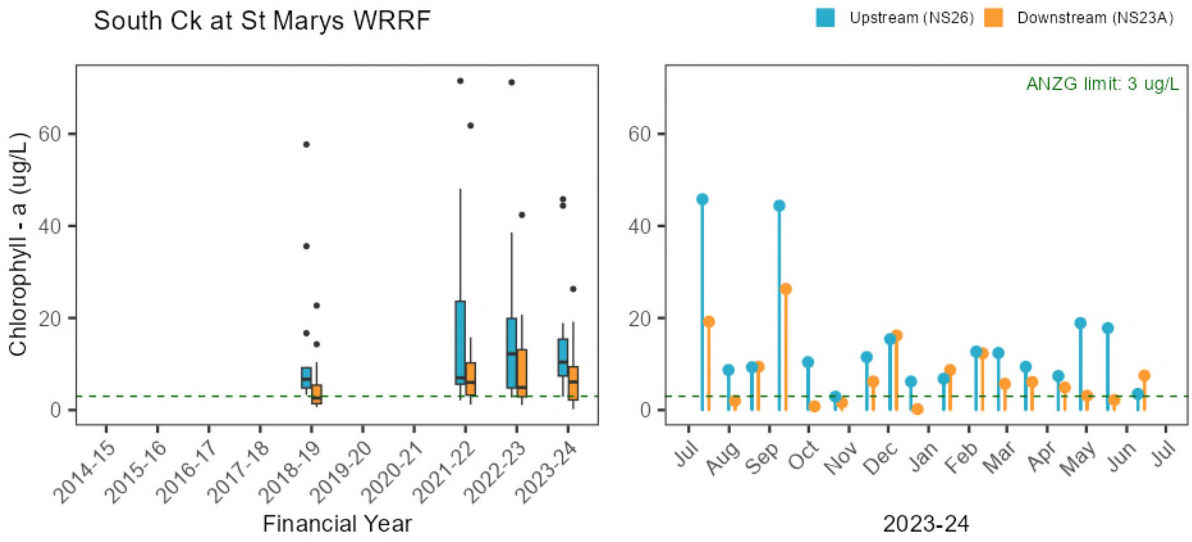


Figure 4-44 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of St Marys WRRF

Ecosystem Receptor – Macroinvertebrates

The SIGNAL-SG plot for South Creek demonstrated that the stream health of the downstream site in South Creek was substantially higher in comparison to the upstream site. This indicates that the wastewater discharge from the St Marys WRRF did not have a measurable negative impact on this site. A SIGNAL-SG plot will be presented in future reports for the unnamed creek into which St Marys WRRF discharges once more than two years of data is available for visualisation.

Table 4-41 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of St Marys WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NS242 vs NS241)	NA
Upstream vs downstream creek (NS26 vs NS23A)	U

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

NA - Statistical comparison not conducted due to only one financial year of data

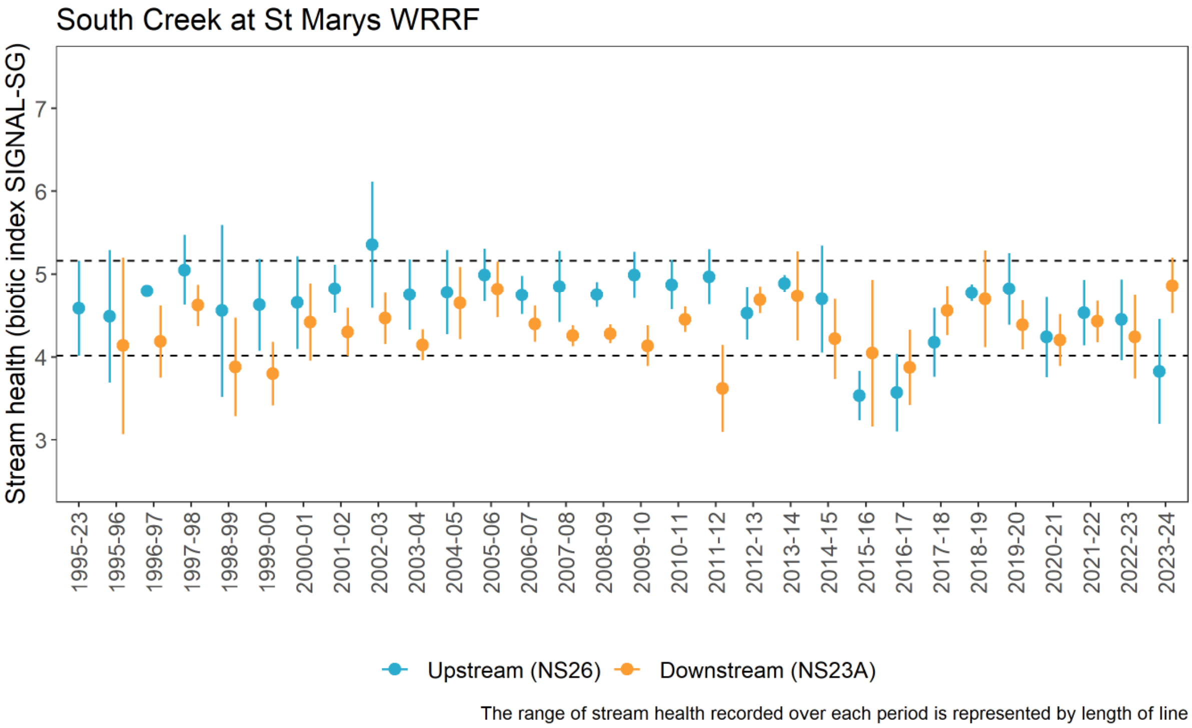


Figure 4-45 Stream health of South Creek upstream and downstream of the confluence of Unnamed creek near St Marys WRRF

Gate 2 – Synthesis of impact of St Marys WRRF discharge

Analytes	Pressure	Stressors		Ecosystem Receptors				Gate 2 synthesis
		Water quality		Phytoplankton as Chlorophyll-a		Macroinvertebrates		
	Effluent	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	Tributary (us vs ds)	River (us vs ds)	
Ammonia nitrogen	↘	NA	-	NA	-	NA	U	Increased nitrogen concentration in St Marys WRRF discharges triggered a subsequent increase in downstream receiving water nitrogen. However, stream health as indicated by macroinvertebrates was impacted at the upstream site , possibly related to other upstream catchment factors. No further analysis to be carried out (Gate 3 analysis).
Oxidised nitrogen		NA	D					
Total nitrogen	↗	NA	D					
Filterable total phosphorus		NA	-					
Total phosphorus	↗	NA	-					
Conductivity		NA	-					
Dissolved oxygen		NA	-					
Dissolved oxygen saturation		NA	-					
pH		NA	-					
Temperature		NA	-					
Turbidity		NA	-					

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

NA - Statistical comparison not conducted due to only one financial year of data

4.1.9. Quakers Hill WRRF

- The South Creek Bubble load limit for total phosphorus (combined St Marys, Quakers Hill and Riverstone WRRF treated discharge load) was exceeded in 2023-24. All other parameters (concentrations and loads) were within EPL limits.
- Total phosphorus and copper concentrations increased, and ammonia nitrogen and total nitrogen concentrations decreased in the Quakers Hill WRRF treated discharge in 2023-24 compared to the last nine years.
- Nutrient concentrations were steady in 2023-24 compared to the previous six years at both upstream and downstream Breakfast Creek sites.
- Oxidised nitrogen and total nitrogen concentrations were significantly higher at the downstream Breakfast Creek site, despite a decrease in ammonia and total nitrogen concentrations in Quakers Hill WRRF treated discharges.
- Chlorophyll-a concentrations were low and remained stable compared to the previous six years, and no significant difference was found in 2023-24 between upstream and downstream sites.
- Stream health, as indicated by macroinvertebrates, was impacted at the upstream Breakfast Creek site indicating other catchment influences. Stream health at the downstream Breakfast Creek site indicated no adverse ecological impact from Quakers Hill WRRF discharge.

Pressure – Wastewater discharge

Table 4-42 Gate 1 Analysis outcome summary – Quakers Hill WRRF

Analytes / Quakers Hill WRRF	Nutrients			Conventional analytes					
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration	↘	↘	↗	→	→	→		→	→
Load			EPL limit exceedance						

Analytes / Quakers Hill WRRF	Trace Metals								Other	
	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Hydrogen sulfide (un-ionised)	Pesticides and PCBs
Concentration	→	→	→	↗				→	→	
Load										

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

All concentration levels were within the EPL limits during the 2023-24 reporting period. The South Creek Bubble load limit (combined St Marys, Quakers Hill and Riverstone WRRF discharge load) for total phosphorus was exceeded during the 2023-24 period.

Statistical analysis identified significantly increasing trends in total phosphorus and copper, and significantly decreasing trends in ammonia nitrogen and total nitrogen in the treated discharge from Quakers Hill WRRF in 2023-24 compared to the previous nine years.

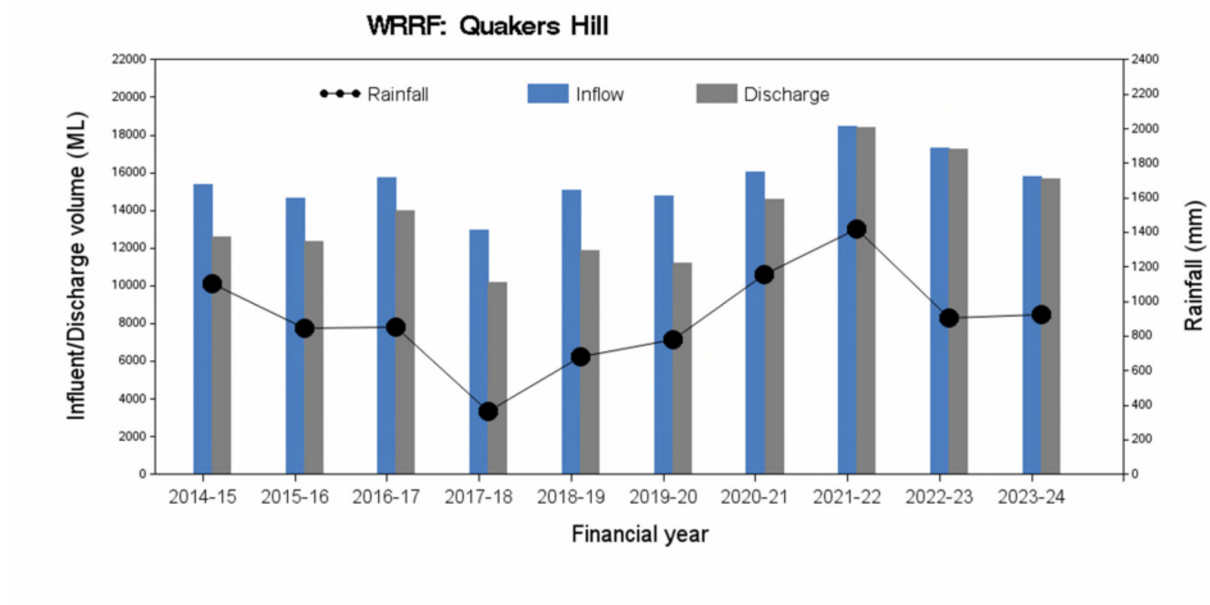
The increasing total phosphorus trend can be linked to the diversion of influent flows to the commissioned activated granular sludge (AGS) process under the Lower South Creek Treatment Upgrade Program (LSCTUP). Quakers Hill WRRF continues to optimise polymer and alum chemical application to lower final effluent phosphorus concentrations.

The increasing trend in copper concentration can be linked to the temporary treatment process using AGS. Previously sludge centrate was sent to the NSOOS, however now the AGS centrate is reintroduced to the plant inlet resulting in increased copper concentrations throughout the treatment process.

The South Creek Bubble total phosphorus load limit exceedance was largely due to wet weather events in the catchment between January and April 2024 with all three facilities within the South

Creek Bubble operating under wet weather conditions. Quakers Hill WRRF contributed 58.7% of the total phosphorus load from 40.9% of the total flow from the three South Creek facilities.

Sydney Water has commenced discussions with the EPA on reviewing concentration and load limit exceedances associated with rainfall events, including the initiation of environmental assessments at five WRRFs (St Marys, Hornsby Heights, West Hornsby, Quakers Hill and Wollongong).



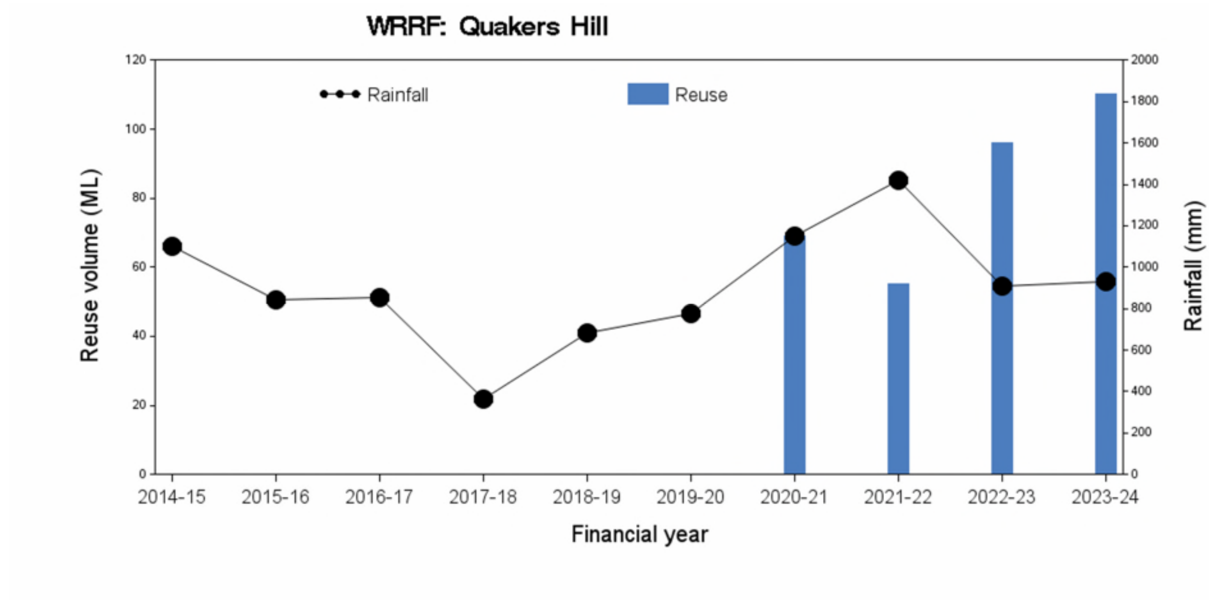
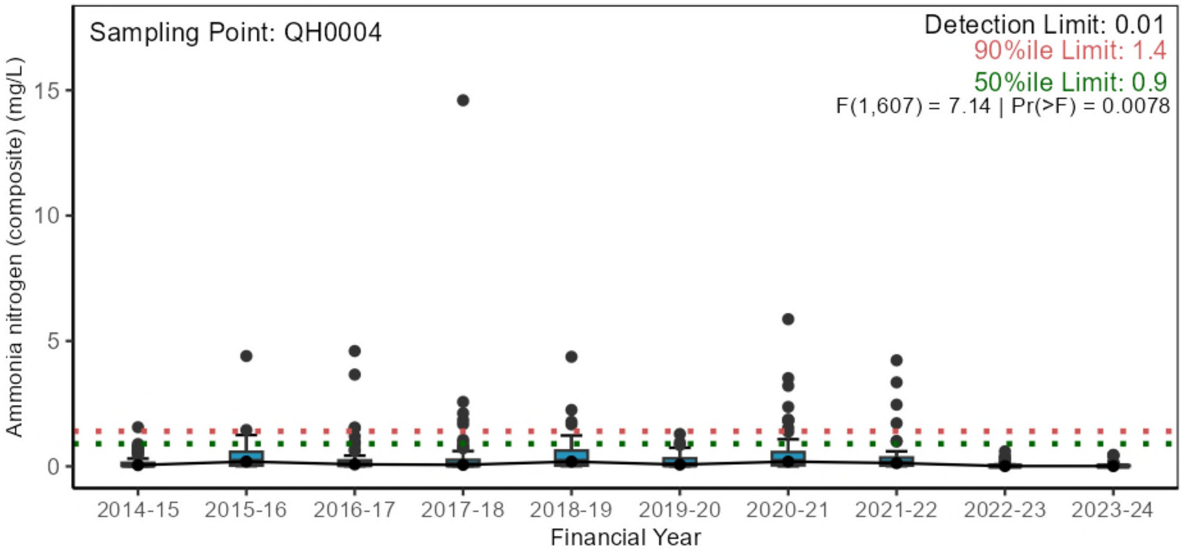
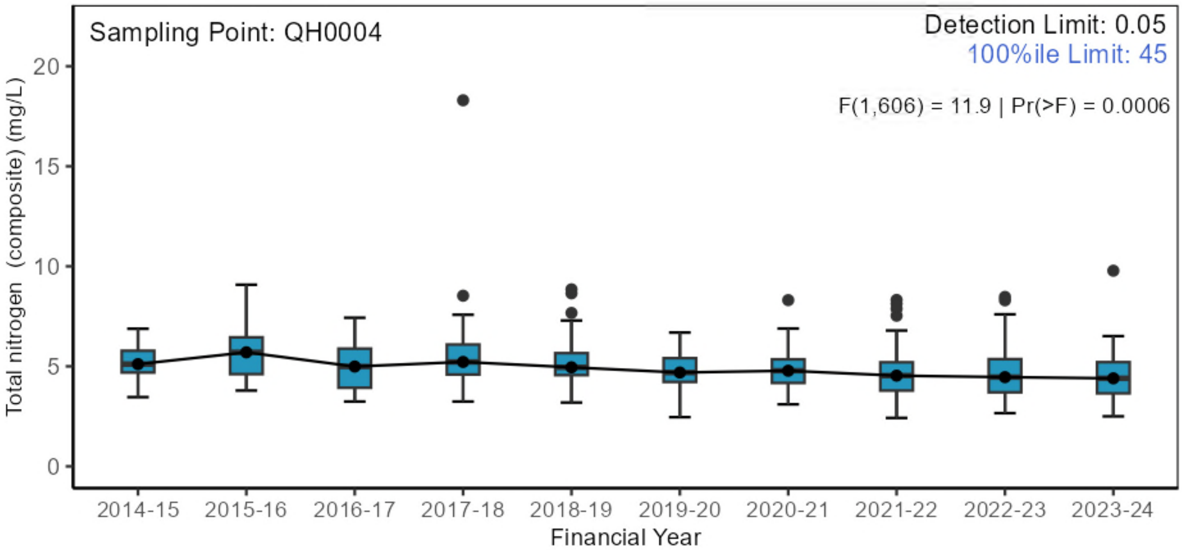
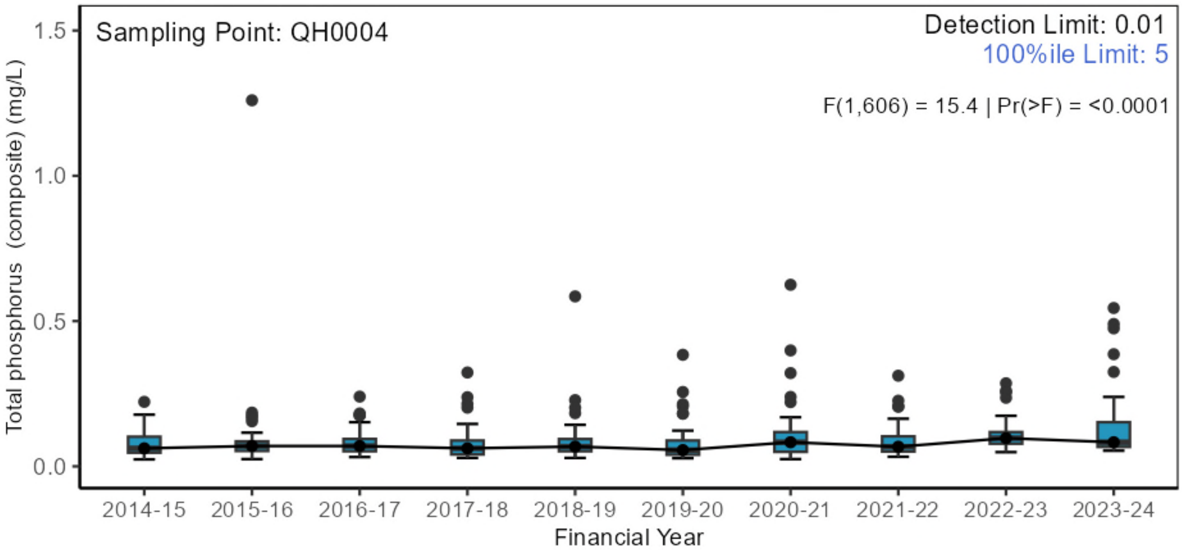
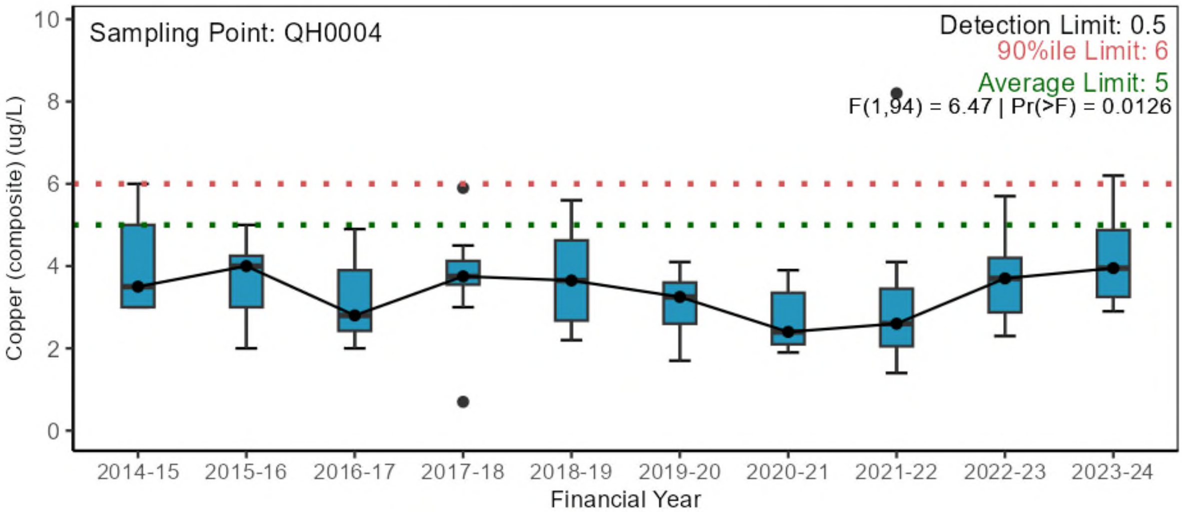


Figure 4-46 Quakers Hill WRRF inflow, discharge and reuse volume with catchment rainfall


Sampling Point: QH0004
Detection Limit: 0.01
90%ile Limit: 1.4
50%ile Limit: 0.9
F(1,607) = 7.14 | Pr(>F) = 0.0078
Ammonia nitrogen (composite) (mg/L)
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year


Sampling Point: QH0004
Detection Limit: 0.05
100%ile Limit: 45
F(1,606) = 11.9 | Pr(>F) = 0.0006
Total nitrogen (composite) (mg/L)
20
15
10
5
0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year





Statistical test excludes data prior to 2016-17 due to method detection limit change.

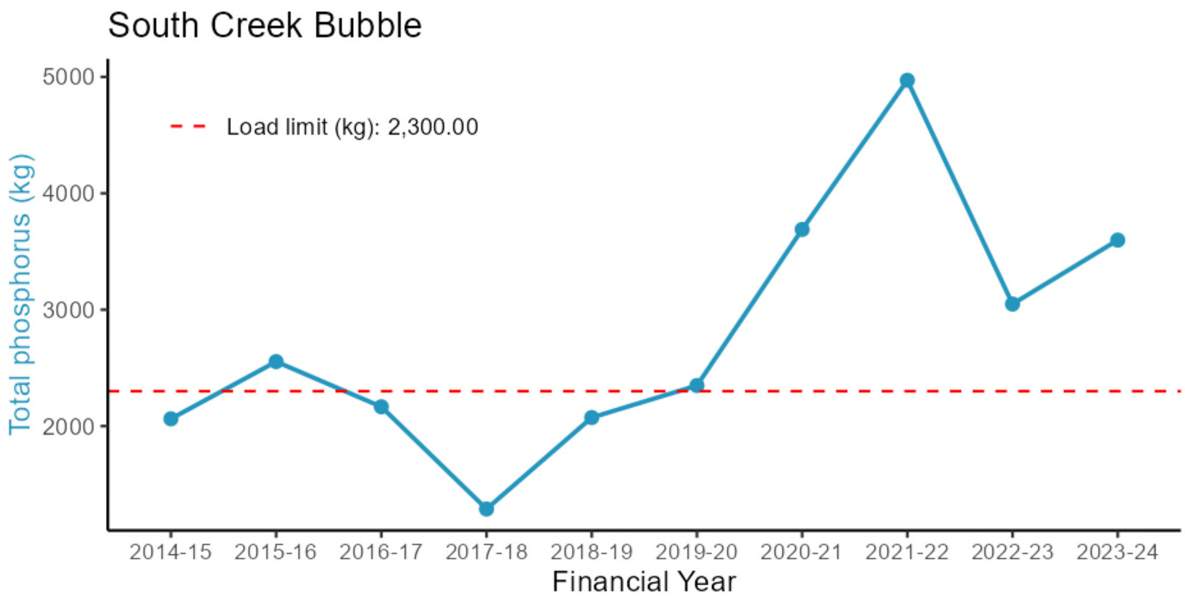


Figure 4-47 Quakers Hill WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-43 Gate 1 Analysis outcome summary – water quality upstream and downstream of Quakers Hill WRRF discharge point

Analytes / Quakers Hill WRRF		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NS090)	→	**→**	**→**	→	**→**	→	→	**→**	→	→	→
	Downstream tributary (NS087)	→	**→**	**→**	→	**→**	→	→	→	→	→	**→**

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(shaded)	Median value outside the guideline limit in 2023-24				

Analytes / Quakers Hill WRRF		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NS090 vs NS087)	-	D	D	-	-	-	D	D	-	-	U

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

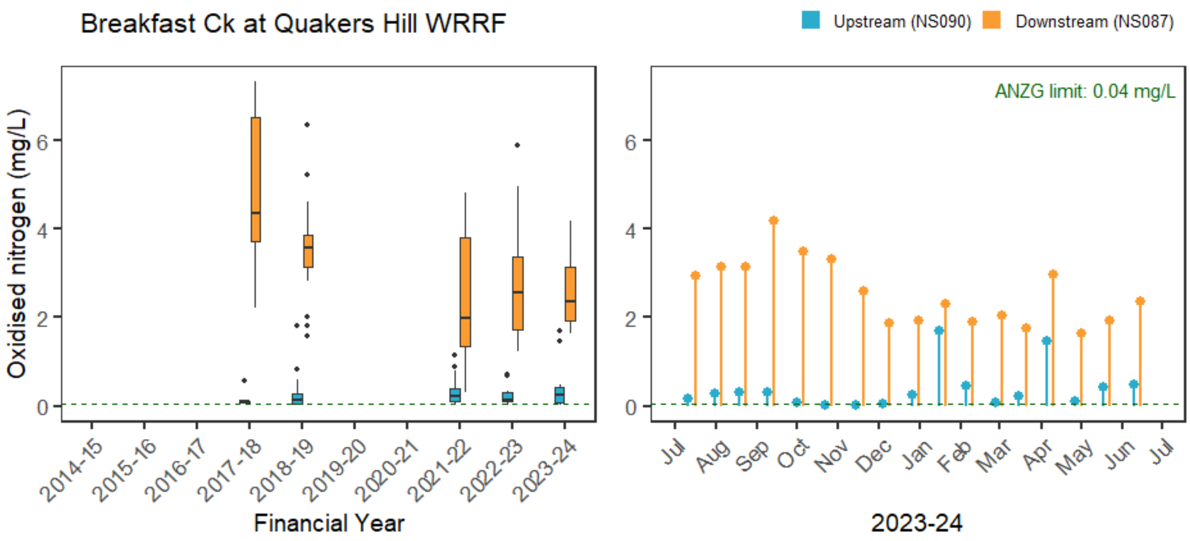
Quakers Hill WRRF discharges into Breakfast Creek that joins with Eastern Creek before flowing into South Creek. The upstream catchment includes a mix of land uses with semi-urban towns, reserves and residential housing.

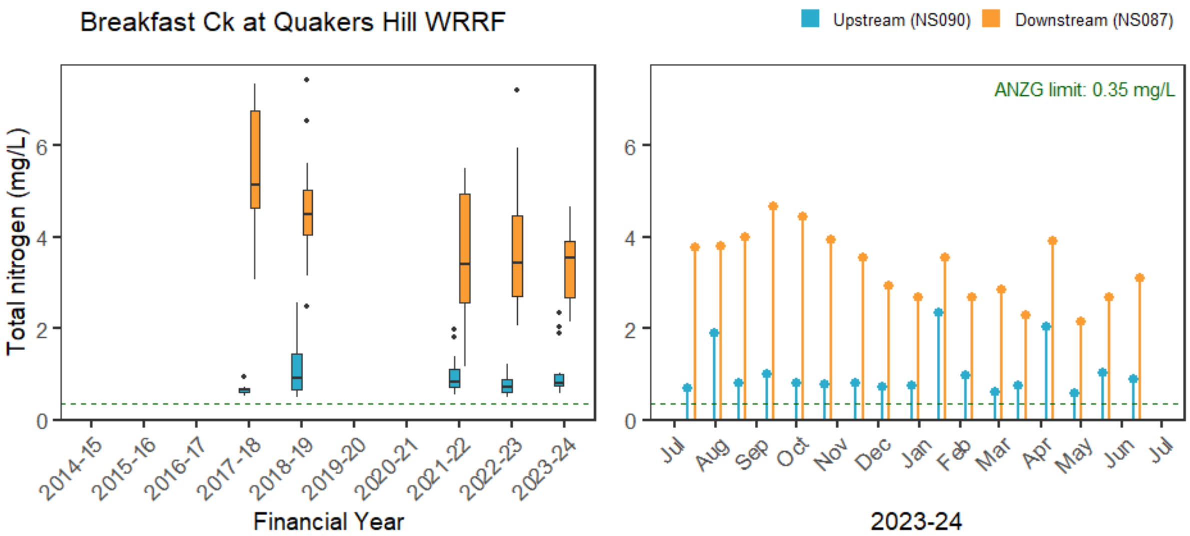
In 2023-24, there were no significant increasing/decreasing trends identified in nutrients or physico-chemical analyte concentrations at the upstream or downstream creek sites compared to the previous six years.

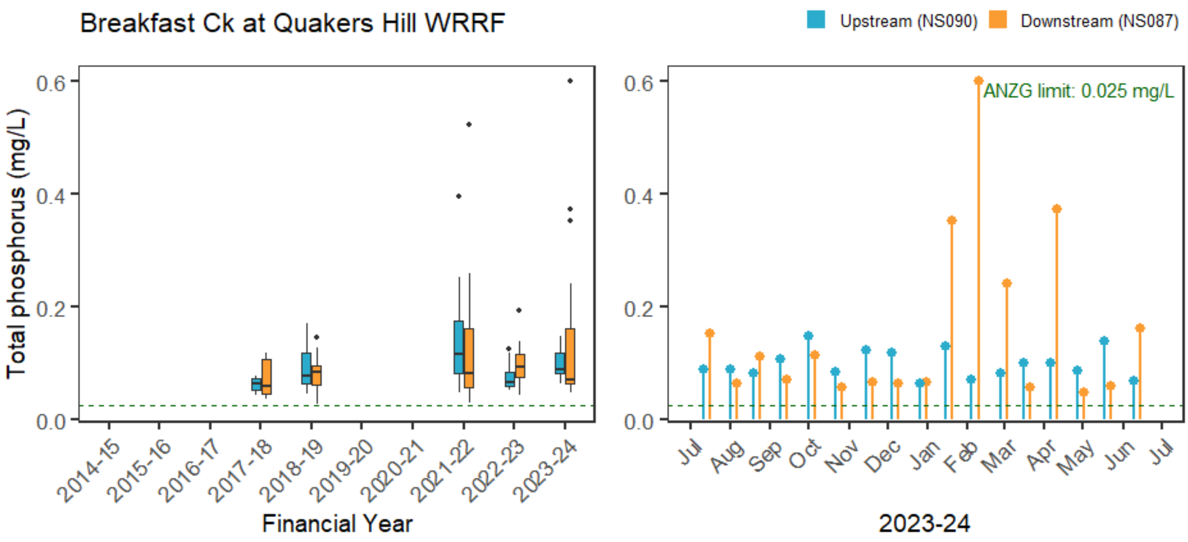
In the 2023-24 period, the median concentrations of oxidised nitrogen, total nitrogen and total phosphorus exceeded the respective ANZG (2018) guidelines at both upstream and downstream sites of Breakfast Creek. The median dissolved oxygen saturation was less than the lower guideline limit at upstream site and median turbidity was less than the lower guideline at downstream site.

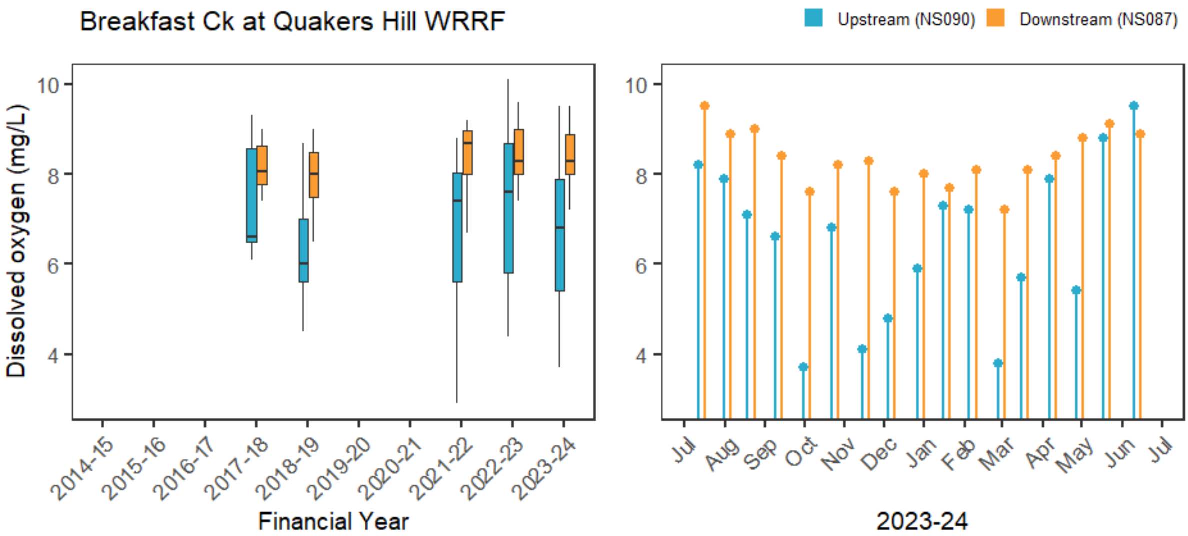
Oxidised nitrogen and total nitrogen concentrations at the downstream site were significantly higher than the upstream site. This is in contrast to the downward trends in ammonia and nitrogen concentrations in Quakers Hill WRRF treated discharges.

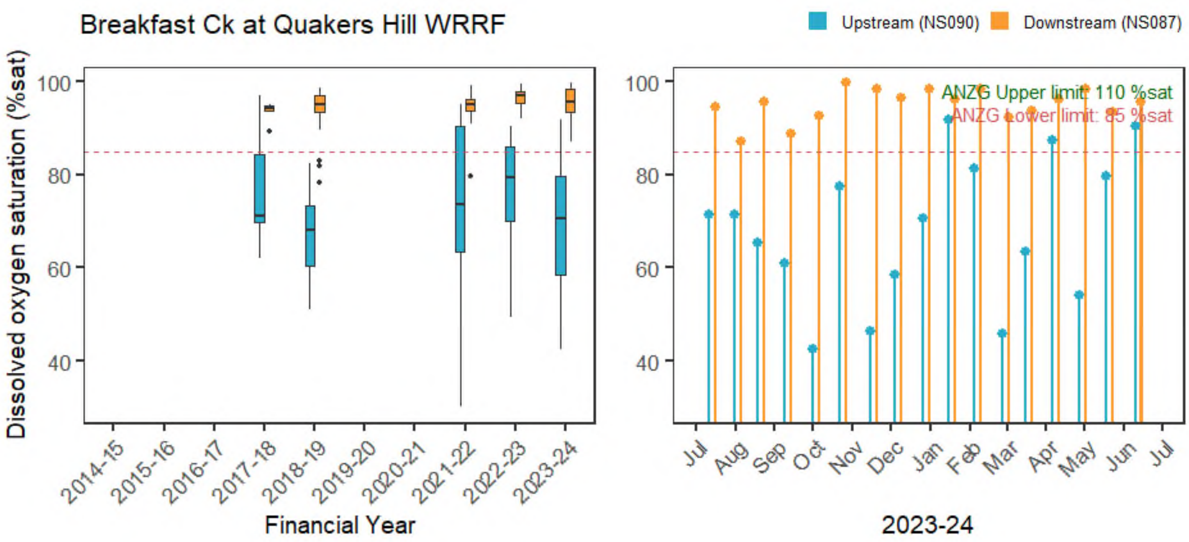
Dissolved oxygen concentration and saturation were significantly higher at the downstream Breakfast Creek site indicating a benefit from the Quakers Hill WRRF discharge.






Breakfast Ck at Quakers Hill WRRF
Upstream (NS090)
Downstream (NS087)
Total phosphorus (mg/L)
ANZG limit: 0.025 mg/L
Financial Year
2023-24


Breakfast Ck at Quakers Hill WRRF
Upstream (NS090)
Downstream (NS087)
Dissolved oxygen (mg/L)
Financial Year
2023-24


Breakfast Ck at Quakers Hill WRRF
Upstream (NS090)
Downstream (NS087)
Dissolved oxygen saturation (%sat)
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
Financial Year
2023-24

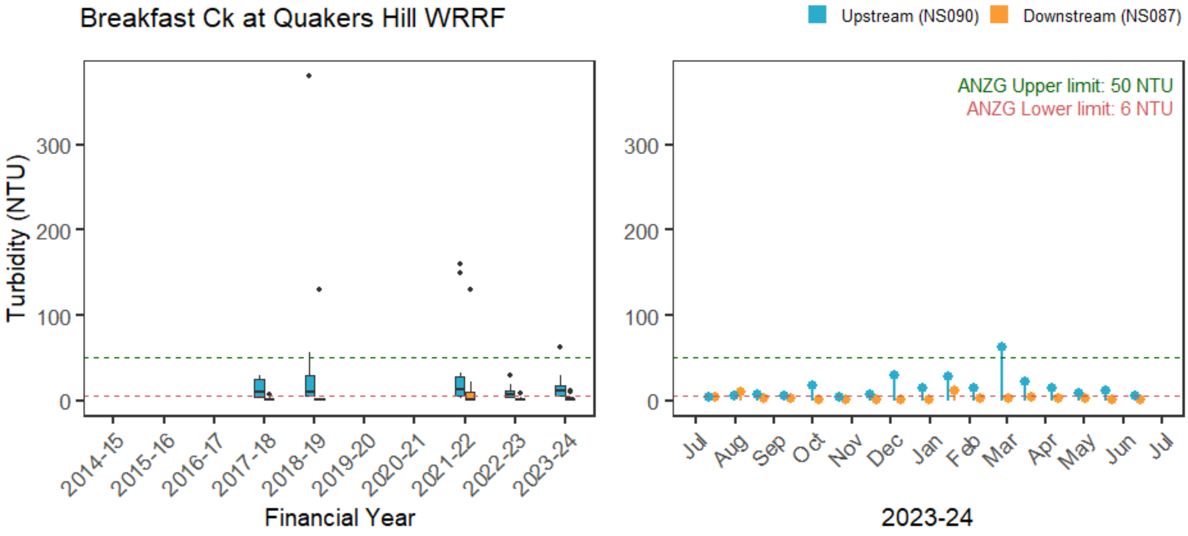


Figure 4-48 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Quakers Hill WRRF

Ecosystem Receptor – Phytoplankton

Table 4-44 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Quakers Hill WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NS090)	→
Downstream tributary (NS087)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NS090 vs NS087)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there was no significant increasing or decreasing trend identified for chlorophyll-a at the upstream or downstream sites compared to the previous six years.

In the 2023-24 period, the median chlorophyll-a concentration was within the ANZG (2018) guideline at both upstream and downstream sites.

Chlorophyll-a concentrations were generally low at the Breakfast Creek sites. Statistically, the upstream chlorophyll-a concentration was not significantly different from the downstream concentration.

Ecosystem Receptor – Macroinvertebrates

SIGNAL-SG plots suggest downstream stream health was improved in 2023-24 compared to the upstream site, and this was confirmed with statistical analysis. These results indicate that wastewater discharge from Quakers Hill WRRF did not have a measurable impact on stream health during 2023-24, consistent with trends from previous years.

Table 4-45 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Quakers Hill WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NS090 vs NS087)	U

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

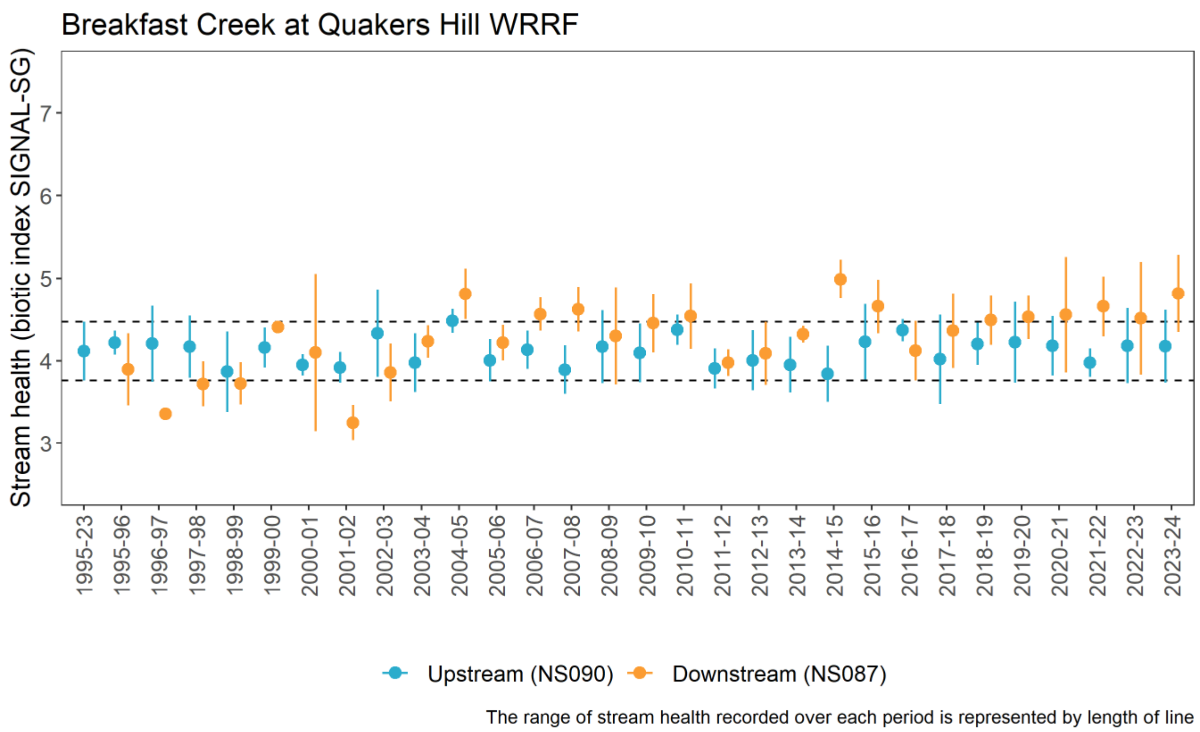


Figure 4-49 Stream health of Breakfast Creek upstream and downstream of Quakers Hill WRRF

Gate 2 – Synthesis of impact of Quakers Hill WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as Chlorophyll-a	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Ammonia nitrogen	↘	-	-	U	Oxidised nitrogen and total nitrogen at the downstream site were significantly higher than the upstream site concentration, despite a decrease in ammonia and total nitrogen concentrations in Quakers Hill discharges. Stream health as indicated by macroinvertebrates at downstream site was not impacted, no further analysis (Gate 3) to be carried out.
Oxidised nitrogen		D			
Total nitrogen	↘	D			
Filterable total phosphorus		-			
Total phosphorus	↗	-			
Conductivity		-			
Dissolved oxygen		D			
Dissolved oxygen saturation		D			
pH		-			
Temperature		-			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.10. Riverstone WRRF

- The South Creek Bubble load limit for total phosphorus (combined St Marys, Quakers Hill and Riverstone WRRF treated discharged load) was exceeded in 2023-24. All other parameters (concentrations and loads) monitored in the discharge from Riverstone WRRF were within EPL limits. There was a decreasing trend in total nitrogen concentration in the discharge compared to the last nine years.
- Nutrient concentrations in 2023-24 remained stable compared to the last seven years and no significant difference was found between the upstream and downstream Eastern Creek sites.
- Chlorophyll-a concentrations in 2023-24 also remained stable compared to the previous seven years, and no significant difference was found between the upstream and downstream sites.
- No adverse ecological impact (as indicated by macroinvertebrates) were detected in Eastern Creek downstream of Riverstone WRRF discharge.

Pressure – Wastewater discharge

Table 4-46 Gate 1 Analysis outcome summary – Riverstone WRRF

Analytes / Riverstone WRRF	Nutrients			Conventional analytes						Trace Metals				Other
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc	Hydrogen sulfide (un-ionised)
Concentration	→	↘	→	→	→	→	(Analyte not required in EPL or no concentration limit)	→	→	→	→	→	→	→
Load	(Analyte not required in EPL or no concentration limit)	(Within EPL limit)	(EPL limit exceedance)	(Within EPL limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)	(Within EPL limit)	(Within EPL limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)	(Analyte not required in EPL or no concentration limit)

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge from Riverstone WRRF were within EPL limits during the 2023-24 period. The South Creek Bubble load limit (combined St Marys, Quakers Hill and Riverstone WRRF discharged load) for total phosphorus was exceeded during the 2023-24 reporting period.

Statistical analysis identified a significantly decreasing trend in total nitrogen during 2023-24 compared to the previous nine years.

The South Creek Bubble total phosphorus load limit exceedance was largely due to wet weather events in the catchment between January and April 2024 with all three facilities within the South Creek Bubble operating under wet weather conditions. Riverstone WRRF contributed 4.1% of the total phosphorus load from 15.4% of the total flow from the three South Creek facilities.

Sydney Water have commenced discussions with the EPA on reviewing concentration and load limit exceedances associated with rainfall events, including the initiation of environmental assessments at five WRRFs (St Marys, Hornsby Heights, West Hornsby, Quakers Hill and Wollongong).

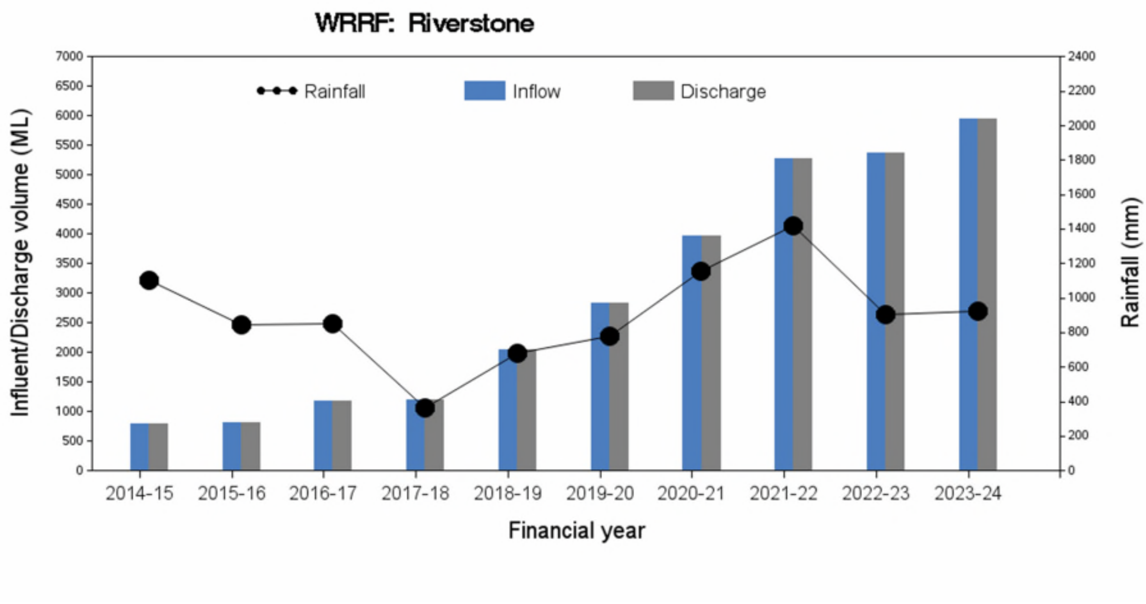
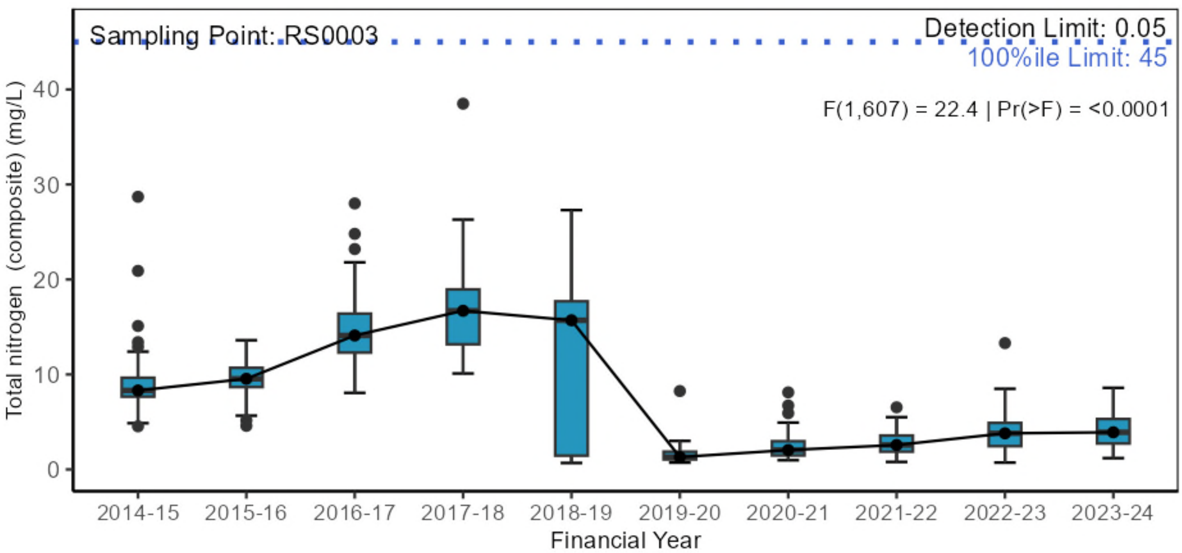


Figure 4-50 Riverstone WRRF inflow and discharge volume with catchment rainfall



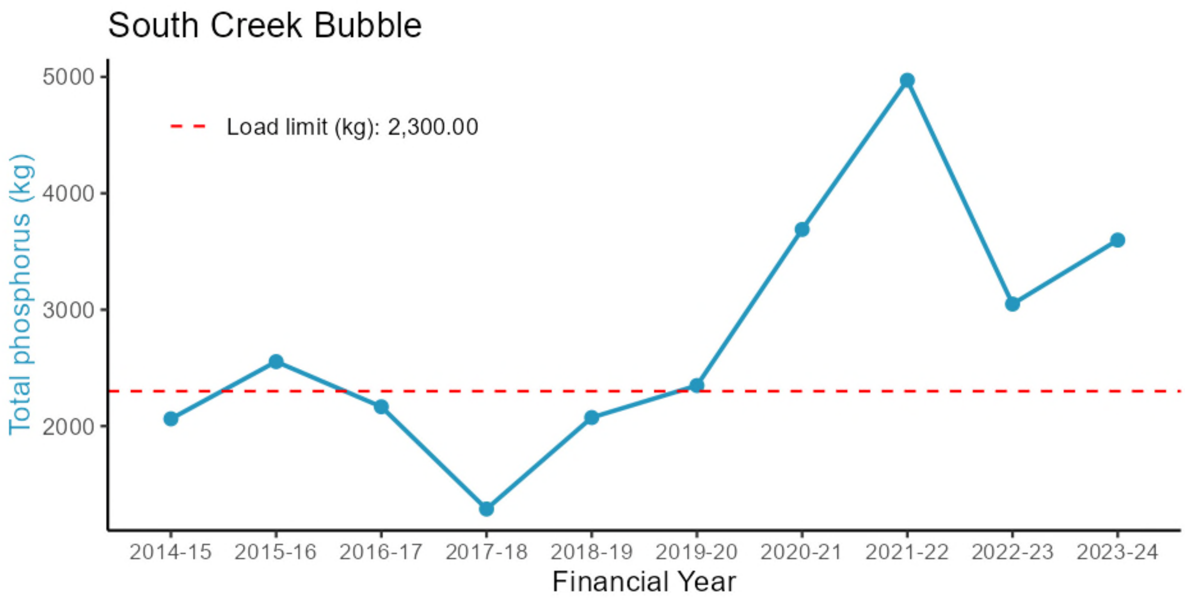


Figure 4-51 Riverstone WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-47 Gate 1 Analysis outcome summary – water quality upstream and downstream of Riverstone WRRF discharge point

Riverstone WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NS082)	→	→	→	→	→	→	→	→	→	→	→
Tributary	Downstream tributary (NS081)	→	→	→	→	→	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	Median value outside the guideline limit in 2023-24				

Riverstone WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NS082 vs NS081)	-	-	-	-	-	-	-	-	-	-	-

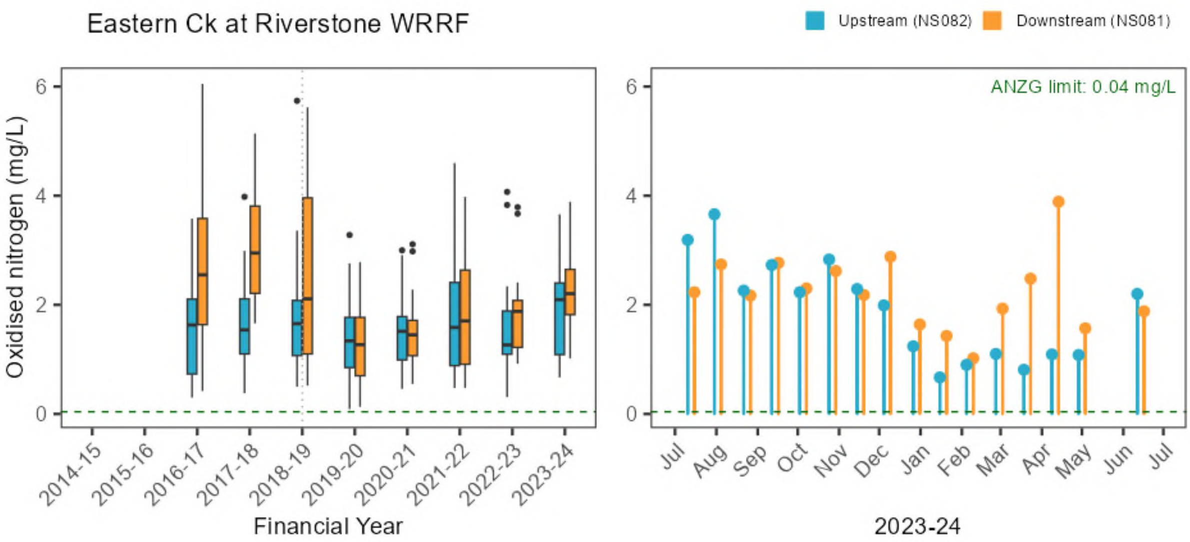
D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

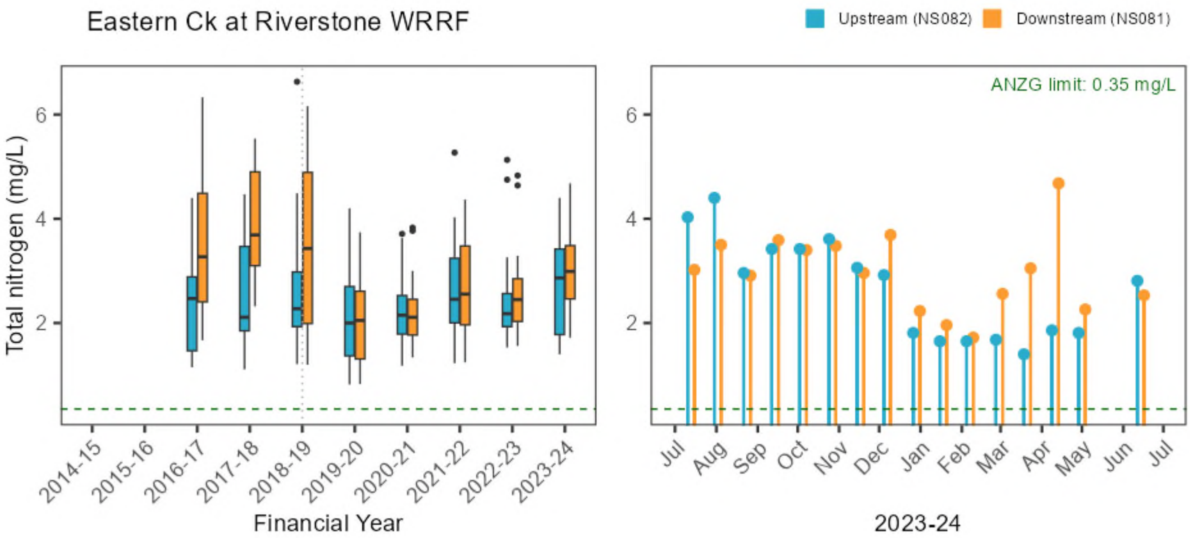
Riverstone WRRF discharges into Eastern Creek which joins with South Creek before draining to the Hawkesbury River at Windsor. The upstream catchment includes a mix of agricultural land uses, rural and residential areas that have grown in recent years.

Statistical analysis confirmed that nutrient concentrations and all other physico-chemical analytes were steady during 2023-24 at both upstream and downstream Eastern Creek sites compared to the previous seven years.

In the 2023-24 period, the median oxidised nitrogen, total nitrogen and total phosphorus exceeded the respective ANZG (2018) guidelines at both upstream and downstream sites. The 2023-24 median of all other nutrients and physio-chemical analytes were within the respective guidelines.

There was no statistically significant difference found in nutrients or other physico-chemical analyte concentrations between upstream and downstream sites, indicating no evident influence from Riverstone WRRF discharges.





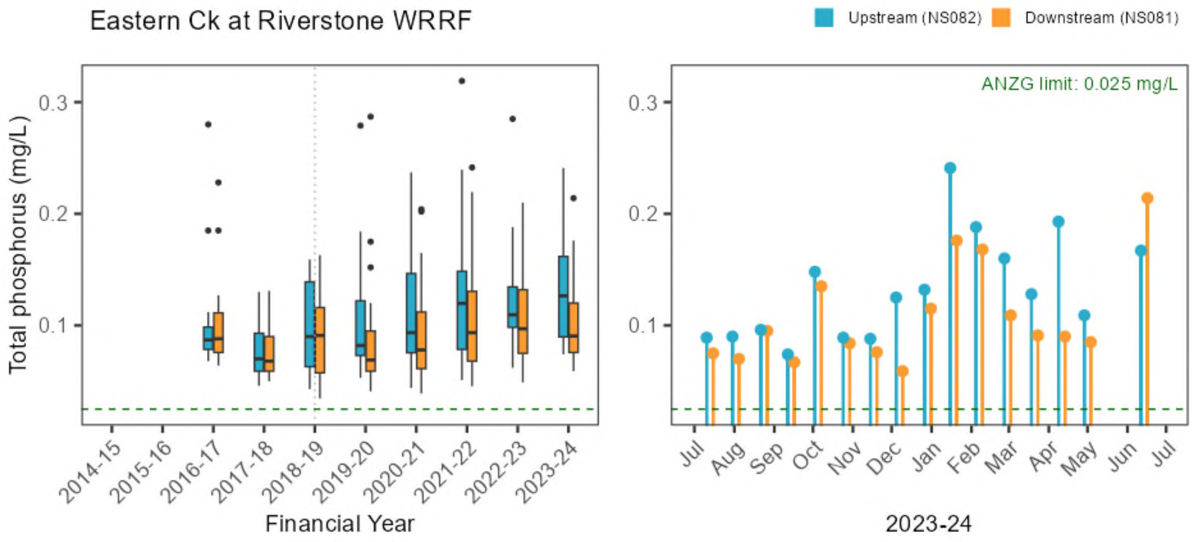


Figure 4-52 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Riverstone WRRF

Ecosystem Receptor – Phytoplankton

Table 4-48 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Riverstone WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NS082)	→
Downstream tributary (NS081)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NS082 vs NS081)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there were no significant increasing/decreasing trends identified for chlorophyll-a at either the upstream or downstream Eastern Creek sites compared to the previous seven years.

In the 2023-24 period, the median chlorophyll-a concentrations exceeded the respective ANZG (2018) guidelines at both sites.

Statistical analysis confirmed that in 2023-24, there was no significant difference found in chlorophyll-a concentrations between the upstream and downstream site. However, upstream chlorophyll-a concentrations were marginally elevated when compared to downstream concentrations, reaching a maximum of 12.6 µg/L (17 November 2023).

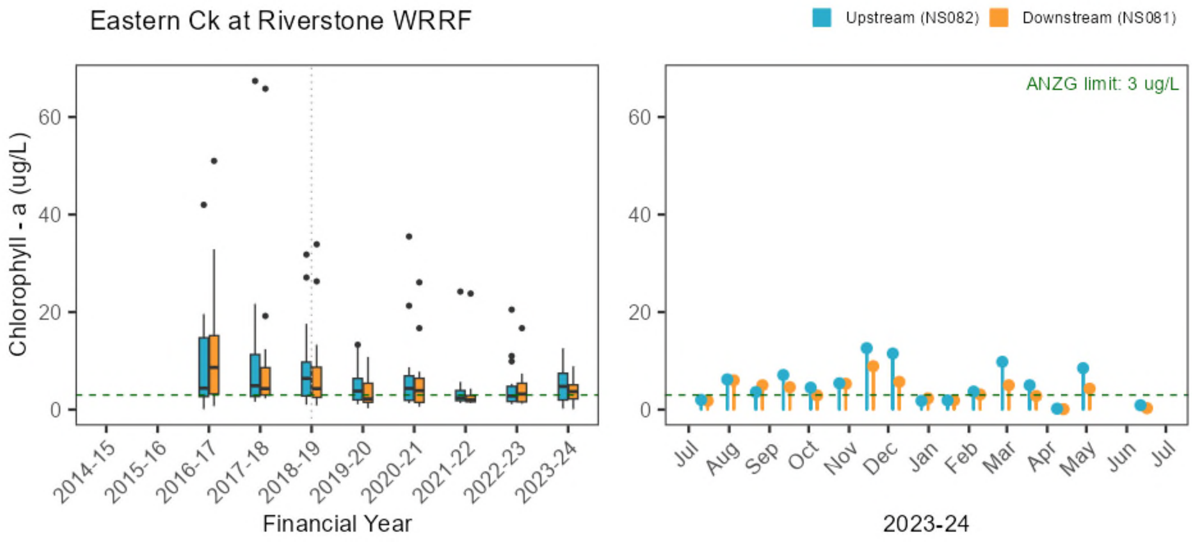


Figure 4-53 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Riverstone WRRF

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested no localised ecosystem impacts in Eastern Creek into which Riverstone WRRF discharges.

Table 4-49 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Riverstone WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NS082 vs NS081)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

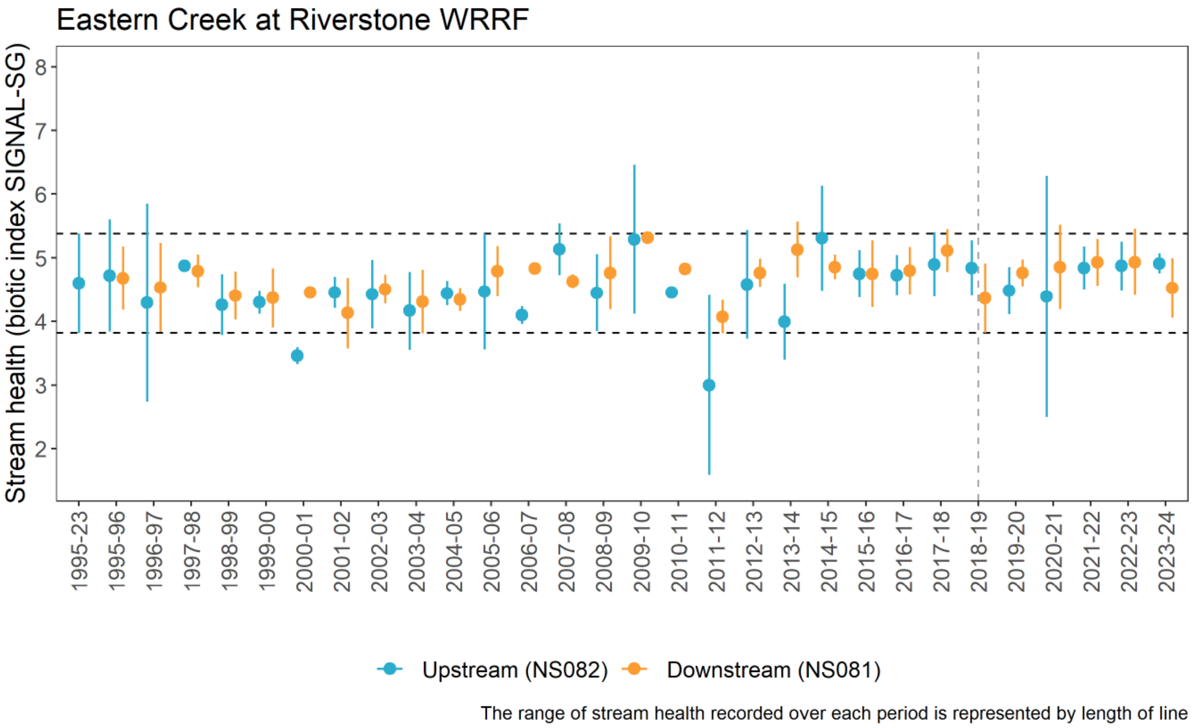


Figure 4-54 Stream health of Eastern Creek upstream and downstream of Riverstone WRRF. Grey line indicates beginning of WRRF upgrades.

Gate 2 – Synthesis of impact of Riverstone WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as chlorophyll-a	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Total ammonia nitrogen	→	-	-	-	Decreased nitrogen or routine discharges from Riverstone WRRF has no resulting impact in downstream receiving water quality or ecosystem health. No further analysis (Gate 3) to be carried out.
Oxidised nitrogen		-			
Total nitrogen	↘	-			
Filterable total phosphorus		-			
Total phosphorus	→	-			
Conductivity		-			
Dissolved oxygen		-			
Dissolved oxygen saturation		-			
pH		-			
Water temperature		-			
Turbidity		-			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
(yellow)	EPL limit exceedance	(grey)	Analyte not monitored		

4.1.11. Rouse Hill WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Rouse Hill WRRF were within EPL limits. There was a decreasing trend in total nitrogen concentration in the Rouse Hill WRRF discharge in 2023-24 compared to the past nine years.
- All nutrient parameters remained stable at both upstream and downstream Second Ponds Creek sites in 2023-24 compared to the previous six years.
- Total ammonia nitrogen, oxidised nitrogen and total nitrogen concentrations were significantly higher at the downstream Second Ponds Creek site compared to upstream, despite a decrease in total nitrogen concentrations in Rouse Hill WRRF treated discharge.
- Filterable total phosphorus and total phosphorus concentrations were significantly higher at the upstream Second Ponds Creek site compared to downstream, indicating an influence from other phosphorus-rich catchment run-off.
- Chlorophyll-a concentrations was significantly higher at the downstream Second Ponds Creek site in 2023-24 compared to the previous six years. However, no significant difference was identified in chlorophyll-a between upstream and downstream Second Ponds Creek sites.
- No adverse ecological impacts (as indicated by macroinvertebrates) were observed in Second Ponds Creek into which Rouse Hill WRRF discharge.

Pressure – Wastewater discharge

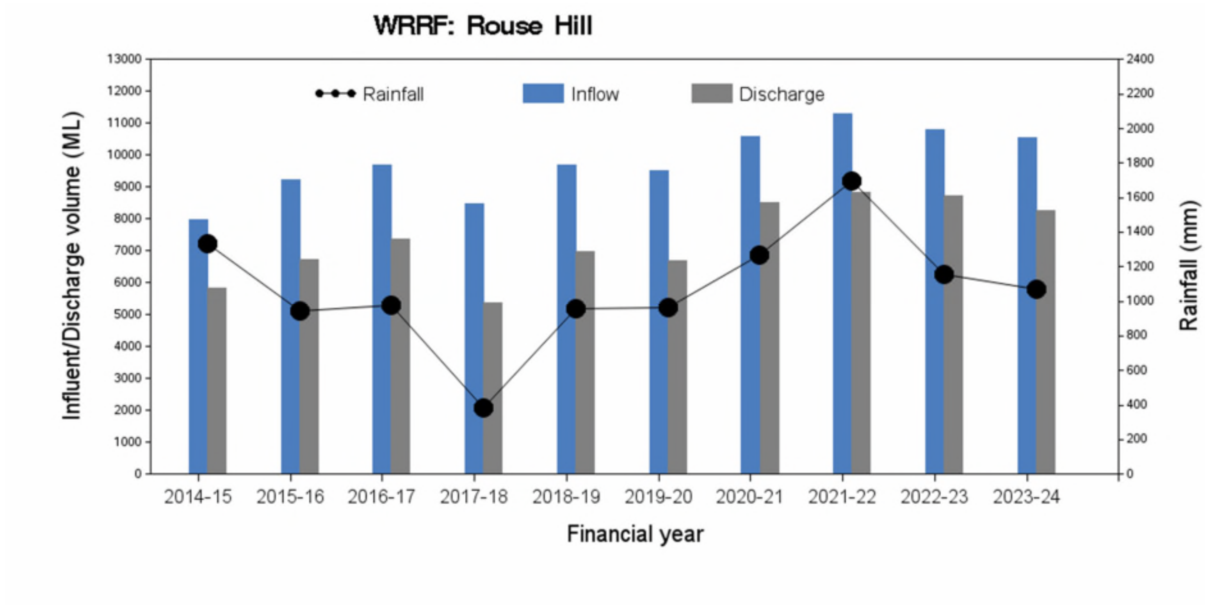
Table 4-50 Gate 1 Analysis outcome summary –Rouse Hill WRRF

Analytes / Rouse Hill WRRF	Nutrients			Conventional analytes						Trace Metals			
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Total residual chlorine	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc
Concentration	→	↘	→	→	→	→		→	→	→	→	→	→
Load													

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the treated discharge from Rouse Hill WRRF were within the EPL limits during the 2023-24 period.

Statistical analysis identified a significantly decreasing trend in total nitrogen during 2023-24 compared to the previous nine years.



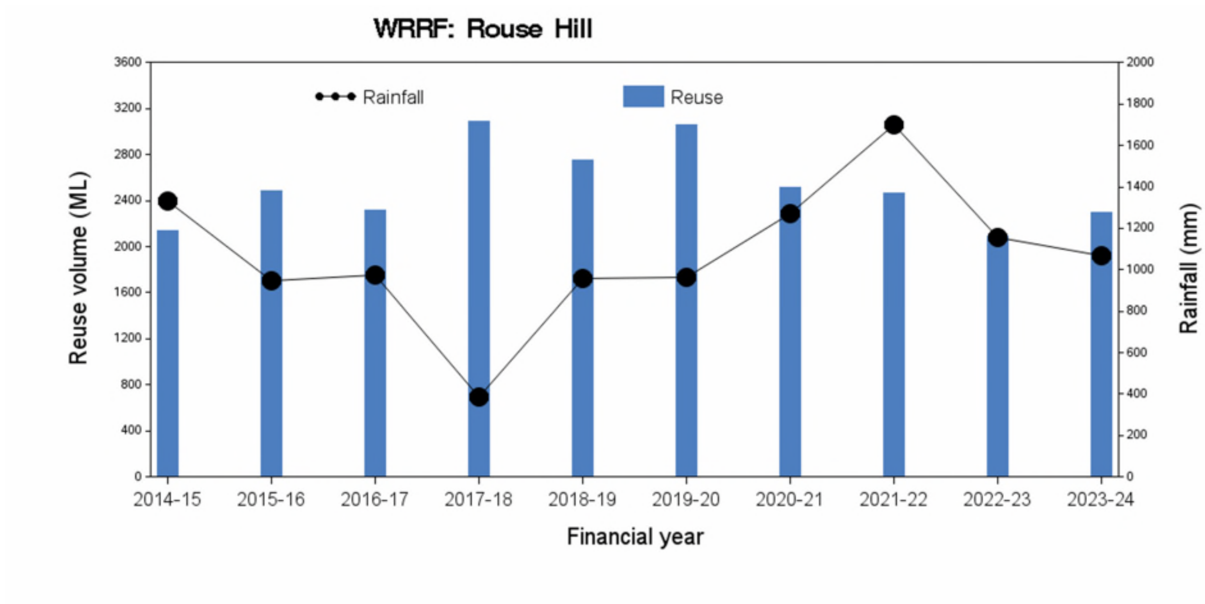


Figure 4-55 Rouse Hill WRRF inflow, discharge and reuse volume with catchment rainfall

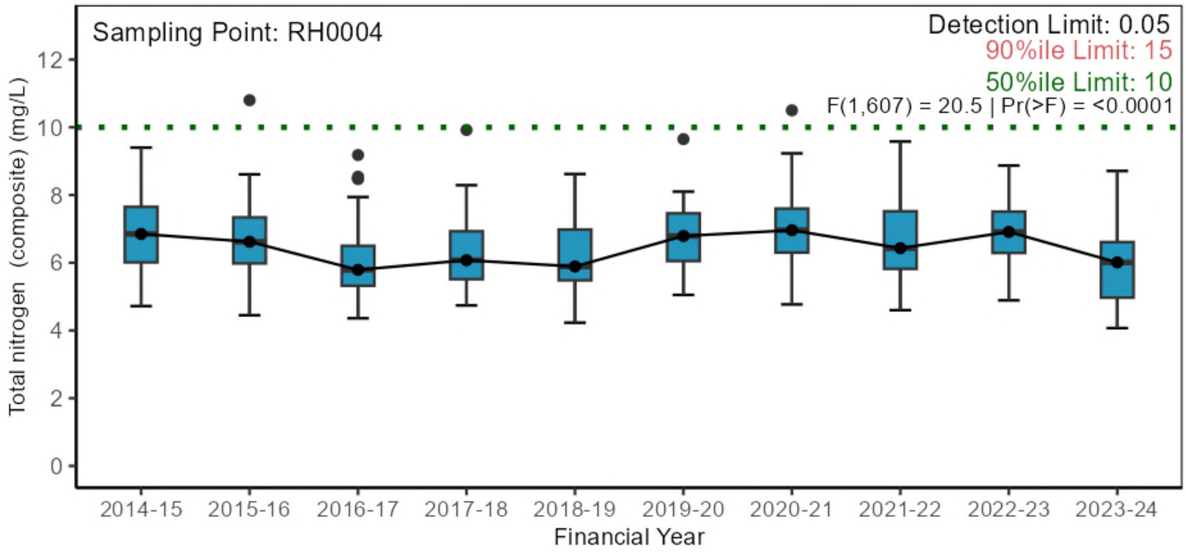


Figure 4-56 Rouse Hill WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-51 Gate 1 Analysis outcome summary – water quality upstream and downstream of Rouse Hill WRRF discharge point

Rouse Hill WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NC53)	→	→	→	→	→	→	→	→	→	→	→
Tributary	Downstream tributary (NC516)	→	→	→	→	→	→	→	→	→	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Rouse Hill WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NC53 vs NC516)	D	D	D	U	U	-	D	D	-	-	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

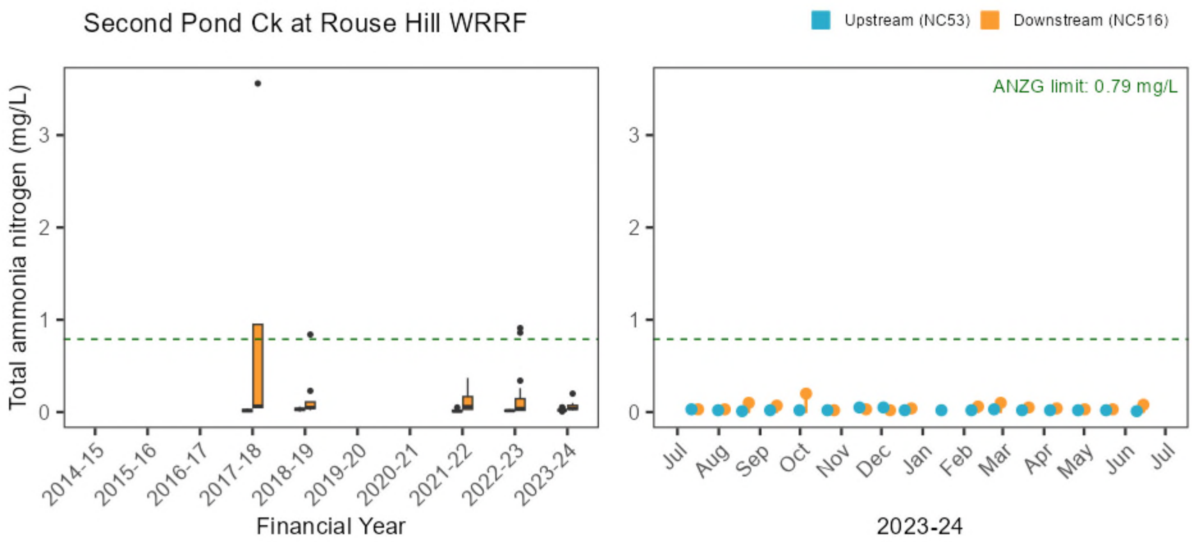
Rouse Hill WRRF discharges into Second Ponds Creek which is an upstream tributary of Cattai Creek draining to the Hawkesbury River. The upstream catchment includes a mix of land uses including developed and fast-growing housing areas.

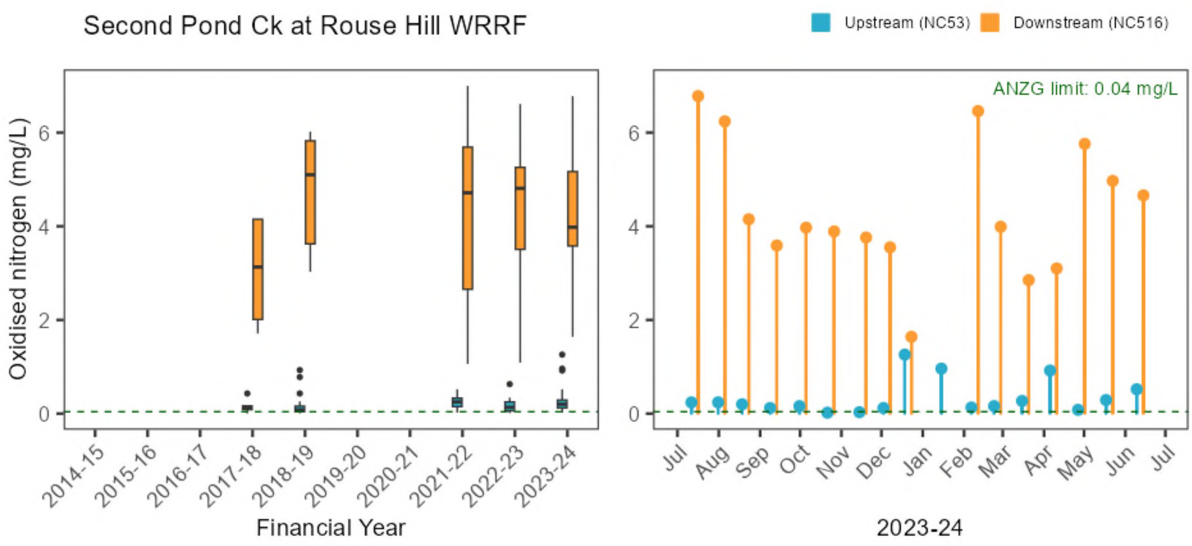
Statistical analysis confirmed nutrient concentrations, and all other physico-chemical analytes were steady during 2023-24 compared to the previous six years, at both upstream and downstream Second Ponds Creek sites.

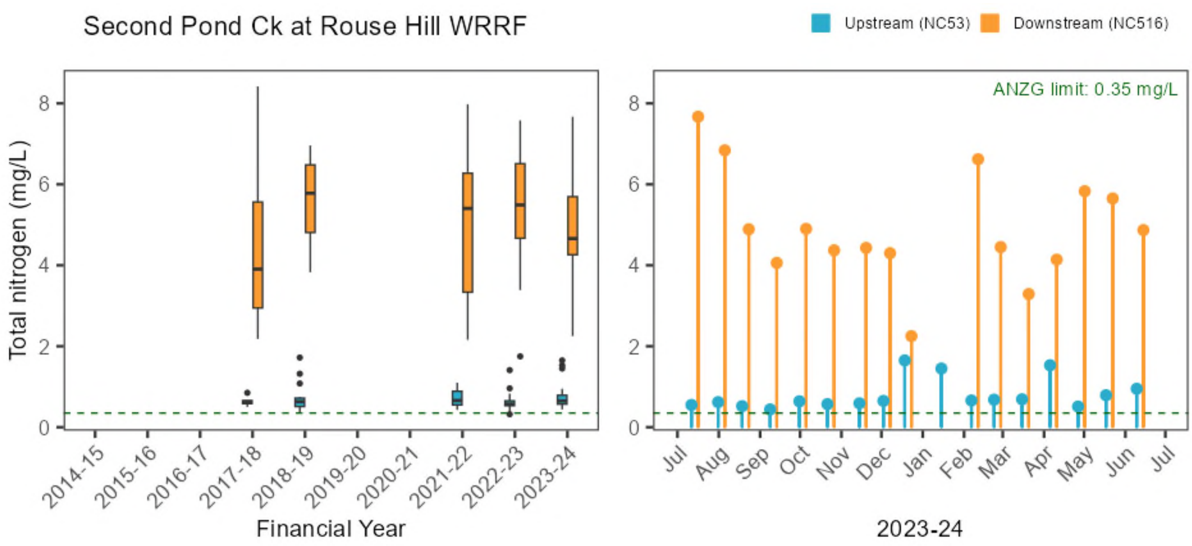
In the 2023-24 period, the median oxidised nitrogen, total nitrogen and total phosphorus concentrations exceeded the respective ANZG (2018) guidelines at both upstream and downstream sites. At the upstream catchment site (NC53), median dissolved oxygen saturation was lower than the lower guideline limit. The median turbidity was below the ANZG (2018) lower limit guideline at downstream site (NC516).

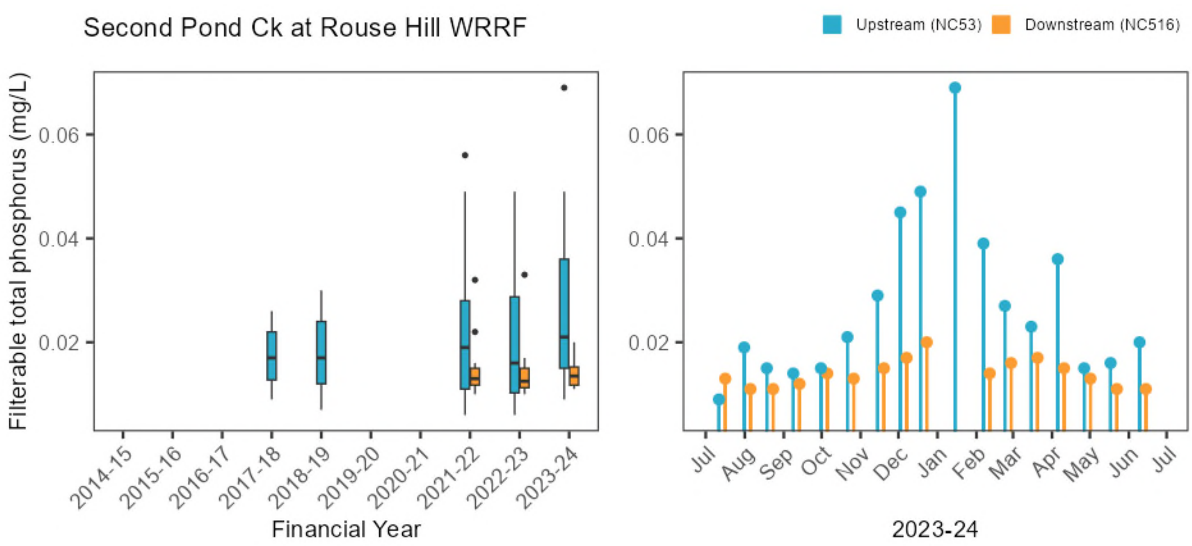
Statistical analysis confirmed that total ammonia nitrogen, oxidised nitrogen and total nitrogen concentrations at the downstream Second Ponds Creek site (NC516) were two, 20 and six times higher than the upstream site in 2023-24 period. This did not align with a decrease in total nitrogen concentration in Rouse Hill treated discharges, suggesting other catchment influences. Filterable total phosphorus and total phosphorus were significantly higher at the upstream site, 1.7 and 1.6 times higher respectively. Other phosphorus rich run-offs from upstream catchment may be associated with this.

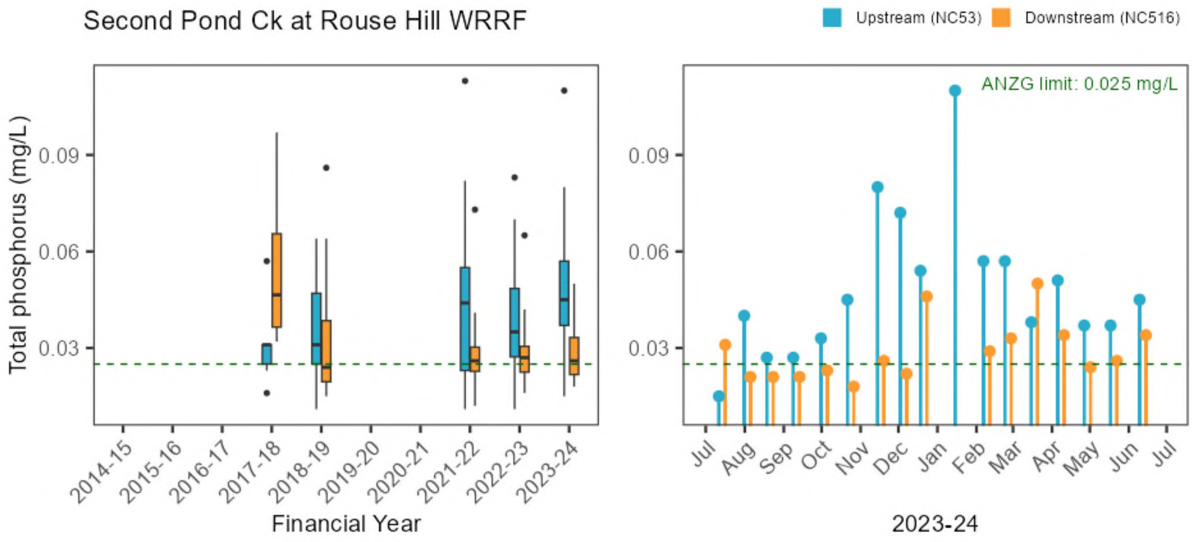
Among physico-chemical analytes, dissolved oxygen concentration and saturation were significantly higher at downstream Second Ponds Creek site in comparison to upstream site. Dissolved oxygen saturation was on average 25% higher at the downstream site compared to the upstream site in 2023-24, indicating a positive influence of routine discharges. There were no significant differences found in the results of other analytes between the upstream and downstream site in 2023-24.



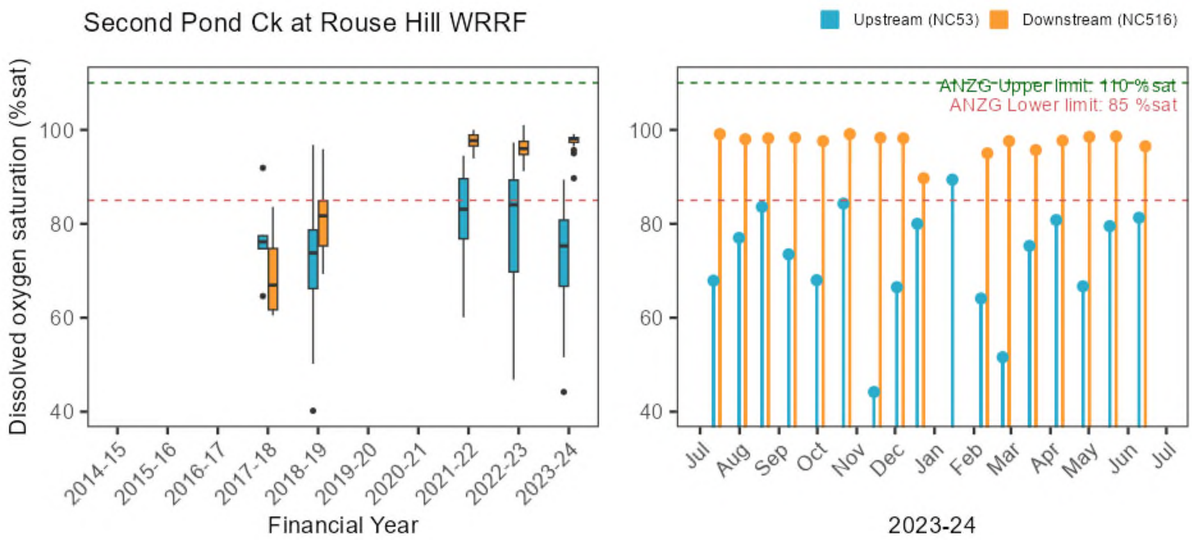

Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
ANZG limit: 0.04 mg/L
Oxidised nitrogen (mg/L)
Financial Year
2023-24


Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
ANZG limit: 0.35 mg/L
Total nitrogen (mg/L)
Financial Year
2023-24


Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
Filterable total phosphorus (mg/L)
Financial Year
2023-24


Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
Total phosphorus (mg/L)
0.09
0.06
0.03
ANZG limit: 0.025 mg/L
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
Dissolved oxygen (mg/L)
9
7
5
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Second Pond Ck at Rouse Hill WRRF
Upstream (NC53)
Downstream (NC516)
Dissolved oxygen saturation (%sat)
100
80
60
40
ANZG Upper limit: 110 %sat
ANZG Lower limit: 85 %sat
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

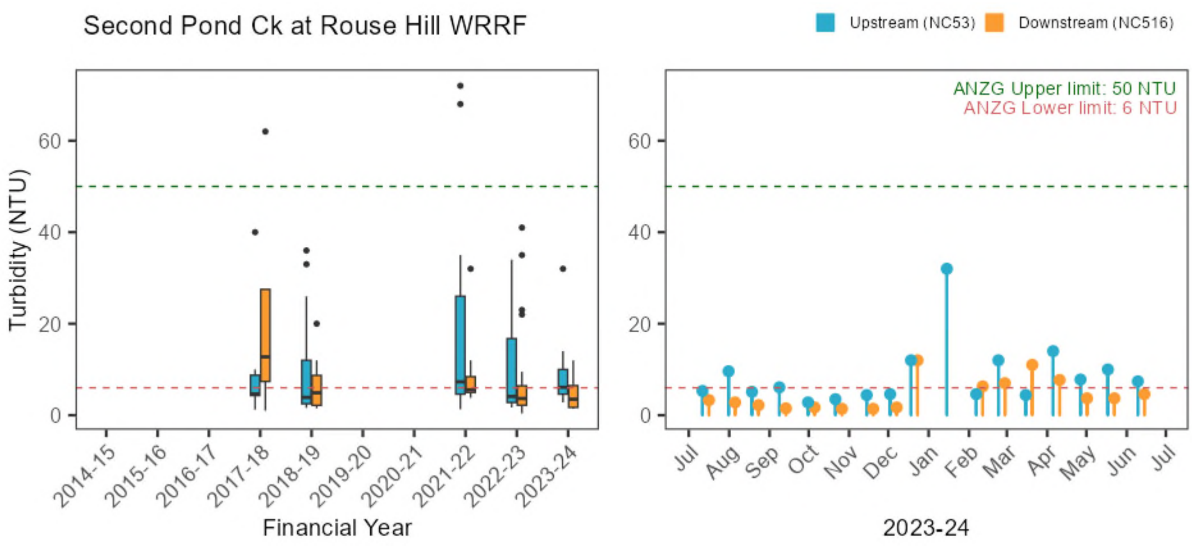


Figure 4-57 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Rouse Hill WRRF

Ecosystem Receptor – Phytoplankton

Table 4-52 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Rouse Hill WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NC53)	→
Downstream tributary (NC516)	↘

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NC53 vs NC516)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there was a significantly decreasing trend in chlorophyll-a at the downstream Second Ponds Creek site (NC516) compared to the previous six years.

The median chlorophyll-a concentrations were within the ANZG (2018) guideline limit at both the upstream and downstream sites.

Chlorophyll-a concentrations were low at both the upstream and downstream sites. Statistical analysis confirmed that in 2023-24, there was no significant difference found in chlorophyll-a concentration between upstream and downstream sites.

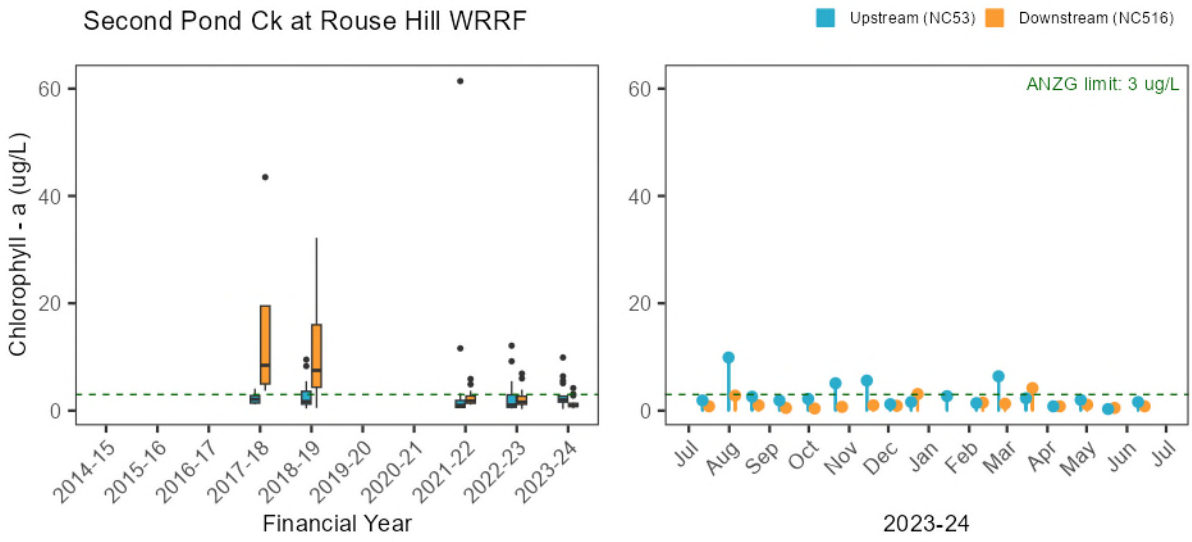


Figure 4-58 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Rouse Hill WRRF

Ecosystem Receptor – Macroinvertebrates

A statistical comparison of the upstream and downstream SIGNAL-SG scores for 2023–24 samples suggested no localised ecosystem impacts in Second Pond Creek.

Table 4-53 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Rouse Hill WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NC53 vs NC516)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

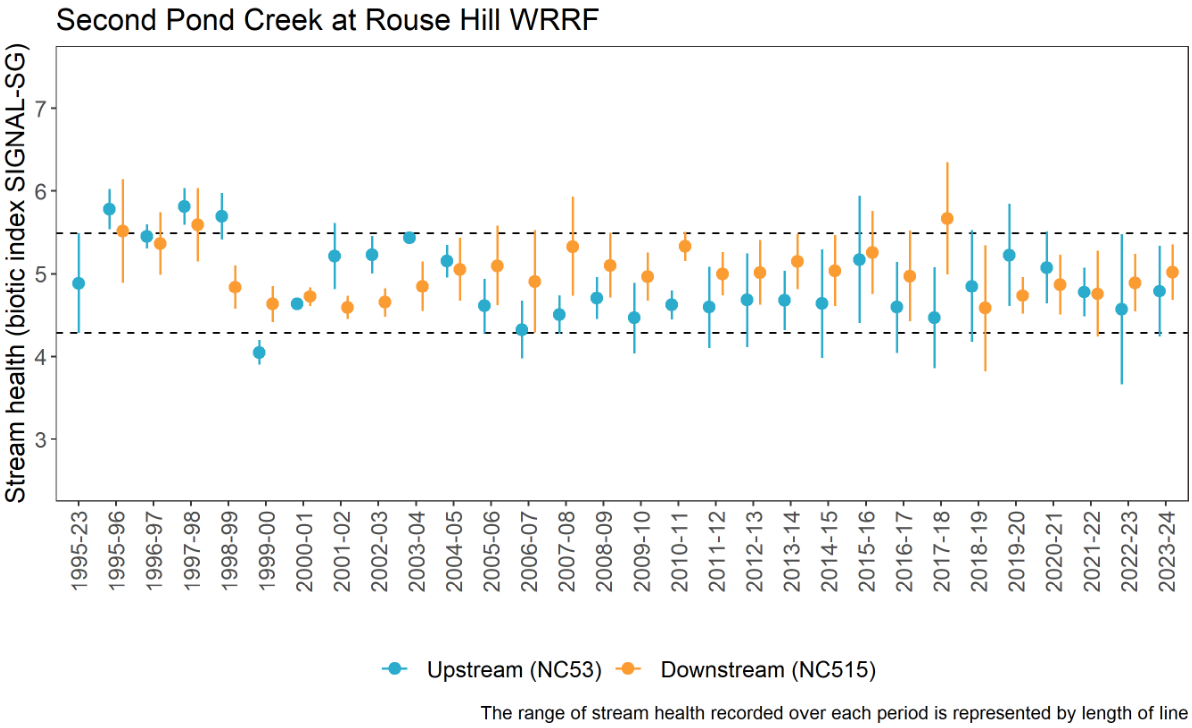


Figure 4-59 Stream health of Second Ponds Creek upstream and downstream of Rouse Hill WRRF

Gate 2 – Synthesis of impact of Rouse Hill WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as Chlorophyll-a	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Ammonia nitrogen	→	D	-	-	Decreased nitrogen in Rouse Hill discharges had no resulting benefit on downstream receiving water nitrogen. Although total ammonia concentration at the downstream site was higher than the upstream, these were low and within the ANZG toxicity guideline for 95% species protection. There was no ecosystem health impact observed at the downstream site in terms of phytoplankton or macroinvertebrates. No further analysis (Gate 3) to be carried out.
Oxidised nitrogen		D			
Total nitrogen	↘	D			
Filterable total phosphorus		U			
Total phosphorus	→	U			
Conductivity		-			
Dissolved oxygen		D			
Dissolved oxygen saturation		D			
pH		-			
Temperature		-			
Turbidity		-			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.12. Castle Hill WRRF

- Aluminium exceeded the average concentration limit in Castle Hill WRRF treated discharge during 2023-24. All other parameters (concentrations and loads) were within EPL limits. There were increasing trends in total nitrogen and aluminium concentrations, and a decreasing trend in total phosphorus concentration in the discharge.
- Oxidised and total nitrogen concentrations increased significantly at the downstream Cattai Creek site in 2023-24 compared to the past six years.
- Oxidised nitrogen, total nitrogen and filterable total phosphorus concentrations were significantly higher at the downstream Cattai Creek site compared to the upstream site, indicating a potential impact from the Castle Hill WRRF.
- Chlorophyll-a concentrations decreased significantly at the downstream site in 2023-24 compared to the previous six years. However, no significant difference was identified in chlorophyll-a concentrations between upstream and downstream sites.
- Stream health (as indicated by macroinvertebrates) suggested a localised adverse ecological impact at the downstream Cattai Creek site in which Castle Hill WRRF discharges.

Pressure – Wastewater discharge

Table 4-54 Gate 1 Analysis outcome summary – Castle Hill WRRF

Analytes / Castle Hill WRRF	Nutrients			Conventional analytes					Trace Metals					Other	
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Cadmium	Copper	Iron	Zinc	Diazinon	Hydrogen sulfide (un-ionised)
Concentration	→	↗	↘	→	→		→	→	↗	→	→	→	→	→	→
Load															

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

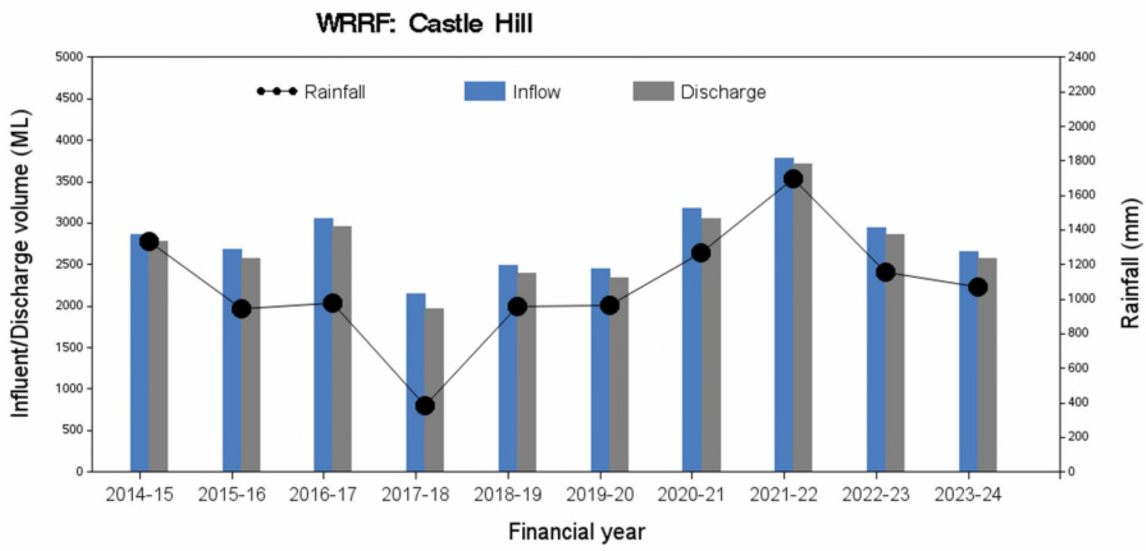
All concentration and load levels in the treated discharge from Castle Hill WRRF were within EPL limits during the 2023-24 period.

Statistical analysis identified significantly increasing trends in total nitrogen and aluminium concentrations during 2023-24 compared to the previous nine years. A significantly decreasing trend was observed in total phosphorus concentration during the reporting period.

The increasing trend in total nitrogen concentrations can be linked to changes in the biological processes which reduced nitrogen removal from March 2023 to April 2024. While bioreactor performance was impacted, various process optimisations were undertaken at Castle Hill WRRF including aeration to assist in denitrification.

The increasing trend in aluminium concentrations and subsequent EPL non-compliance can also be linked to the change in bioreactor sludge characteristics. Reduced total phosphorus concentration led to subsequent overdosing of the alum-based coagulant. Chemical dosing optimisations were ongoing to reduce aluminium, along with overhauling the remaining tertiary filters during the latter stages of 2023-24 to improve removal of particulate aluminium.

As part of the Hawkesbury-Nepean Nutrient Management Framework (HNNMF), Castle Hill WRRF is installing ultrafiltration, a new anoxic tank and mixed liquor recycle pumps. These upgrades are required to achieve compliance with incoming total nitrogen (6 mg/L) and total phosphorus (0.1 mg/L) 50th percentile limits from 1st July 2025. An enhanced wet weather phosphorus removal system will be also installed as part of the upgrade program.



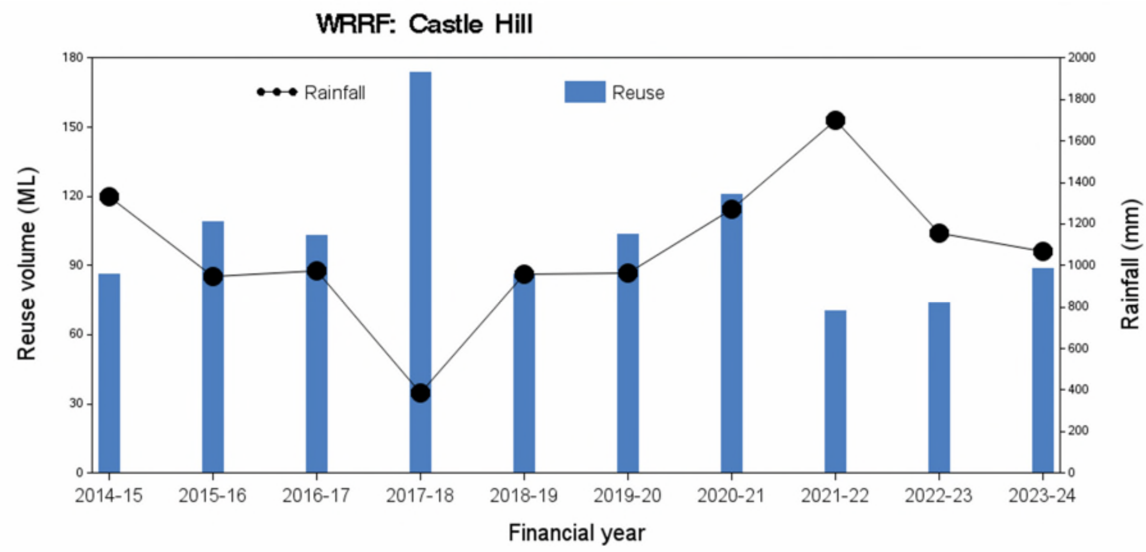
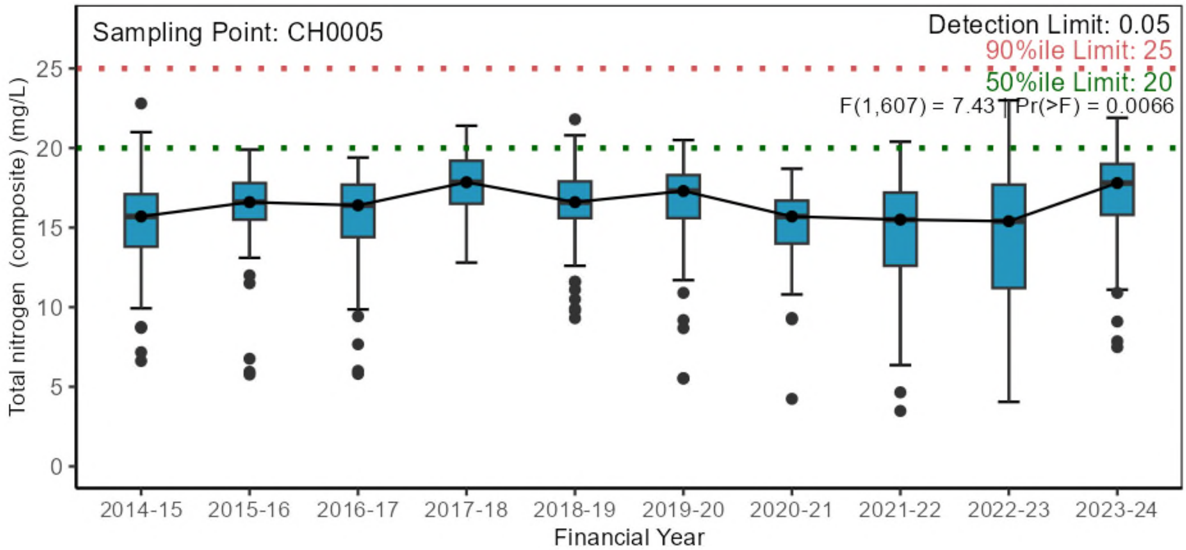
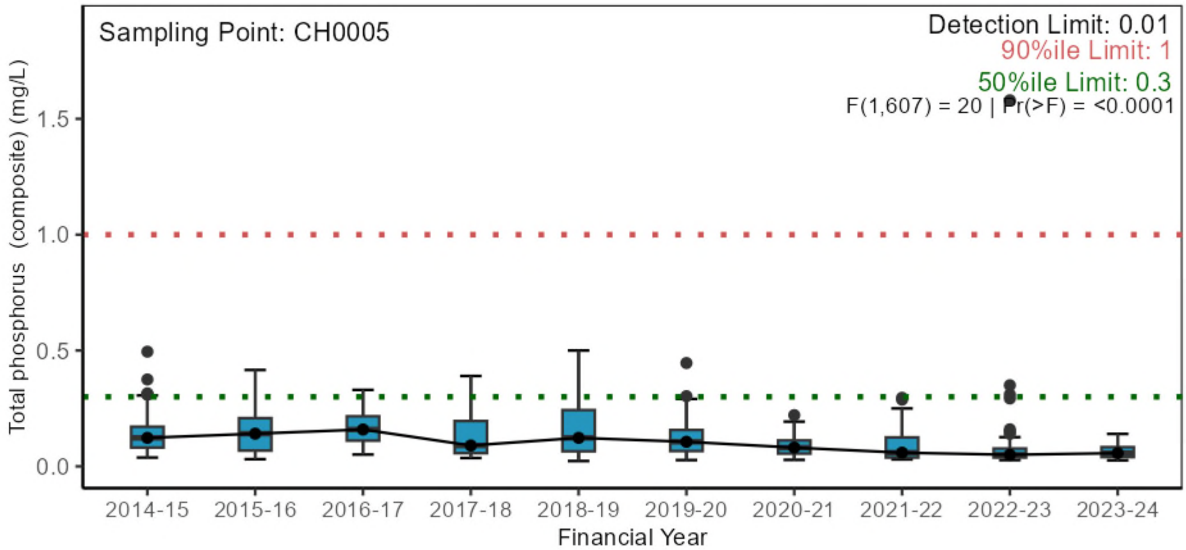


Figure 4-60 Castle Hill WRRF inflow, discharge and reuse volume with catchment rainfall



Sampling Point: CH0005
Detection Limit: 0.05
90%ile Limit: 25
50%ile Limit: 20
F(1,607) = 7.43 | Pr(>F) = 0.0066
Total nitrogen (composite) (mg/L)
0
5
10
15
20
25
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Sampling Point: CH0005
Detection Limit: 0.01
90%ile Limit: 1
50%ile Limit: 0.3
F(1,607) = 20 | Pr(>F) = <0.0001
Total phosphorus (composite) (mg/L)
0.0
0.5
1.0
1.5
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year

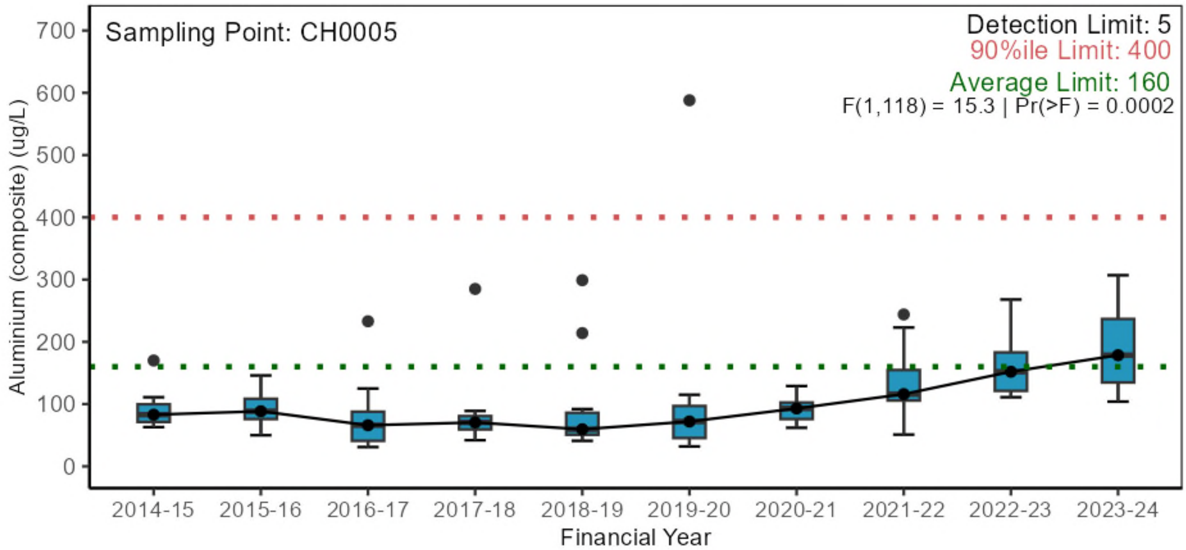


Figure 4-61 Castle Hill WRRF discharge and reuse quality exception plots

Stressor – Water quality

Table 4-55 Gate 1 Analysis outcome summary – water quality upstream and downstream of Castle Hill WRRF discharge point

Castle Hill WRRF / Analytes		Nutrient analytes					Physico-chemical analytes						
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NC8)	→	→	→	→	→	→	→	→	→	→	→
Tributary	Downstream tributary (NC75)	→	↗	↗	→	→	→	→	→	↘	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(orange)	Median value outside the guideline limit in 2023-24				

Castle Hill WRRF / Analytes		Nutrient analytes					Physico-chemical analytes						
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NC8 vs NC75)	-	D	D	D	-	D	-	-	U	-	U

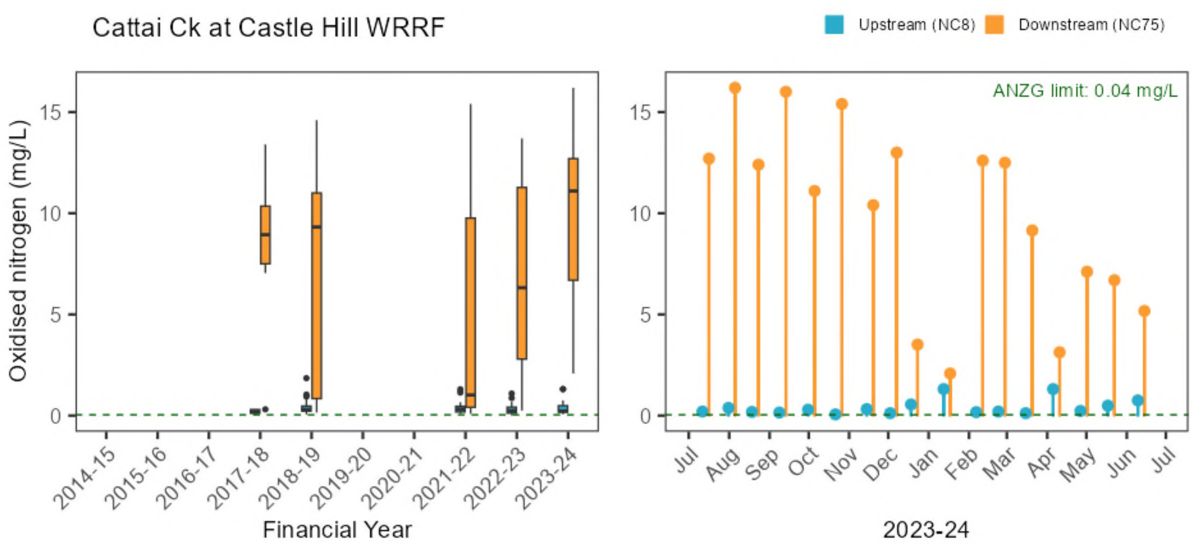
D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

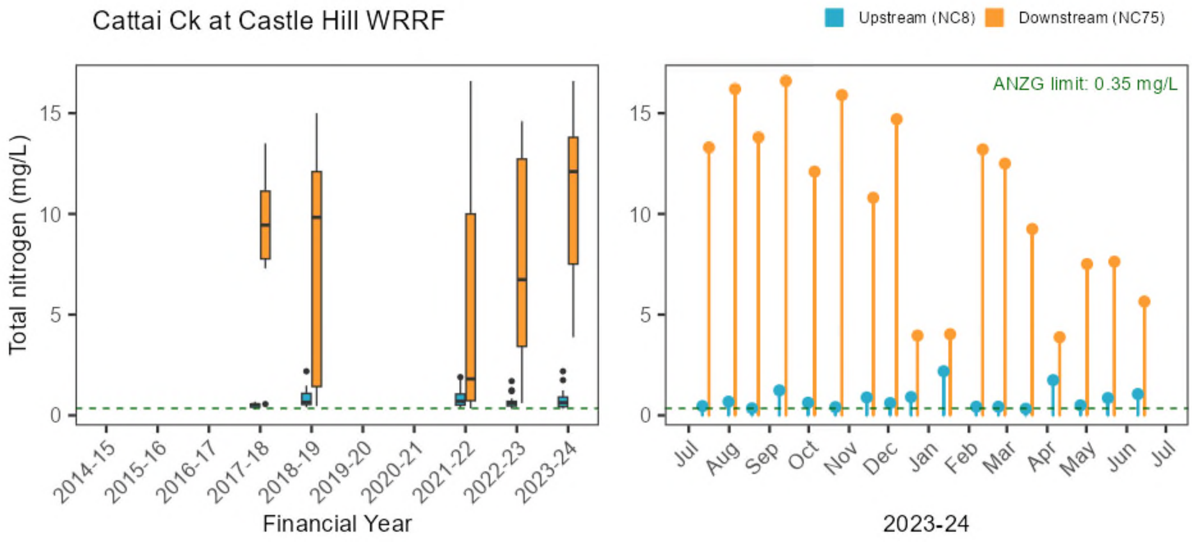
Castle Hill WRRF discharges into Castle Hill Creek which joins with Cattai Creek about 500 m downstream. The upstream catchment control site on Cattai Creek (NC8) includes a mix of land uses with developed and rapidly growing housing areas.

Statistical analysis identified significantly increasing temporal trends in oxidised nitrogen and total nitrogen at the downstream Cattai Creek site (NC75) during 2023-24 compared to the previous six years. Concentrations of other nutrient and physico-chemical analytes were steady at this site. Nutrient concentrations and all other physico-chemical analytes were steady at the upstream Cattai Creek site.

In the 2023-24 period, the median oxidised nitrogen, total nitrogen and total phosphorus concentrations exceeded the respective ANZG (2018) guidelines at both upstream and downstream site. Median turbidity was below the ANZG (2018) lower guideline limit at downstream site (NC75).

Oxidised nitrogen, total nitrogen and filterable total phosphorus concentrations were significantly higher at the downstream Cattai Creek site. This is potentially linked with the increasing nitrogen trends from Castle Hill WRRF discharges. Conductivity was significantly lower at the downstream site while pH and turbidity were significantly higher at the upstream site. On 15 January 2024 turbidity was very high at the upstream site (310 NTU) due to an extreme wet weather event and resulting catchment run-off.




Cattai Ck at Castle Hill WRRF
Upstream (NC8)
Downstream (NC75)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
0
5
10
15
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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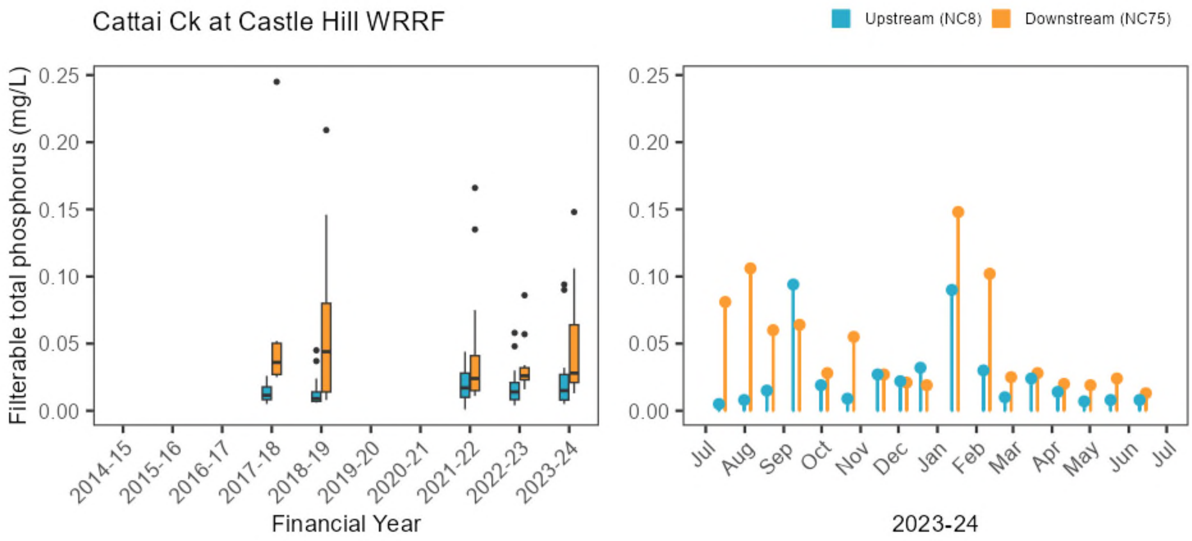
Jul
2023-24


Cattai Ck at Castle Hill WRRF
Upstream (NC8)
Downstream (NC75)
Filterable total phosphorus (mg/L)
0.00
0.05
0.10
0.15
0.20
0.25
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
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Nov
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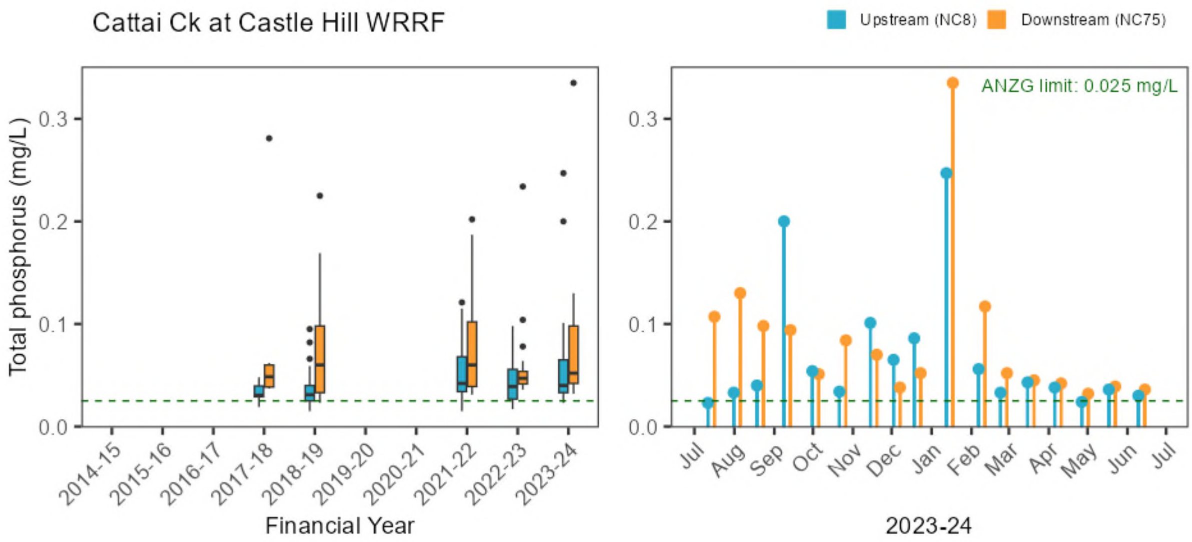
Jul
2023-24


Cattai Ck at Castle Hill WRRF
Upstream (NC8)
Downstream (NC75)
Total phosphorus (mg/L)
ANZG limit: 0.025 mg/L
0.0
0.1
0.2
0.3
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
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2023-24

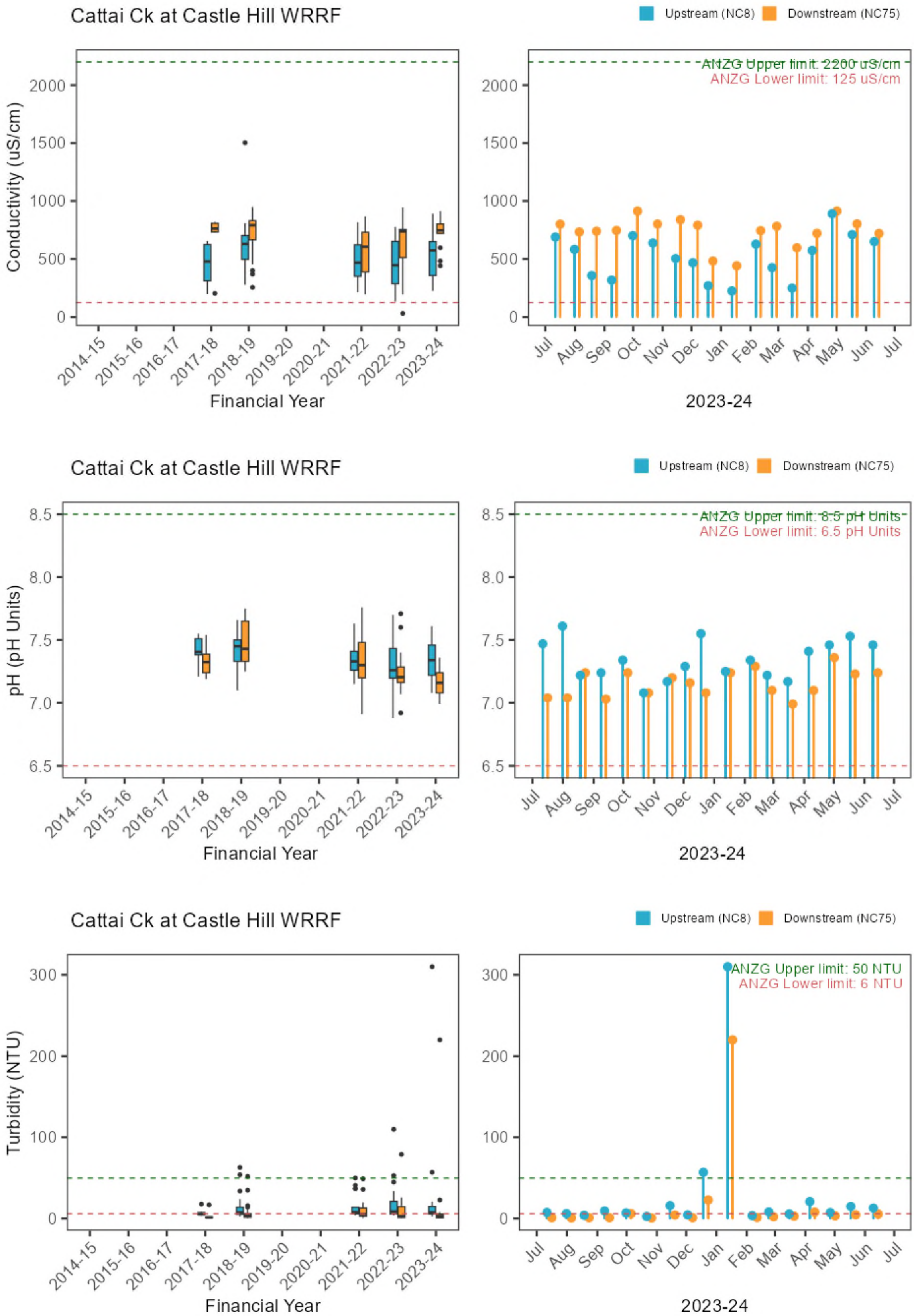


Figure 4-62 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Castle Hill WRRF

Ecosystem Receptor – Phytoplankton

Table 4-56 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Castle Hill WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NC8)	→
Downstream tributary (NC75)	↘

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NC8 vs NC75)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there was a significantly decreasing trend identified for chlorophyll-a at the downstream Cattai Creek site compared to the previous six years.

In the 2023-24 period, the median chlorophyll-a concentrations were within the ANZG (2018) guideline at both sites.

Chlorophyll-a concentrations were generally low at the Cattai Creek sites with a low water retention time. Statistically, upstream concentrations were not significantly different from downstream concentrations.

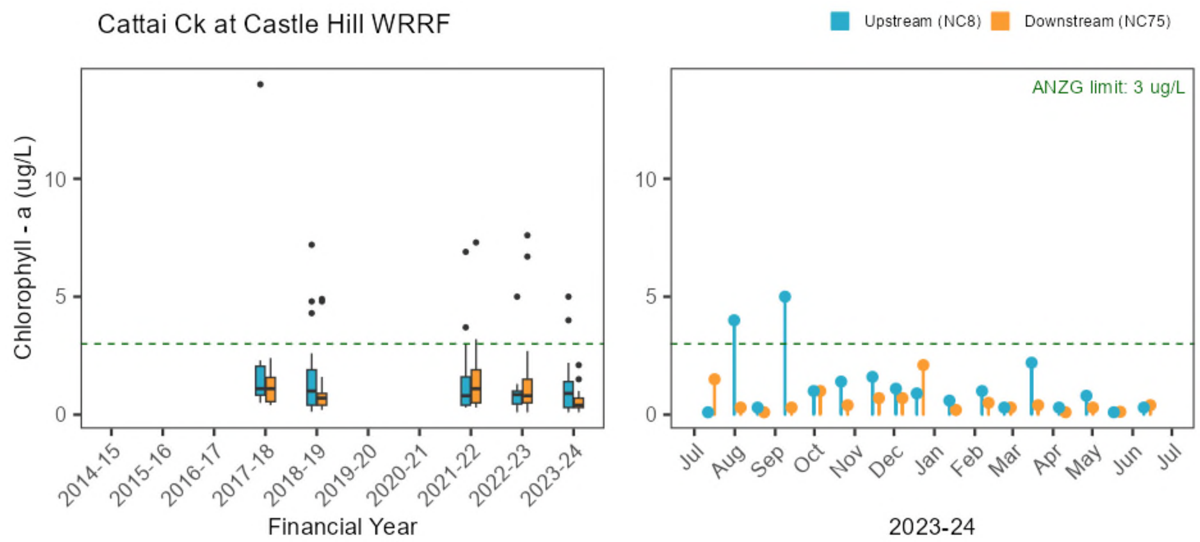


Figure 4-63 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Castle Hill WRRF

Ecosystem Receptor – Macroinvertebrates

A comparison of the upstream-downstream SIGNAL-SG scores for 2023–24 samples returned a marginally statistically significant test outcome and confirmed the visual trend of the SIGNAL-SG plot where stream health for the upstream site was slightly higher compared to the downstream site.

Table 4-57 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Castle Hill WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NC8 vs NC75)	D

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

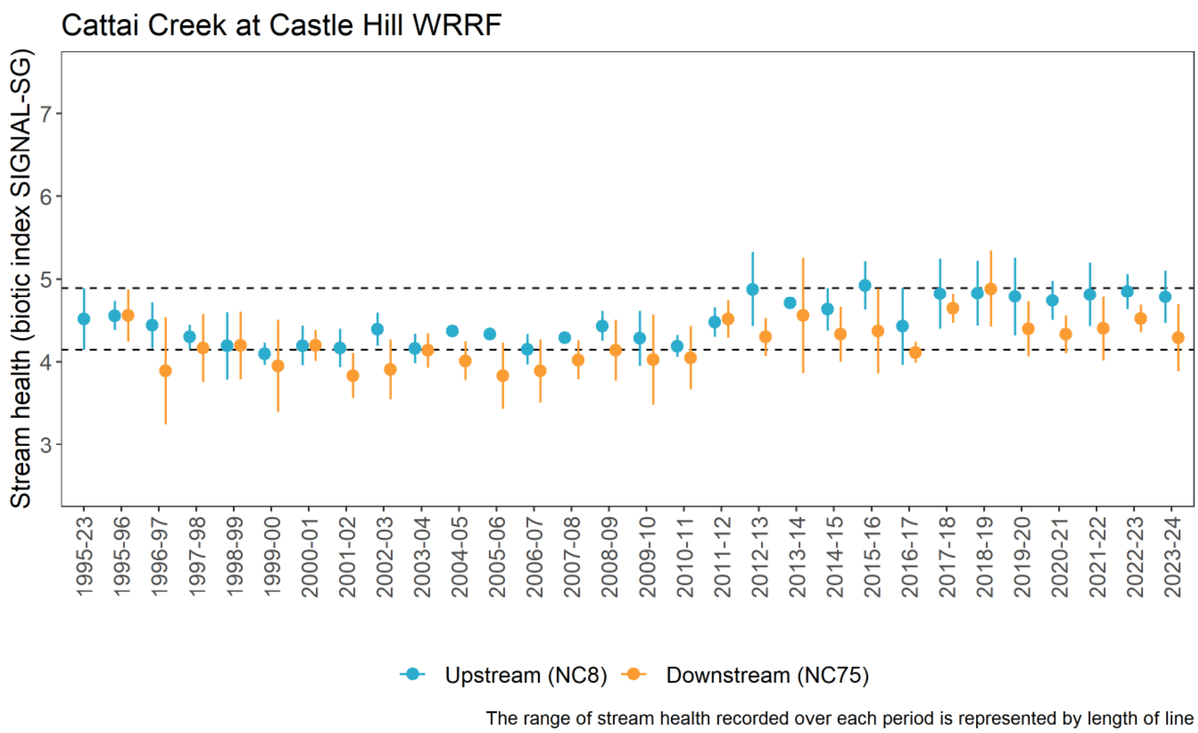


Figure 4-64 Stream health of Cattai Creek upstream and downstream of Castle Hill WRRF

Gate 2 – Synthesis of impact of Castle Hill WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as chlorophyll-α	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Total ammonia nitrogen	→	-	-	D	The increased nitrogen concentration in the discharge from Castle Hill WRRF resulted in a subsequent increase in the downstream receiving water nitrogen concentration. Stream health, as indicated by macroinvertebrates, was impacted at the downstream creek site. Further investigation to be carried out (Gate 3 analysis).
Oxidised nitrogen		D			
Total nitrogen	↗	D			
Filterable total phosphorus		D			
Total phosphorus	↘	-			
Conductivity		D			
Dissolved oxygen		-			
Dissolved oxygen saturation		-			
pH		U			
Water temperature		-			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.13. West Hornsby WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from West Hornsby WRRF in 2023-24 were within EPL limits. There were decreasing trends in total nitrogen, biochemical oxygen demand and zinc concentrations in the treated discharge compared to the previous nine years.
- Nutrient concentrations were steady in 2023-24 compared to the previous six years at both the upstream and downstream sites on Waitara Creek.
- Oxidised and total nitrogen concentrations were significantly higher at the downstream site compared to upstream concentrations which does not reflect the decreased trend in total nitrogen concentration in West Hornsby WRRF discharges.
- Chlorophyll-a concentrations were low with no significant difference between the upstream and downstream Waitara Creek sites.
- Stream health outcomes (as indicated by macroinvertebrates) suggest the downstream community in Waitara Creek was not adversely impacted by wastewater discharge from West Hornsby WRRF in 2023-24.

Pressure – Wastewater discharge

All concentration and load levels in the treated discharge from West Hornsby WRRF were within EPL limits during the 2023-24 period.

Statistical analysis identified significantly decreasing trends in total nitrogen, biochemical oxygen demand and zinc concentrations during 2023-24 compared to the previous nine years.

Table 4-58 Gate 1 Analysis outcome summary – West Hornsby WRRF

Analytes / West Hornsby WRRF	Nutrients			Conventional analytes					Trace Metals				Other
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc	Hydrogen sulfide (un-ionised)
Concentration	→	↘	→	↘	→		→	→	→	→	→	↘	→
Load													

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

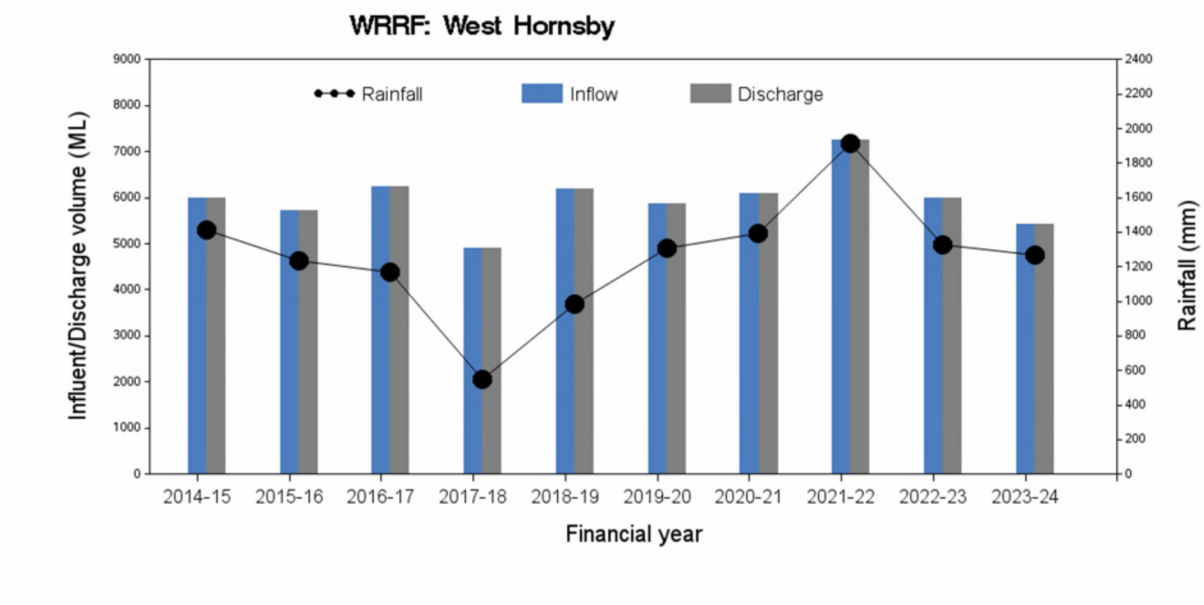
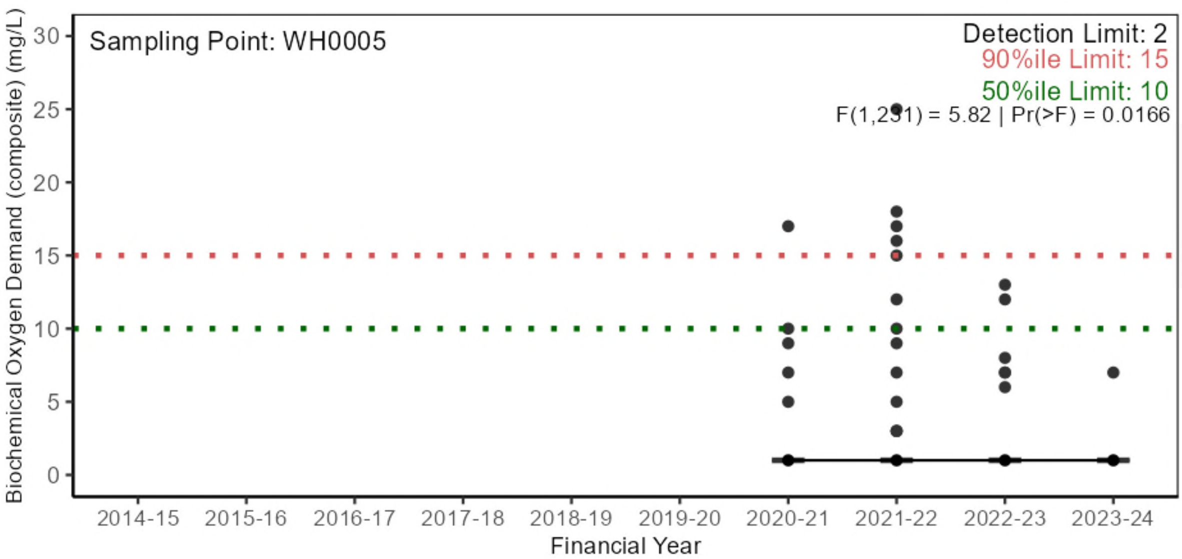
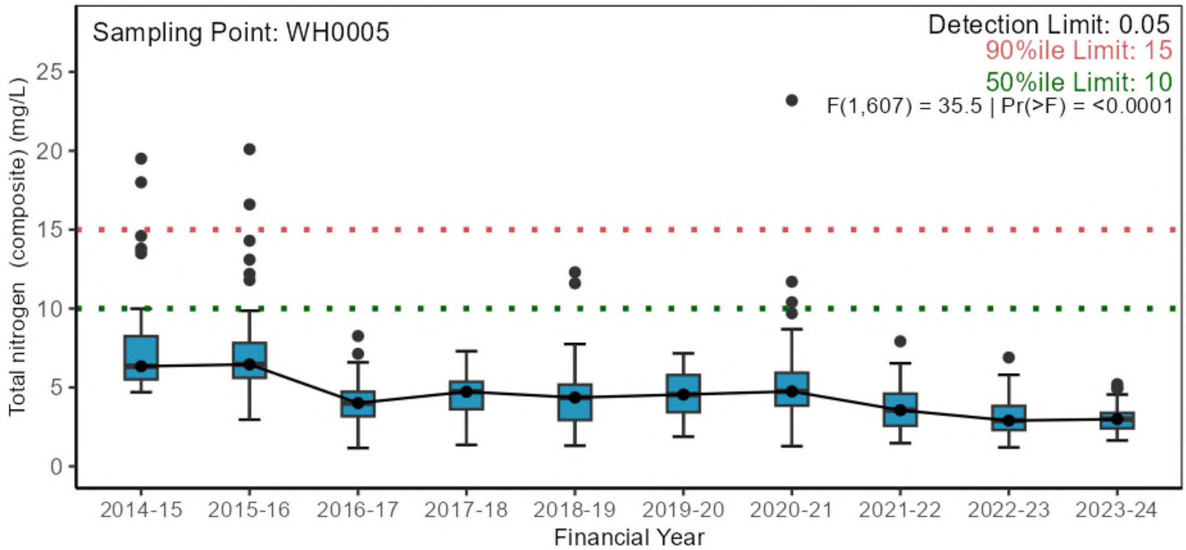
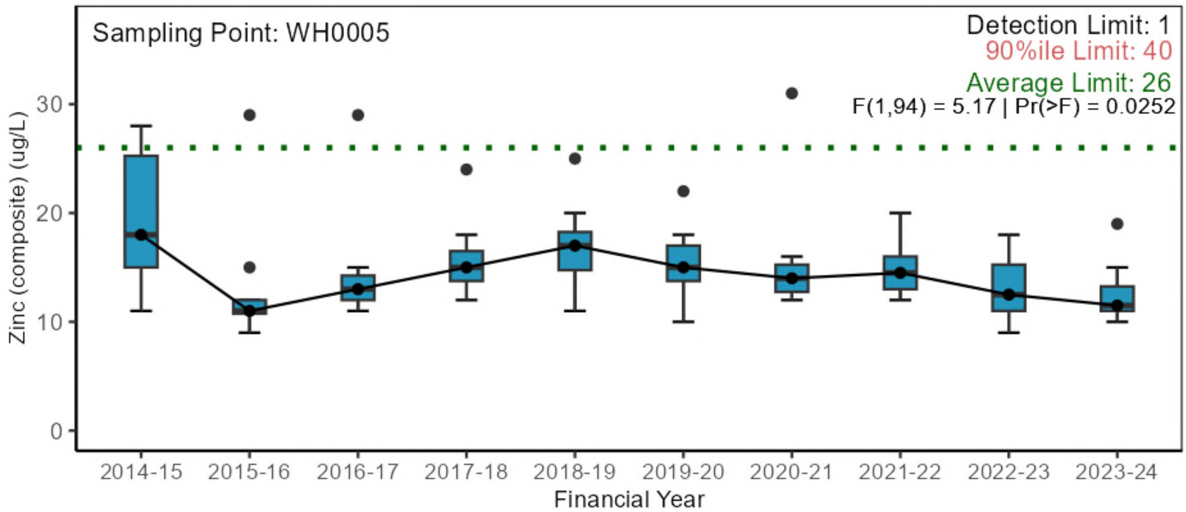


Figure 4-65 West Hornsby WRRF inflow and discharge volume with catchment rainfall







Statistical test excludes data prior to 2016-17 due to method detection limit change.

Figure 4-66 West Hornsby WRRF discharge quality exceptions plots

Stressor – Water quality

Table 4-59 Gate 1 Analysis outcome summary – water quality upstream and downstream of West Hornsby WRRF discharge point

West Hornsby WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream tributary (NB83)	→	→ [median outside guideline]	→ [median outside guideline]	→	→ [median outside guideline]	→	→	→	→	→	→ [median outside guideline]
Tributary	Downstream tributary (NB825)	→	→ [median outside guideline]	→ [median outside guideline]	→	→ [median outside guideline]	→	→	→	→	→	→ [median outside guideline]

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
[yellow shading]	Median value outside the guideline limit in 2023-24				

West Hornsby WRRF \ Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Water temperature	Turbidity
Tributary	Upstream vs downstream current year (NB83 vs NB825)	-	D	D	-	-	D	-	D	-	D	U

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

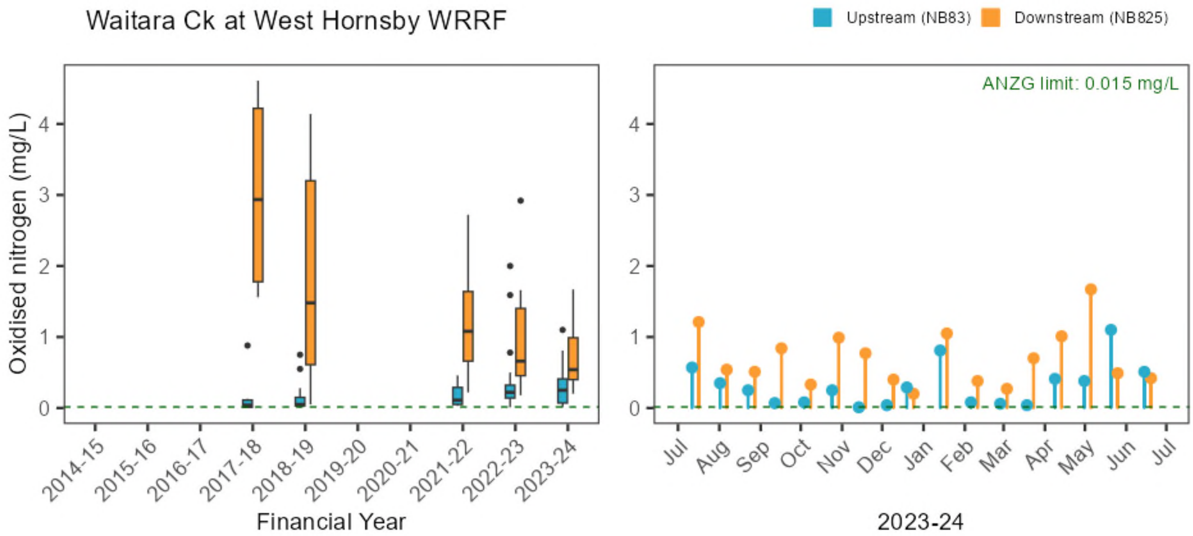
West Hornsby WRRF discharges into Waitara Creek which is a tributary of Berowra Creek, draining to the Berowra estuary of the Hawkesbury-Nepean River. The upstream Waitara Creek catchment includes a mix of land uses including bushland, rural and housing both developing and developed.

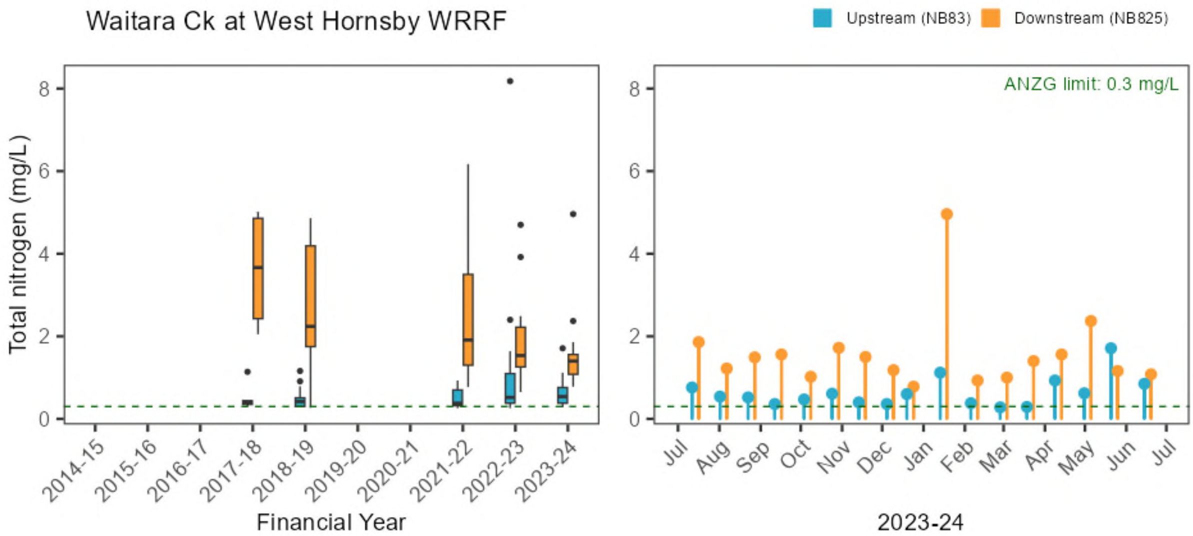
In the 2023-24 period, none of the nutrients or any other physico-chemical analyte exhibited a significant trend at either the upstream or downstream sites on Waitara Creek compared to the previous six years.

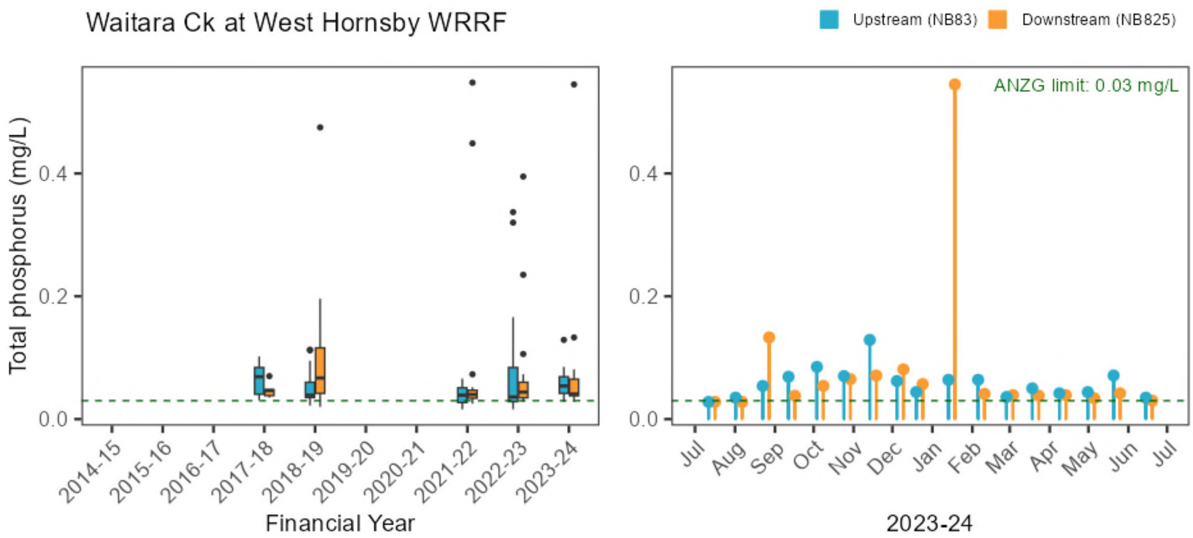
Oxidised nitrogen, total nitrogen and total phosphorus concentrations exceeded the respective ANZG (2018) guidelines at both Waitara Creek sites. The median turbidity was below the ANZG (2018) lower guideline limit at both sites.

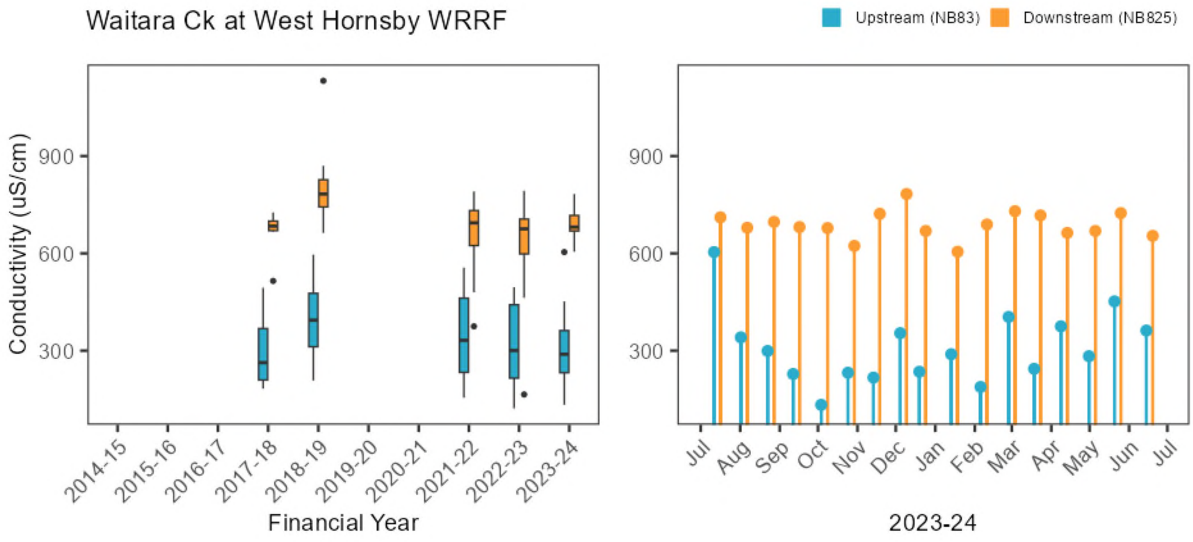
Oxidised and total nitrogen concentrations were significantly higher at the downstream site compared to the upstream site. These observations do not reflect the decreased trend in total nitrogen in the West Hornsby treated wastewater discharge.

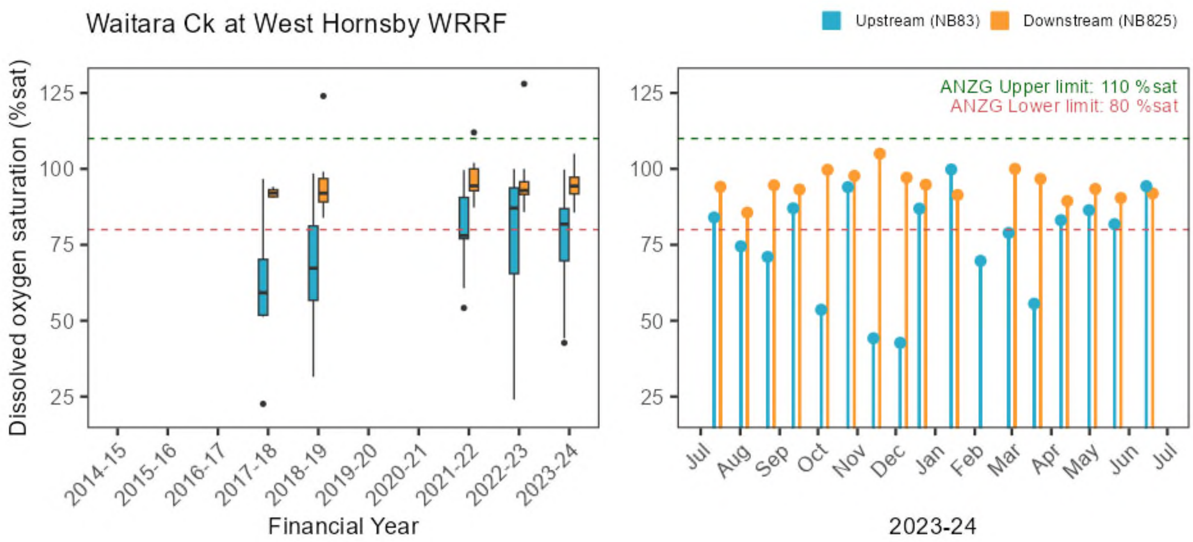
Conductivity, dissolved oxygen saturation and water temperature were significantly higher at the downstream site compared to the upstream site.

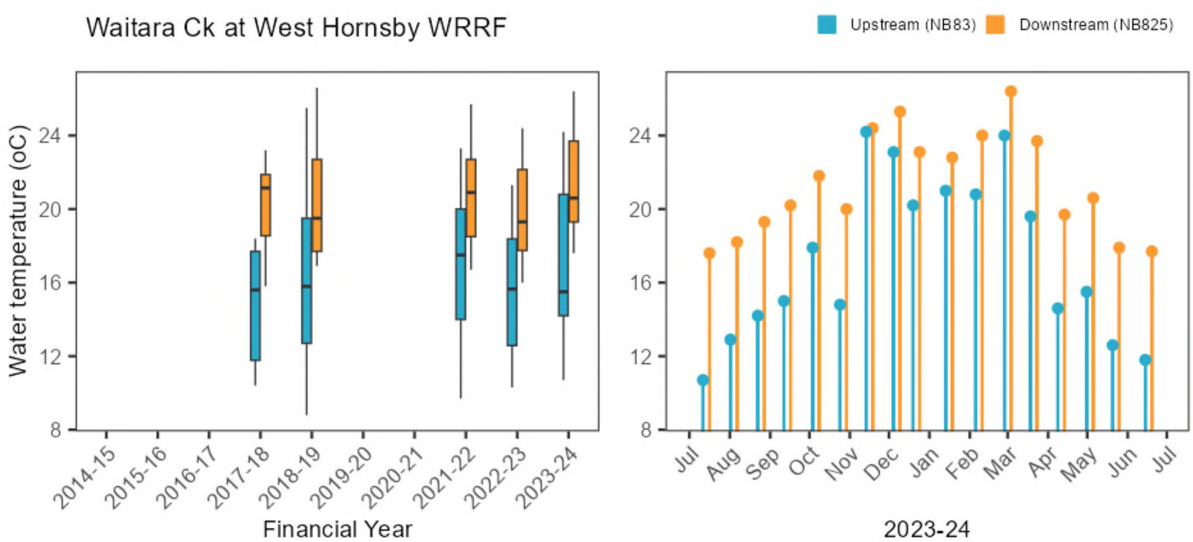

Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
Oxidised nitrogen (mg/L)
ANZG limit: 0.015 mg/L
Financial Year
2023-24


Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
Total nitrogen (mg/L)
ANZG limit: 0.3 mg/L
Financial Year
2023-24


Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
Total phosphorus (mg/L)
ANZG limit: 0.03 mg/L
Financial Year
2023-24


Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
Conductivity (uS/cm)
Financial Year
2023-24


Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
ANZG Upper limit: 110 %sat
ANZG Lower limit: 80 %sat
Dissolved oxygen saturation (%sat)
Financial Year
2023-24


Waitara Ck at West Hornsby WRRF
Upstream (NB83)
Downstream (NB825)
Water temperature (oC)
Financial Year
2023-24

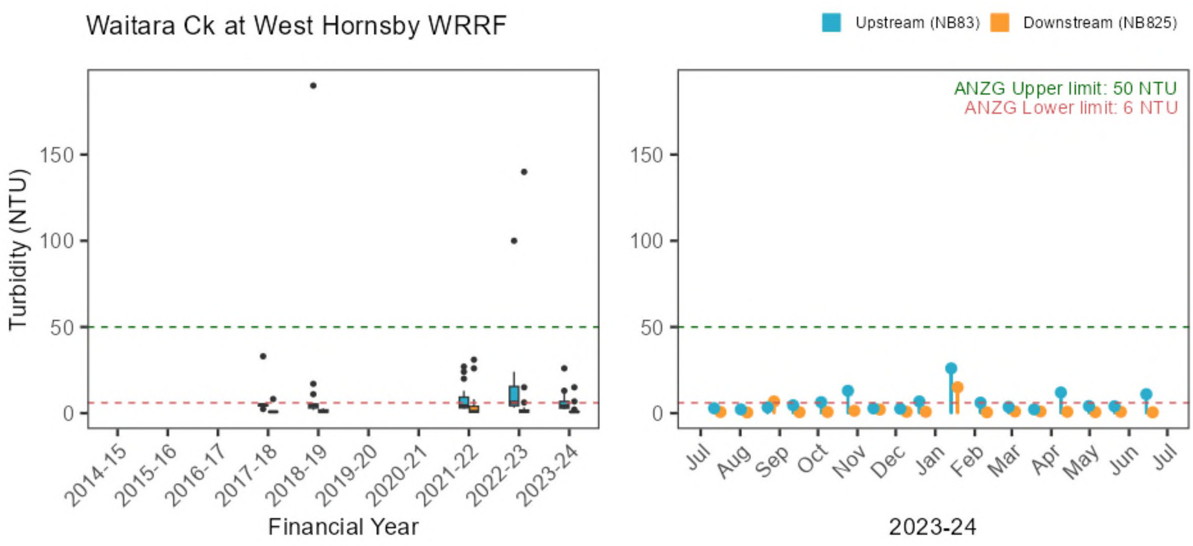


Figure 4-67 Nutrients and physico-chemical water quality exception plots, upstream and downstream of West Hornsby WRRF discharge point

Ecosystem Receptor – Phytoplankton

Table 4-60 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of West Hornsby WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream tributary (NB83)	→
Downstream tributary (NB825)	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream tributary (NB83 vs NB825)	-

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

In 2023-24, there were no significantly increasing or decreasing trends identified for chlorophyll-a at the upstream or downstream Waitara Creek sites compared to the previous six years.

The median chlorophyll-a concentrations were within the ANZG (2018) guideline limit at both the upstream and downstream sites.

Chlorophyll-a concentrations were low at both the upstream and downstream sites, with no significant difference between them.

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested no localised ecosystem impacts in Waitara Creek, downstream of West Hornsby WRRF.

Table 4-61 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of West Hornsby WRRF discharge point

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream tributary (NB83 vs NB825)	-

D	Downstream impact, SIGNAL lower (p<0.05)	U	Upstream impact, SIGNAL lower (p<0.05)	-	No difference (p>0.05)

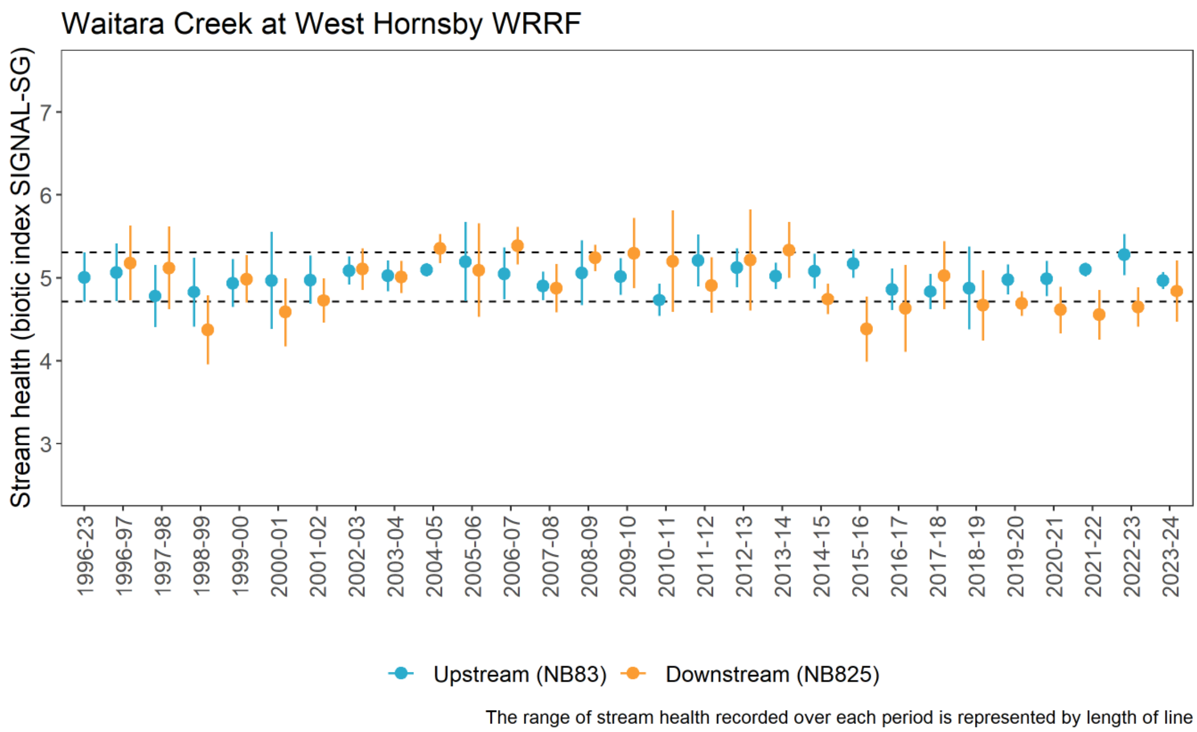


Figure 4-68 Stream health of Waitara Creek upstream and downstream of West Hornsby WRRF

Gate 2 – Synthesis of impact of West Hornsby WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as chlorophyll-a	Macroinvertebrates	
	Effluent	River (us vs ds)	River (us vs ds)	River (us vs ds)	
Total ammonia nitrogen	→	-	-	-	Total nitrogen at the downstream receiving water site was significantly higher than the upstream concentration, which does not reflect the decreased discharge concentration. No impact identified in phytoplankton or macroinvertebrate ecosystem health. No further analysis (Gate 3) to be carried out.
Oxidised nitrogen		D			
Total nitrogen	↘	D			
Filterable total phosphorus		-			
Total phosphorus	→	-			
Conductivity		D			
Dissolved oxygen		-			
Dissolved oxygen saturation		D			
pH		-			
Water temperature		D			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.14. Hornsby Heights WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Hornsby Heights WRRF in 2023-24 were within EPL limits. There was a decreasing trend in total nitrogen concentration in the treated discharge compared to the previous nine years.
- Nutrient concentrations were steady in 2023-24 compared to the previous six years at both the upstream and downstream sites on Calna Creek.
- Oxidised nitrogen, total nitrogen, filterable total phosphorus and total phosphorus concentrations were significantly higher at the downstream site compared to upstream site, which does not reflect the decreased total nitrogen concentration in Hornsby Heights WRRF treated discharge.
- Chlorophyll-a concentrations were low and no significant difference was observed between the upstream and downstream Calna Creek sites in 2023-24.
- Stream health results (as indicated by macroinvertebrates) suggest the downstream community structure in Calna Creek has been adversely impacted by wastewater discharge from Hornsby Heights WRRF, consistent with outcomes in previous years. This will be investigated further in the 2024-25 interpretive report.

Pressure – Wastewater discharge

All concentration and load levels in the treated discharge from Hornsby Heights WRRF were within the EPL limits during the 2023-24 period. Under EPL 750 condition L3.6, as set by the EPA, the three-day geometric mean (3DGM) concentration limits at Hornsby Heights WRRF may be exceeded when a wet weather bypass was the sole cause of the exceedance. This condition was met for total suspended solids on 19th February 2024.

Statistical analysis identified a significantly decreasing trend in total nitrogen concentrations during 2023-24 compared to the previous nine years.

Table 4-62 Gate 1 Analysis outcome summary – Hornsby Heights WRRF

Analytes / Hornsby Heights WRRF	Nutrients			Conventional analytes					Trace Metals				Other	
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Iron	Zinc	Hydrogen sulfide (un-ionised)	Diazinon
Concentration	→	↘	→	→	→		→	→	→	→	→	→	→	→
Load														

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

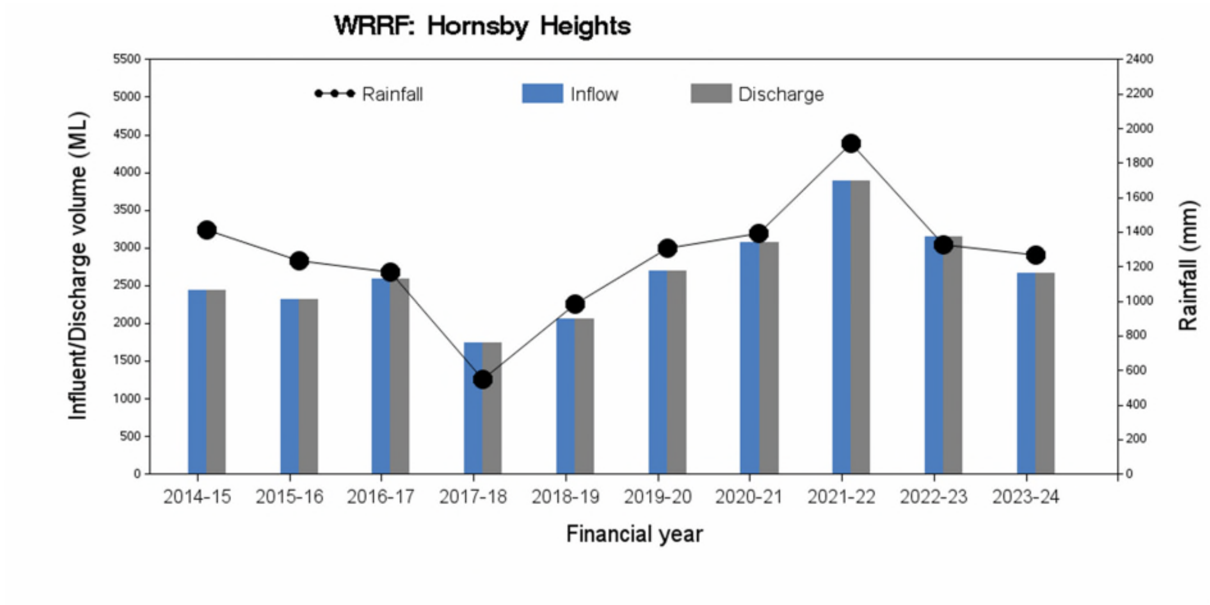


Figure 4-69 Hornsby Heights WRRF inflow and discharge volume with catchment rainfall

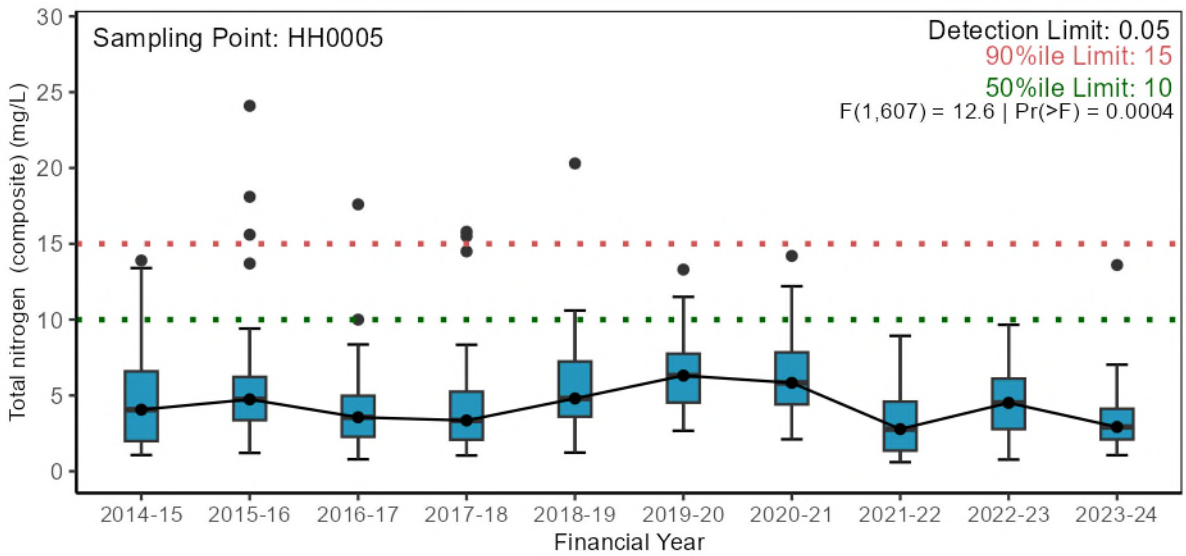


Figure 4-70 Hornsby Heights WRRF discharge quality exception plots

Stressor – Water quality

Table 4-63 Gate 1 Analysis outcome summary – water quality upstream and downstream of Hornsby Heights WRRF discharge point

Hornsby Heights WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
River	Upstream tributary (NB43)	→	→ (shaded)	→	→	→	→	→	→	→	→	→
	Downstream tributary (NB42)	→	→ (shaded)	→ (shaded)	→	→ (shaded)	→	→	→	→	→	→ (shaded)

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(shaded)	Median value outside the guideline limit in 2023-24				

Hornsby Heights WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
Tributary	Upstream vs downstream current year (NB43 vs NB42)	-	D	D	D	D	D	-	D	D	D	U

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

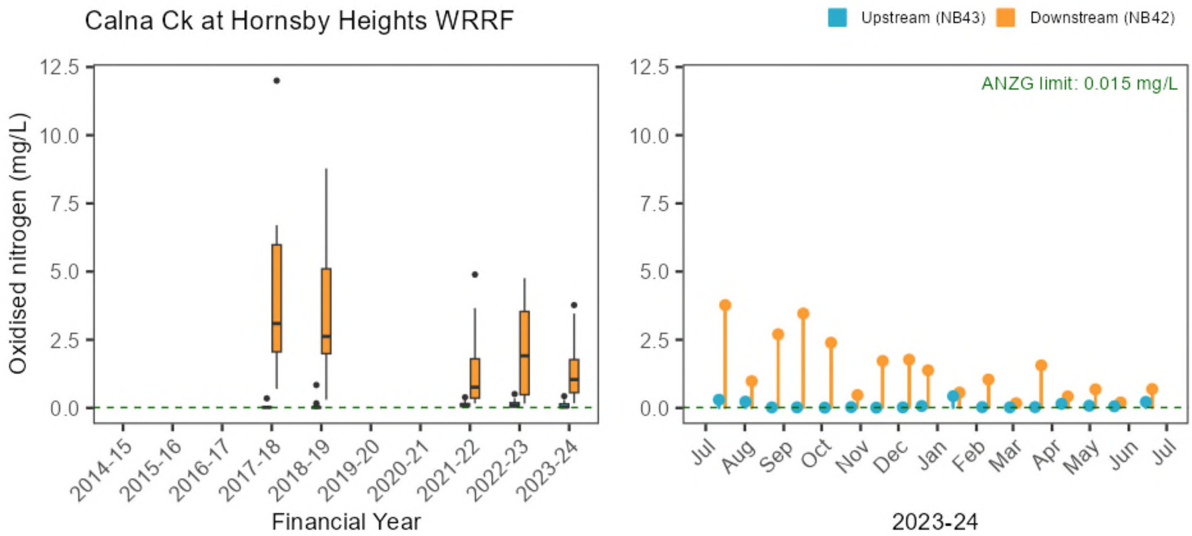
Hornsby Heights WRRF discharges into Calna Creek which is a tributary of Berowra Creek draining to the Berowra estuary of the Hawkesbury-Nepean River. The upstream Calna Creek catchment contains a mix of land uses including rural, residential and bushland.

In 2023-24, none of the nutrients or any other physico-chemical analyte exhibited a significant trend at either the upstream or downstream Calna Creek sites compared to the previous six years.

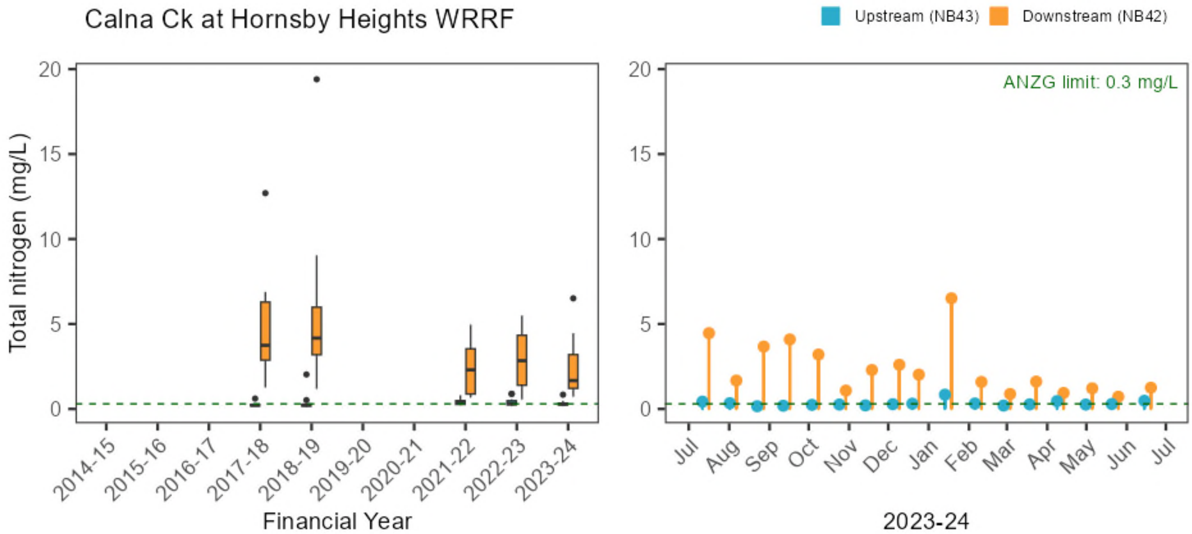
In the 2023-24 period, the median oxidised nitrogen at the upstream site (NB43) exceeded the respective ANZG (2018) guideline. At the downstream site (NB42), median oxidised nitrogen, total nitrogen and total phosphorus concentrations exceeded the guidelines. Median turbidity for this site was below the lower guideline limit.

Statistical analysis confirmed that oxidised nitrogen, total nitrogen, filterable total phosphorus and total phosphorus concentrations were higher at the downstream site compared to upstream site. This does not reflect the decreased total nitrogen trend and no observed trend in total phosphorus in Hornsby Heights WRRF treated discharge.

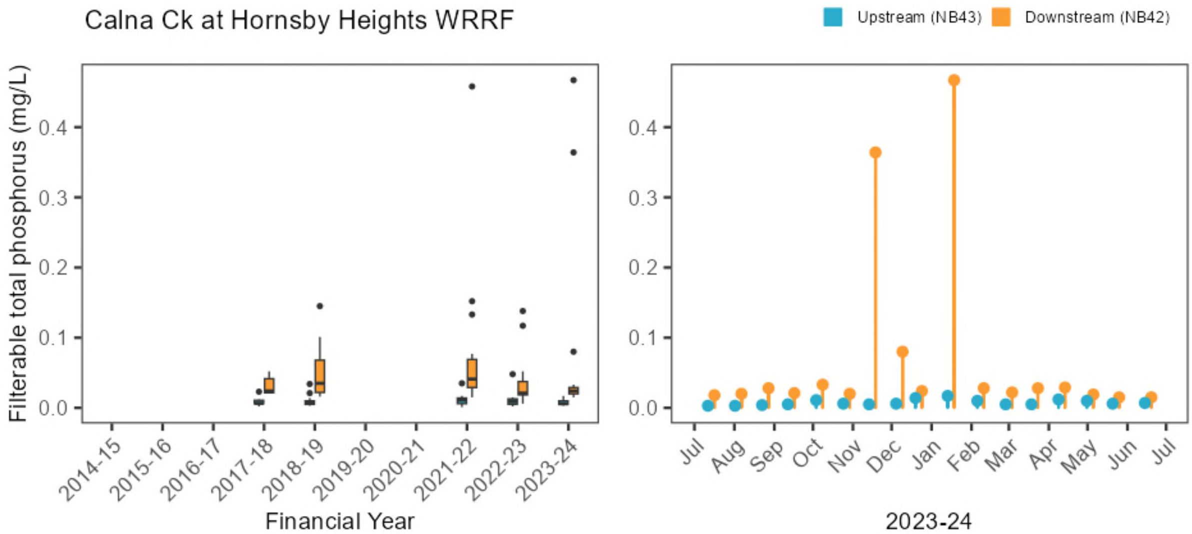
Conductivity, dissolved oxygen saturation, pH and water temperature were also significantly higher at downstream site, while turbidity was significantly higher at the upstream site.



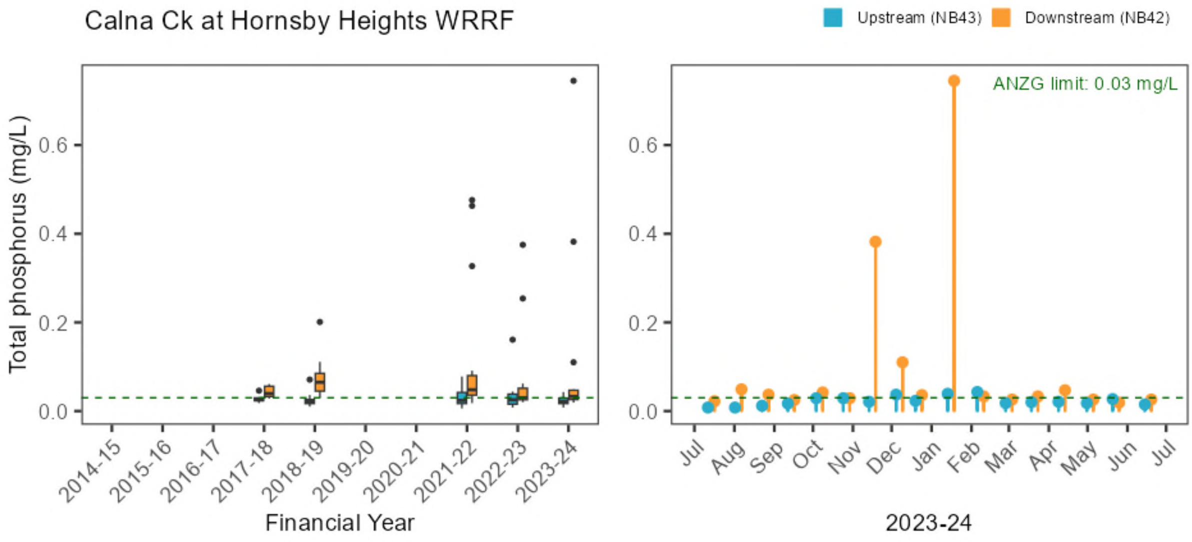
Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Oxidised nitrogen (mg/L)
ANZG limit: 0.015 mg/L
Financial Year
2023-24



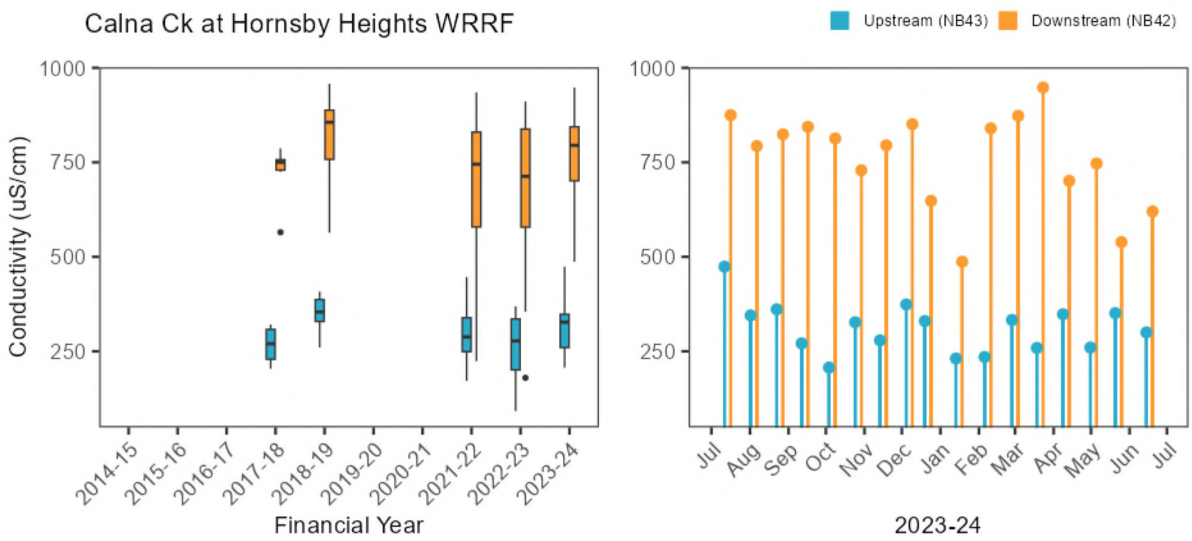
Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Total nitrogen (mg/L)
ANZG limit: 0.3 mg/L
Financial Year
2023-24



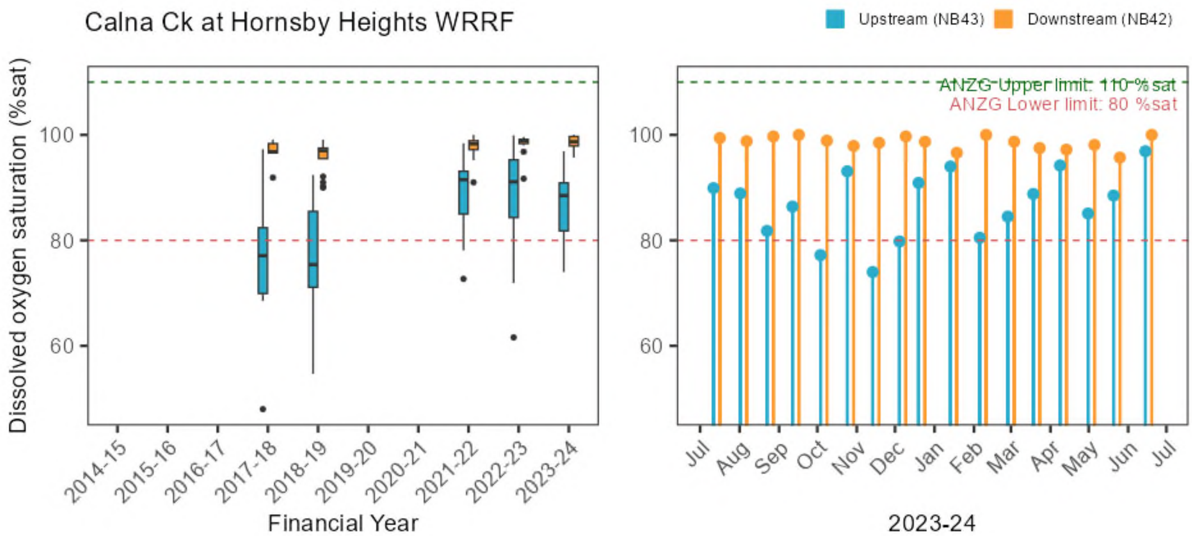
Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Filterable total phosphorus (mg/L)
Financial Year
2023-24



Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Total phosphorus (mg/L)
0.0
0.2
0.4
0.6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.03 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24



Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Conductivity (uS/cm)
250
500
750
1000
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24



Calna Ck at Hornsby Heights WRRF
Upstream (NB43)
Downstream (NB42)
Dissolved oxygen saturation (%sat)
60
80
100
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG Upper limit: 110 %sat
ANZG Lower limit: 80 %sat
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

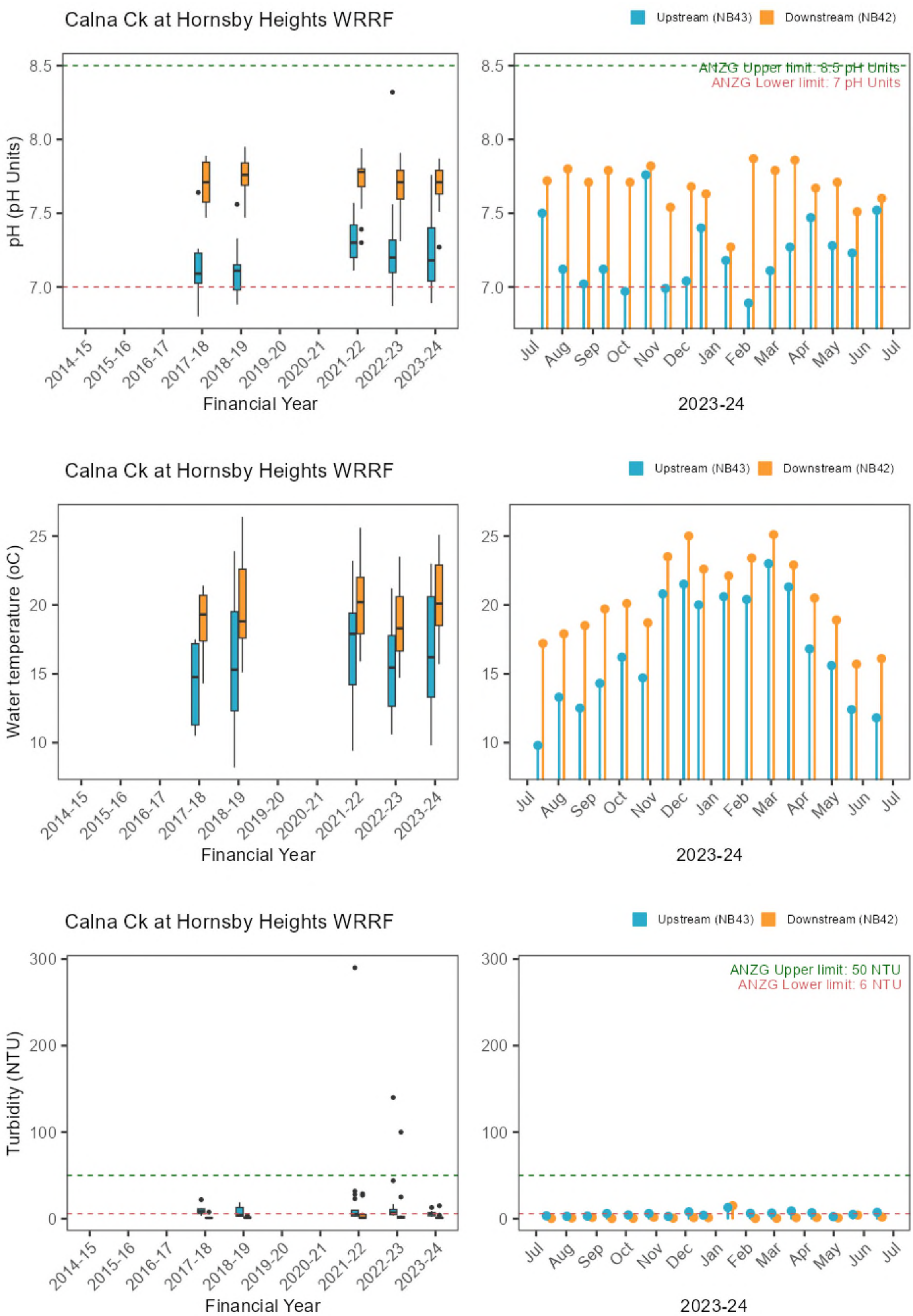


Figure 4-71 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Hornsby Heights WRRF

Ecosystem Receptor – Phytoplankton

Table 4-64 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Hornsby Heights WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream River (NB43)	→
Downstream River (NB42)	→

↗	Upward trend ($p<0.05$)	↘	Downward trend ($p<0.05$)	→	No trend ($p>0.05$)
	Median value outside the guideline limit in 2023-24				

Statistical comparison (paired sites current year)	Chlorophyll-a
Upstream vs downstream River (NB43 vs NB42)	-

D	Downstream higher ($p<0.05$)	U	Upstream higher ($p<0.05$)	-	No difference ($p>0.05$)

In 2023-24, there were no significantly increasing or decreasing trends identified for chlorophyll-a at the upstream or downstream Calna Creek sites compared to the previous six years.

The median chlorophyll-a concentrations were within the ANZG (2018) guideline limit at both the upstream and downstream sites. Chlorophyll-a concentrations were very low at both sites, with no significant difference identified between them.

Ecosystem Receptor – Macroinvertebrates

The 2023-24 macroinvertebrate results suggested localised ecosystem impacts in Calna Creek, downstream of Hornsby Heights WRRF. The SIGNAL-SG plot from the Calna Creek sites upstream and downstream of Hornsby Heights WRRF suggests a persistent impact over the last ten financial years.

Table 4-65 Gate 1 Analysis outcome summary for macroinvertebrates – upstream and downstream of Hornsby Heights WRRF

Statistical comparison (paired sites current year)	SIGNAL
Upstream vs downstream river (NB43 vs NB42)	D

D	Downstream impact, SIGNAL lower ($p<0.05$)	U	Upstream impact, SIGNAL lower ($p<0.05$)	-	No difference ($p>0.05$)

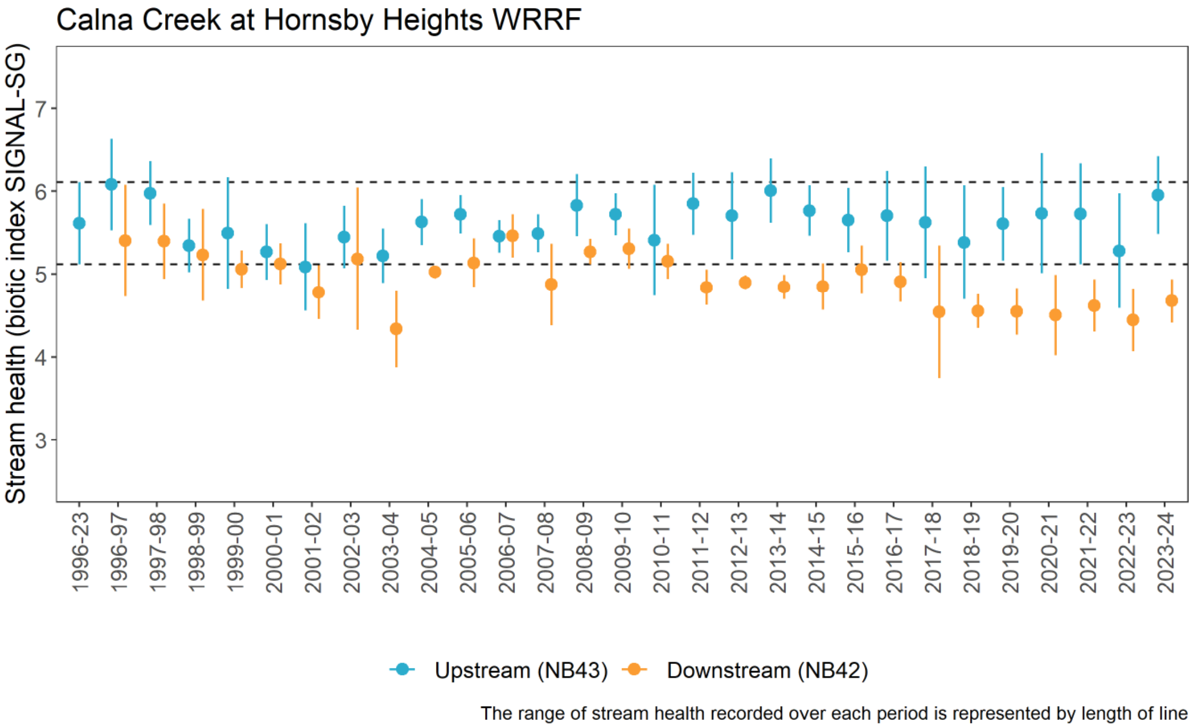


Figure 4-72 Stream health of Calna Creek upstream and downstream of Hornsby Heights WRRF

Gate 2 – Synthesis of impact of Hornsby Heights WRRF discharge

Analytes	Pressure	Stressors	Ecosystem Receptors		Gate 2 synthesis
		Water quality	Phytoplankton as Chlorophyll-a	Macroinvertebrates	
	Effluent	Tributary (us vs ds)	Tributary (us vs ds)	Tributary (us vs ds)	
Ammonia nitrogen	→	-	-	D	Nutrient concentrations in the downstream receiving water were significantly higher than upstream, which does not reflect the decreased or steady trends in the WRRF discharge concentrations. Ecosystem health (macroinvertebrates) was impacted at the downstream site. Further analysis (Gate 3) to be carried out.
Oxidised nitrogen		D			
Total nitrogen	↘	D			
Filterable total phosphorus		D			
Total phosphorus	→	D			
Conductivity		D			
Dissolved oxygen		-			
Dissolved oxygen saturation		D			
pH		D			
Temperature		D			
Turbidity		U			

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
D	Downstream impact (p<0.05)	U	Upstream impact (p<0.05)	-	No difference (p>0.05)
	EPL limit exceedance		Analyte not monitored		

4.1.15. Brooklyn WRRF

- All parameters (concentrations and loads) monitored in the treated discharge from Brooklyn WRRF in 2023-24 were within EPL limits. There was a decreasing trend in total phosphorus concentration in the discharge compared to last nine years.
- Water quality and ecosystem health is not monitored at Brooklyn WRRF as recommended in van Dam et al. 2023

Pressure – Wastewater discharge

Table 4-66 Gate 1 Analysis outcome summary –Brooklyn WRRF

Analytes / Brooklyn WRRF	Nutrients			Conventional analytes			
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Total suspended solids	EC_{50} toxicity
Concentration	→	→	↘	→	→	→	→
Load							

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration levels in the treated discharge from Brooklyn WRRF were within the EPL limits during the 2023-24 reporting period. There are no load limits applicable to Brooklyn WRRF. Statistical analysis identified a significantly decreasing trend in the total phosphorus concentrations during 2023-24 compared to the previous nine years.

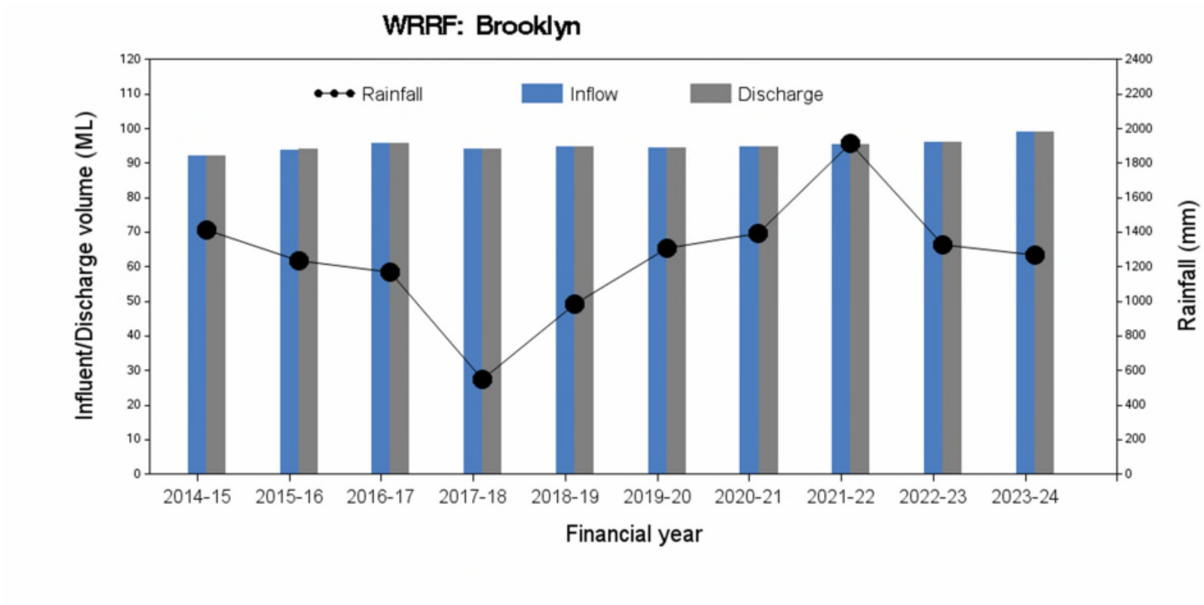


Figure 4-73 Brooklyn WRRF inflow and discharge volume with catchment rainfall

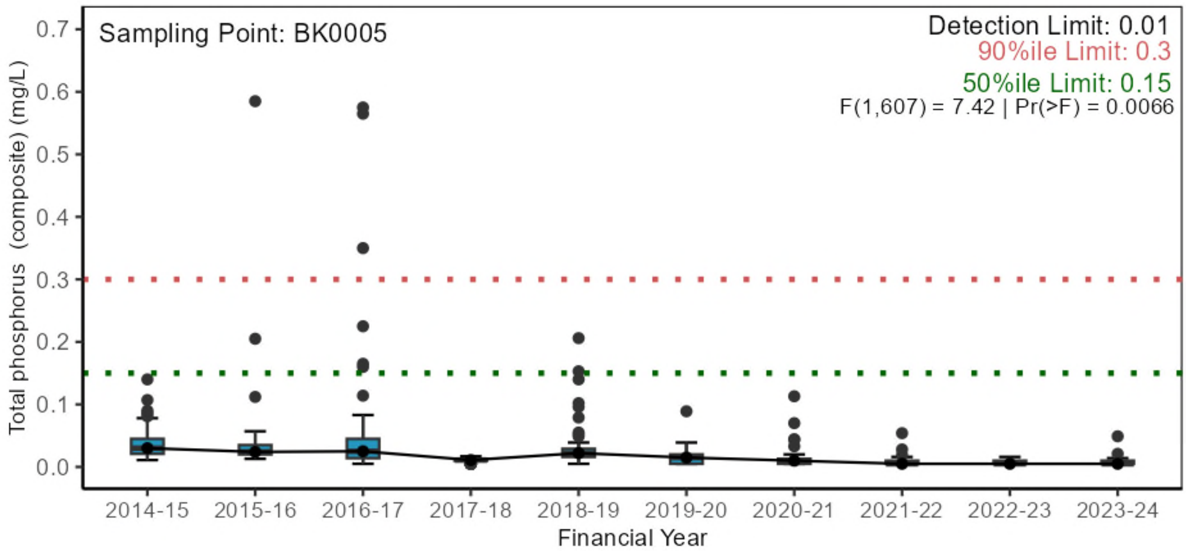


Figure 4-74 Brooklyn WRRF discharge quality exception plot

Stressor – Water quality

Water quality monitoring near the Brooklyn outfall is not recommended for regular monitoring in the new SWAM program given treatment level, receiving environment, mixing and dilution.

Ecosystem Receptor – Phytoplankton

Water quality monitoring near the Brooklyn outfall is not recommended for regular monitoring in the new SWAM program given treatment level, receiving environment, mixing and dilution.

Ecosystem Receptor – Macroinvertebrates

Brooklyn WRRF lies in the Hawkesbury estuary, where freshwater macroinvertebrate monitoring is not suitable due to tidal conditions, depth and fast flows (refer to van Dam et al. 2023 for further information).

4.2. Georges River

The treated wastewater discharged from the Georges River discharging WRRFs in 2023-24 and the population serviced by these WRRFs are shown in Table 4-67.

This section contains a summary of exceptions for each of the Georges River discharging WRRFs.

Trend plots of discharge volume and catchment specific rainfall are presented first, and then reuse volume where applicable.

Trend plots showing the concentration of analytes in the discharge are only presented where they exceeded the respective annual EPL limit for a WRRF during the 2023-24 monitoring period, or there was a significant increase/decrease in concentrations in 2023-24 in comparison to earlier years.

All trend plots showing the analyte concentration and load data for the Georges River WRRFs, including applicable concentration and load limits, can be found in Volume 2 (Appendix A-1 to A-15).

All trend plots on nutrients, toxicants, physico-chemical water quality, trace metals and phytoplankton as chlorophyll-a of the Georges River are included in Volume 2 (Appendix A-1 to A-14).

Trend plots and univariate statistical outcomes for macroinvertebrate biotic index SIGNAL-SG will be presented in 2024-25 onwards, once more than two years of data is collected to enable analysis.

Electronic appendix files on raw data and summary of results for all Georges River WRRFs, receiving water quality by year has also been provided to the EPA (December 2024).

Table 4-67 Georges River WRRFs operated by Sydney Water

WRRFs	Treatment level	Discharge 2023-24 (ML/year)[a]	Projected population 2023-24 [b]	Discharge location
Fairfield*	Primary	1,567	0*	Treated wastewater discharges to Orphan School Creek (to Georges River) during wet weather. Remainder transferred to Malabar WRRF.
Glenfield**	Secondary with disinfection	464	176,687	Treated wastewater discharges to Georges River in wet weather. Remainder transferred to Liverpool WRRF.
Liverpool**	Secondary with disinfection	6,288	89,637	Treated wastewater discharges to Georges River in wet weather. Remainder transferred to Malabar WRRF.

[a] *Discharge volume excludes onsite and offsite reuse.*

[b] *Projected populations (at 30 June 2023) are based on forecasts by the Australian Bureau of Statistics and the DCCEEW.*

**Fairfield WRRF not directly servicing any households.*

***Part of Malabar system. Wastewater is discharged during wet weather only.*

4.2.1. Glenfield WRRF

- All parameters (concentrations) monitored in the discharge from Glenfield WRRF were within EPL limits during the 2023-24 reporting period. There was no increasing or decreasing trend identified for the 2023-24 period.
- Key nutrient analytes (both nitrogen and phosphorus) were notably higher in Bunbury Curran Creek and downstream Georges River in 2023-24 compared to upstream Georges River site. Statistical analysis will be included in SWAM reports from 2024-25 to further validate the trend.
- Chlorophyll-a concentrations were notably higher at downstream Georges River site compared to the upstream Georges River site.
- Stream health, as indicated by macroinvertebrates, was not assessed because of insufficient data (monitoring commenced in 2023-24).

Pressure – Wastewater discharge

Table 4-68 Gate 1 Analysis outcome summary – Glenfield WRRF

Glenfield WRRF / Analytes	Conventional analytes	
	Biochemical oxygen demand	Total suspended solids
Concentration	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration levels in the discharge from Glenfield WRRF were within EPL limits during the 2023-24 reporting period.

Statistical analysis did not identify any significant trends in the discharge from the Glenfield storm plant during the 2023-24 reporting period.

Under dry weather conditions, flows received at Glenfield WRRF are transferred to Liverpool WRRF for recycled water treatment or sent to Malabar WRRF.

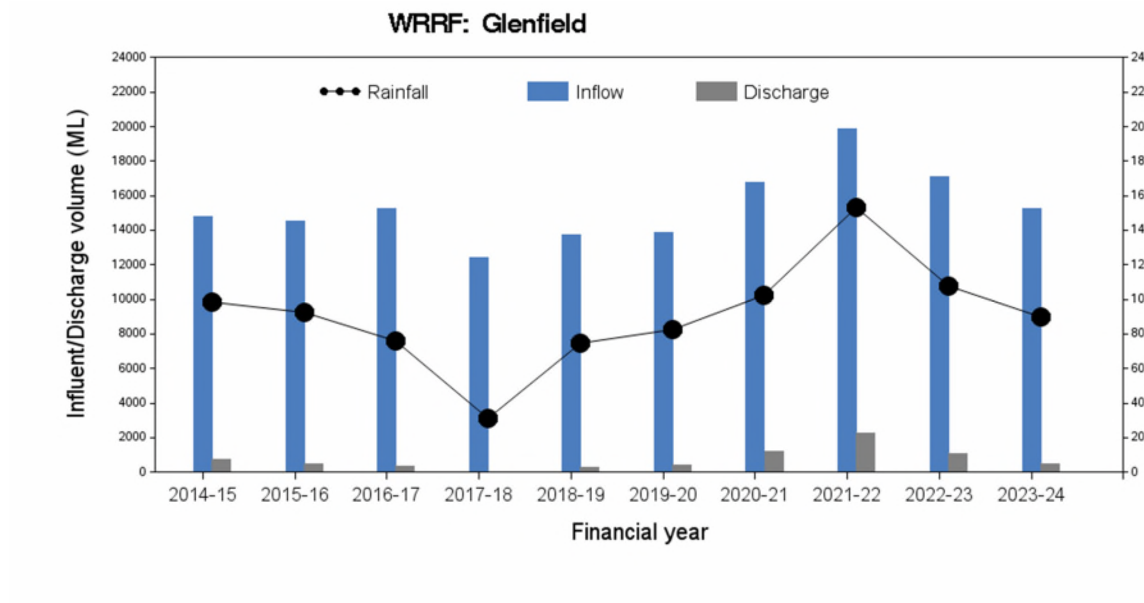


Figure 4-75 Glenfield WRRF discharge plot

Stressor – Water quality

Table 4-69 Gate 1 Analysis outcome summary – water quality upstream and downstream of Glenfield WRRF discharge point

Glenfield WRRF / Analytes		Nutrient analytes					Physico-chemical analytes					
		Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity
River	Upstream river (GR23B)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Upstream creek (GR231A)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Downstream river (GR23)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

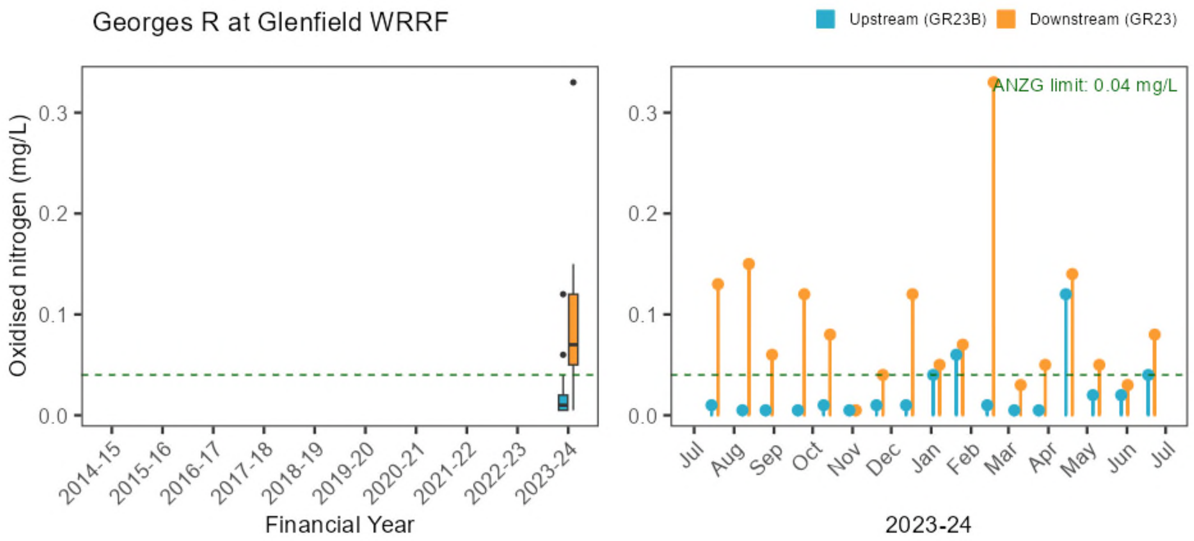
↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(yellow)	Median value outside the guideline limit in 2023-24				

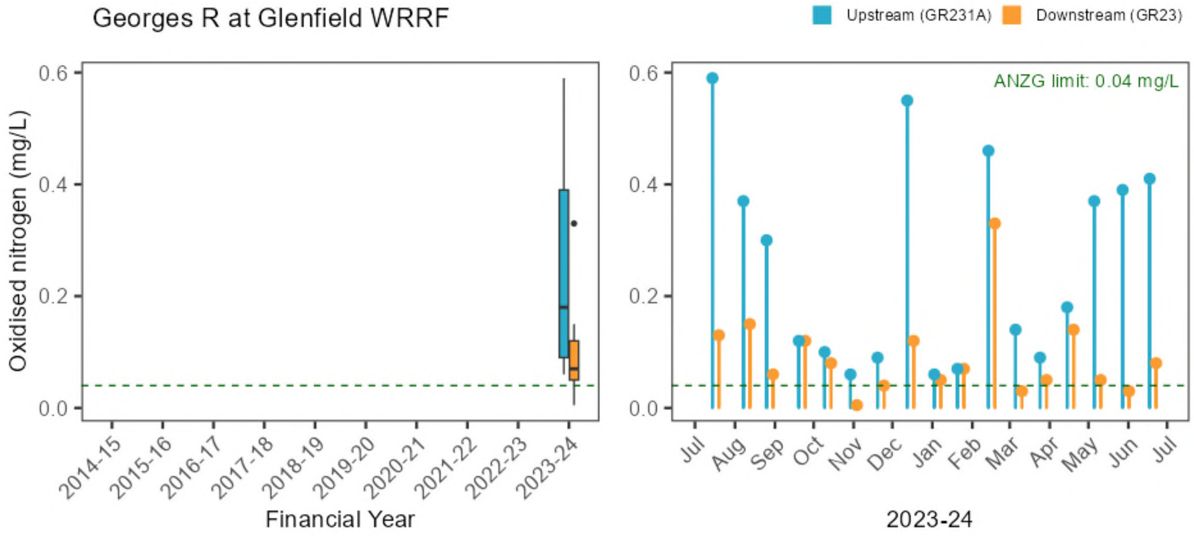
NA - Statistical comparison not conducted due to one year of data

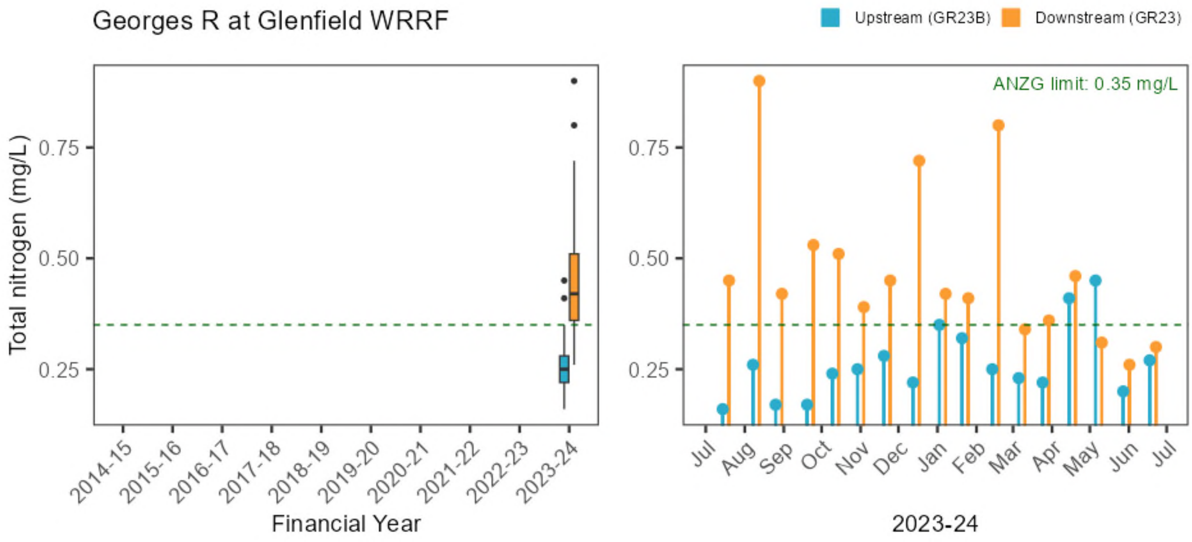
Glenfield WRRF discharges primary and secondary treated wastewater to the Georges River in wet weather conditions when the facility's capacity is exceeded. There are also other sources of pollution upstream of the discharge, including stormwater and agricultural runoff. The adjacent catchment of Bunbury Curran Creek is predominantly high-density residential areas and towns of Macquarie Field, Glenfield, Macquarie Links and Ingleburn with a narrow nature corridor or vacant lands.

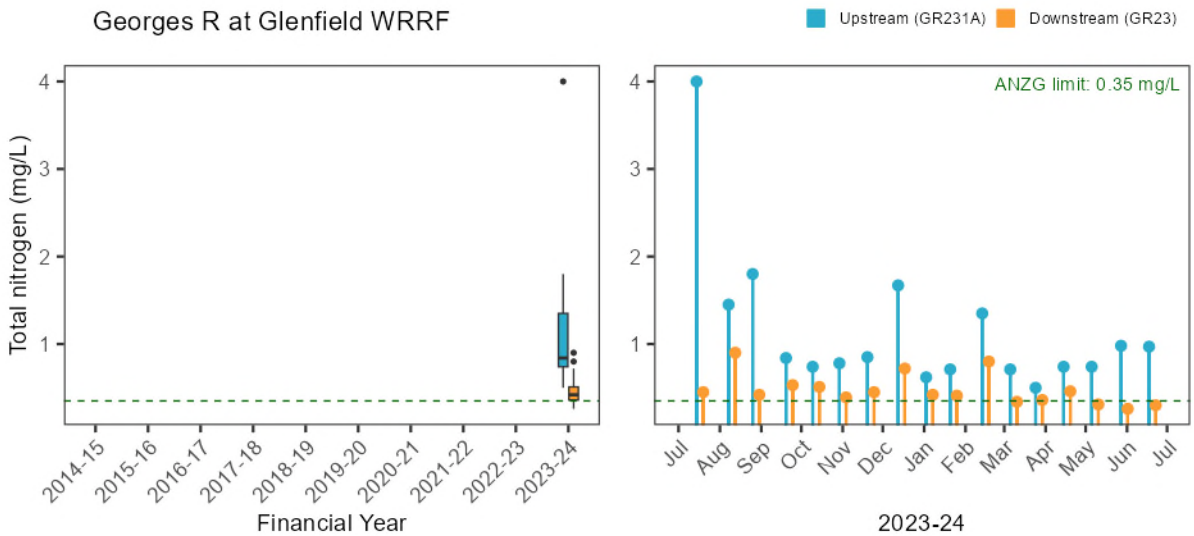
During the 2023-24 period, the median oxidised nitrogen and total nitrogen concentrations exceeded the respective ANZG guideline in Bunbury Curran Creek (GR231A) and downstream Georges River (GR23) sites. At Bunbury Curran Creek site (GR231A), median total phosphorus concentration also exceeded the guideline. Dissolved oxygen saturation was less than the lower guideline limit at Bunbury Curran Creek (GR231A) and downstream Georges River (GR23) sites. Median turbidity was below the lower guideline limit of 6 NTU at both Georges River sites.

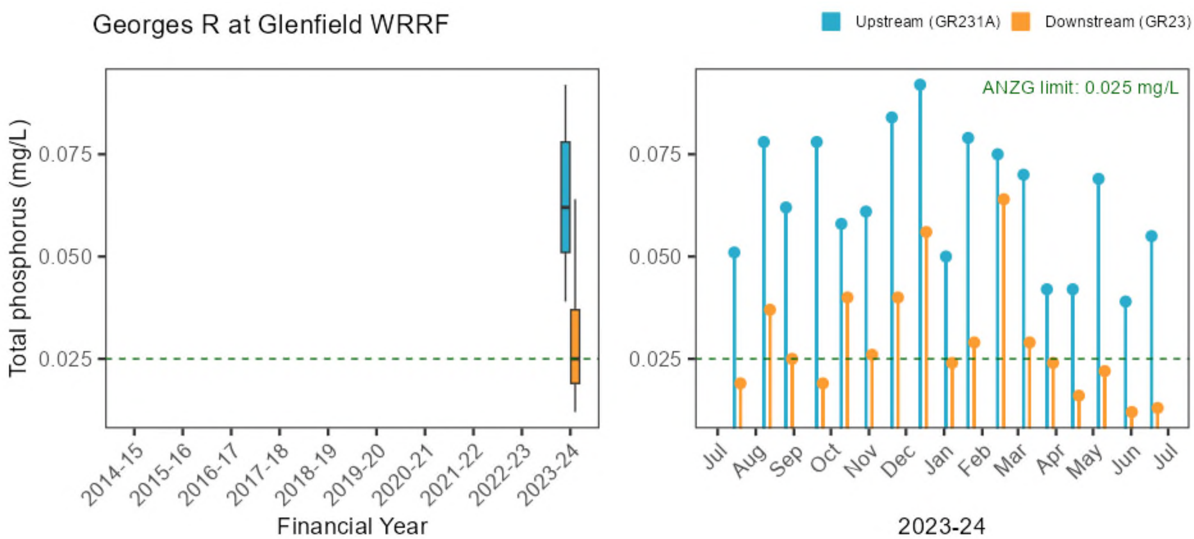
Data summaries suggest concentrations of key nutrient analytes (oxidised nitrogen, total nitrogen and total phosphorus) in Bunbury Curran Creek and the downstream Georges River site were notably higher in comparison to upstream Georges River concentrations. Glenfield WRRF wet weather discharges were limited to the second half of the 2023-24 reporting period (discharge days: 6 February, 5 – 7 April, 7, 10 – 14 May and 6 – 8 June 2024). Monitoring data indicate a mixed impact from both Glenfield WRRF discharges and other upstream catchment sources. Statistical analysis will be included in SWAM reports from 2024-25 to further validate these trends.






Georges R at Glenfield WRRF
Upstream (GR23B)
Downstream (GR23)
Total nitrogen (mg/L)
0.75
0.50
0.25
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.35 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Georges R at Glenfield WRRF
Upstream (GR231A)
Downstream (GR23)
Total nitrogen (mg/L)
4
3
2
1
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.35 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Georges R at Glenfield WRRF
Upstream (GR231A)
Downstream (GR23)
Total phosphorus (mg/L)
0.075
0.050
0.025
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.025 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

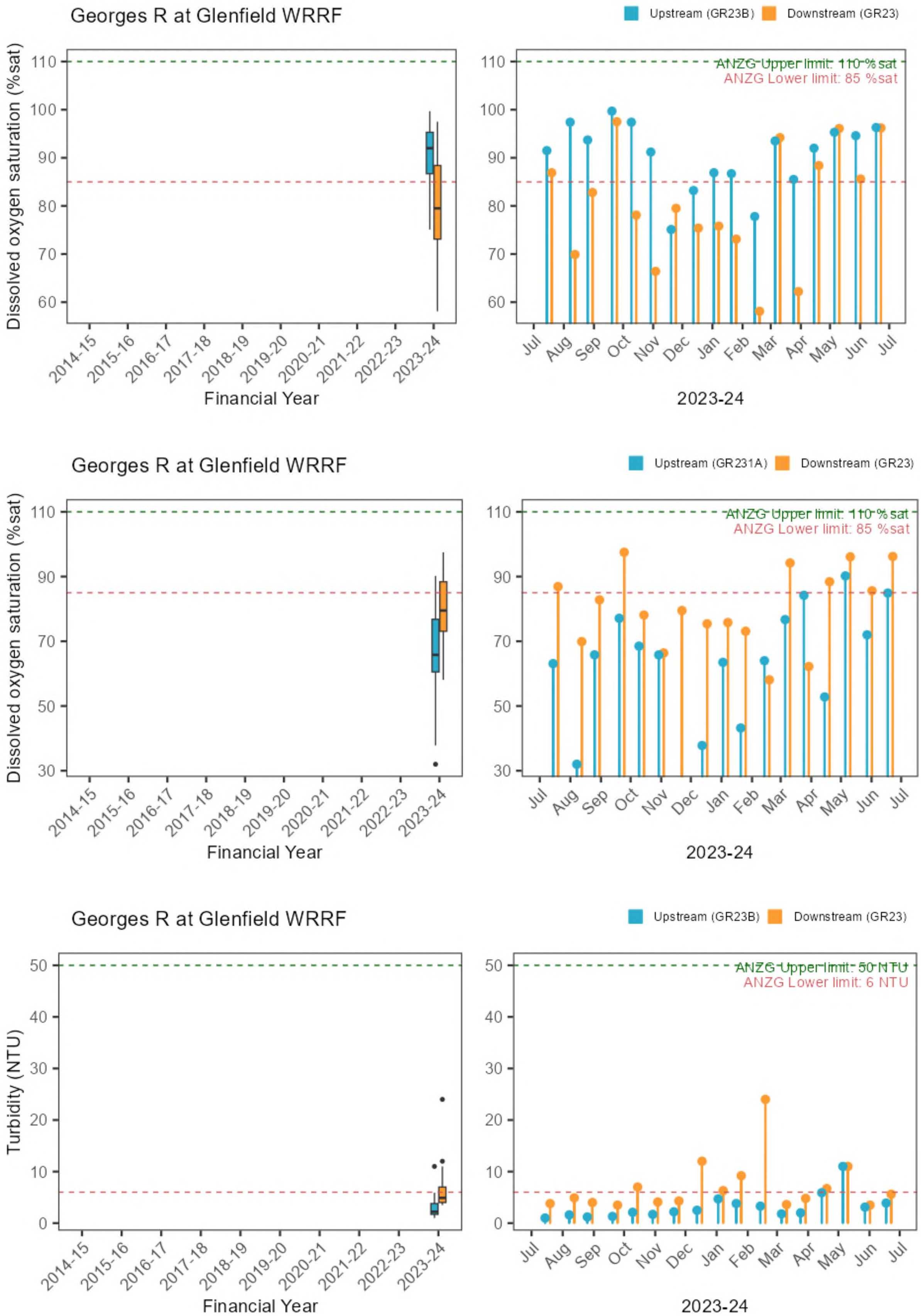


Figure 4-76 Nutrients and physico-chemical water quality exception plots, upstream and downstream of Glenfield WRRF discharge point

Ecosystem Receptor – Phytoplankton

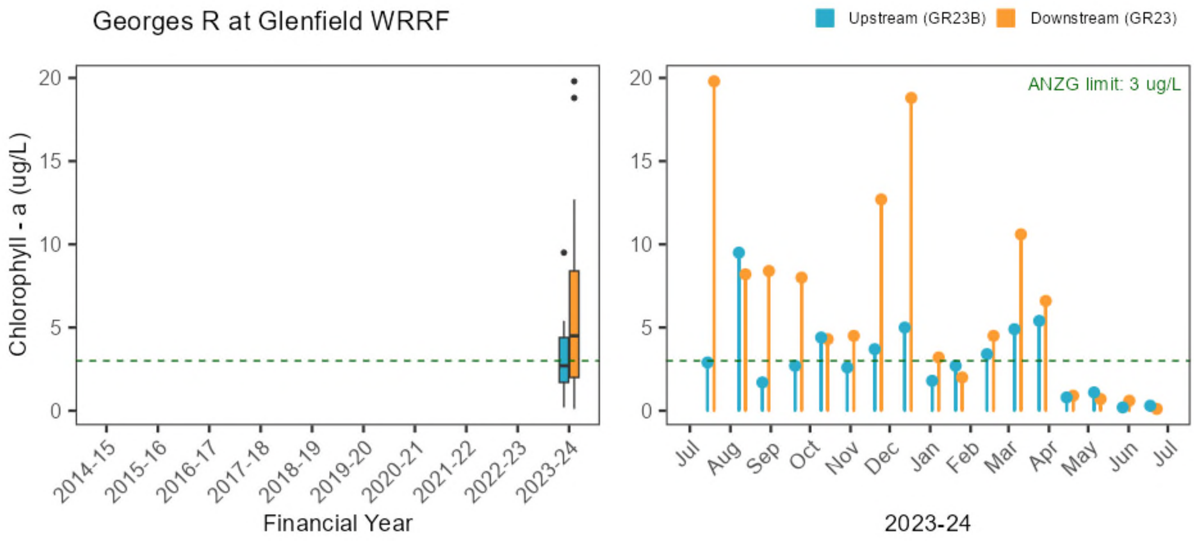
Table 4-70 Gate 1 Analysis outcome summary – phytoplankton as chlorophyll-a, upstream and downstream of Glenfield WRRF discharge point

Statistical comparison (single site current vs past)	Chlorophyll-a
Upstream river (GR23B)	NA
Upstream creek (GR231A)	NA
Downstream river (GR23)	NA

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline limit in 2023-24				

NA - Statistical comparison not conducted due to only one financial year of data

In the 2023-24 period, the median chlorophyll-a concentrations exceeded the ANZG (2018) guidelines at Bunbury Curran Creek (GR231A) and downstream Georges River (GR23). Chlorophyll-a was within the guideline at the upstream site (GR23B). Statistical analysis will be included in SWAM reports from 2024-25 to further explore temporal trends within sites, as well as paired comparisons between upstream and downstream sites.



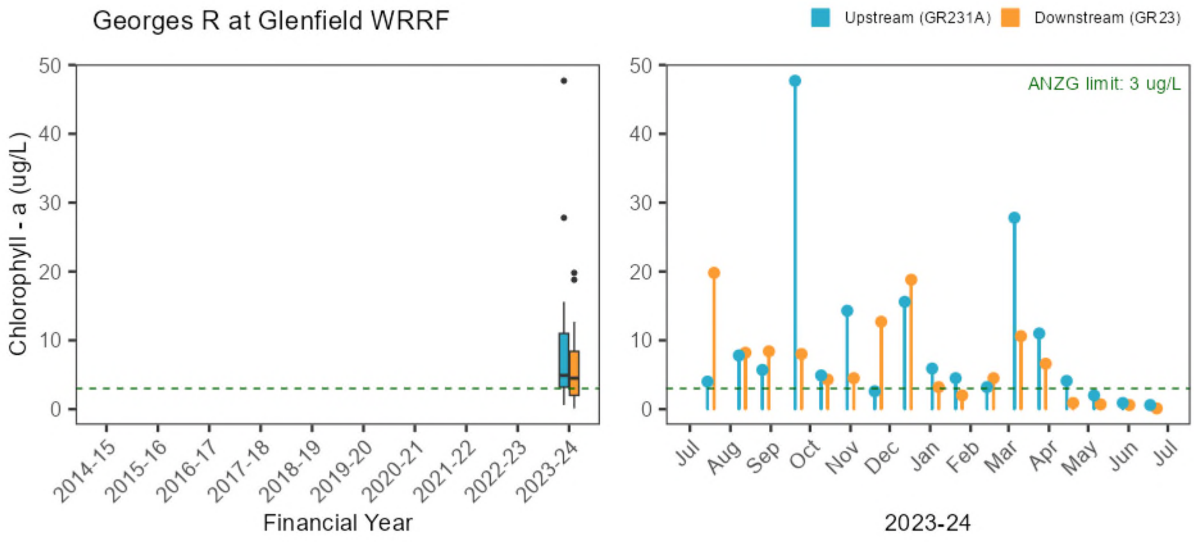


Figure 4-77 Phytoplankton as chlorophyll-a exception plots, upstream and downstream of Glenfield WRRF discharge point

Ecosystem Receptor – Macroinvertebrates

A SIGNAL-SG plot and statistical comparisons will be presented in future reports for Glenfield WRRF once more than two years of data is available for visualisation.

Gate 2 – Synthesis of impact of Glenfield WRRF discharge

Not included this year due to only one financial year of data.

4.2.2. Fairfield WRRF

- All parameters (concentrations) monitored in the discharge from Fairfield WRRF were within the Malabar EPL 372 limits during the 2023-24 reporting period. There was no increasing or decreasing trend identified for the 2023-24 period.
- A feasibility study will be conducted in futures year to inform an appropriate monitoring design and indicators for receiving water quality and ecosystem health

Pressure – Wastewater discharge

Table 4-71 Gate 1 Analysis outcome summary – Fairfield WRRF

Fairfield WRRF / Analytes	Conventional analytes	
	Biochemical oxygen demand	Total suspended solids
Concentration	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration levels in the discharge from the Fairfield storm plant were within EPL limits during the 2023-24 reporting period. Under EPL condition L3.5, as set by the EPA, the 100th percentile limits at Fairfield storm plant may be exceeded when wet weather was the sole cause of the exceedance. This condition was met for biochemical oxygen demand on 6th and 20th February, 5th April, 6th May, and 1st , 2nd, 15th, 16th and 22nd June 2024.

Statistical analysis did not identify any significant trends in the discharge from the Fairfield storm plant during the 2023-24 reporting period.

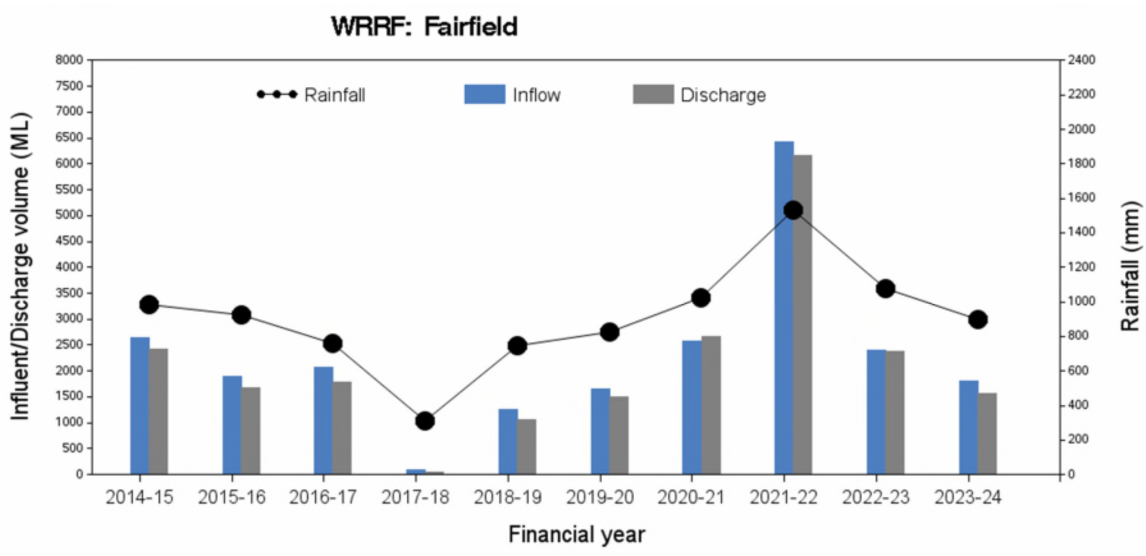


Figure 4-78 Fairfield WRRF discharge plot

Stressor – Water quality

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023)

Ecosystem Receptor – Phytoplankton

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023)

Ecosystem Receptor – Macroinvertebrates

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023)

4.2.3. Liverpool WRRF

- All parameters (concentrations) monitored in the discharge from Liverpool WRRF were within EPL limits during the 2023-24 reporting period. There was no increasing or decreasing trend identified for the 2023-24 period.
- A feasibility study will be conducted in future year to inform an appropriate monitoring design and indicators for receiving water quality and ecosystem health.

Pressure – Wastewater discharge

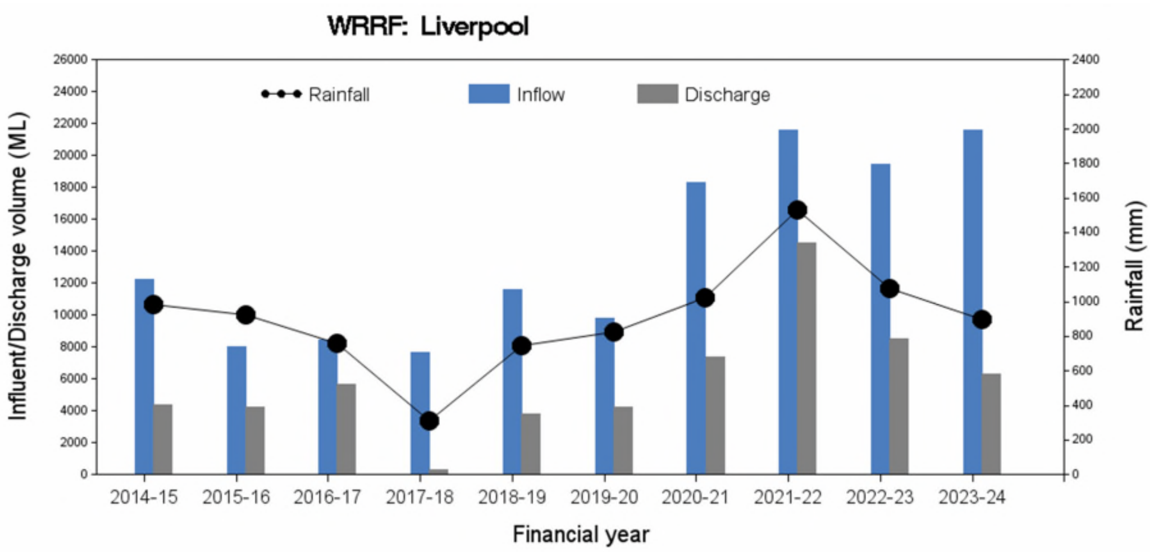
Table 4-72 Gate 1 Analysis outcome summary – Liverpool WRRF

Liverpool WRRF / Analytes	Conventional analytes	
	Biochemical oxygen demand	Total suspended solids
Concentration EPA ID 15 (Chipping Norton Discharge)	→	→
Concentration EPA ID 76 (Recycled Water Reuse)	→	→
Concentration EPA ID 81 (Liverpool Discharge)	→	→

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration levels in the discharge from Liverpool WRRF were within EPL limits during the 2023-24 reporting period. Under EPL 372 condition L3.5, as set by the EPA, the 100th percentile limits can be exceeded during wet weather where it was the sole cause of the exceedance. This condition was met at the effluent diversion structure at Chipping Norton (discharge point EPL ID 15) for biochemical oxygen demand on 1 June 2024 and the main Liverpool WRRF discharge point (EPL ID 81) for total suspended solids on 6 April 2024.

Statistical analysis did not identify any significant trends in the discharge from Liverpool WRRF during the 2023-24 reporting period.



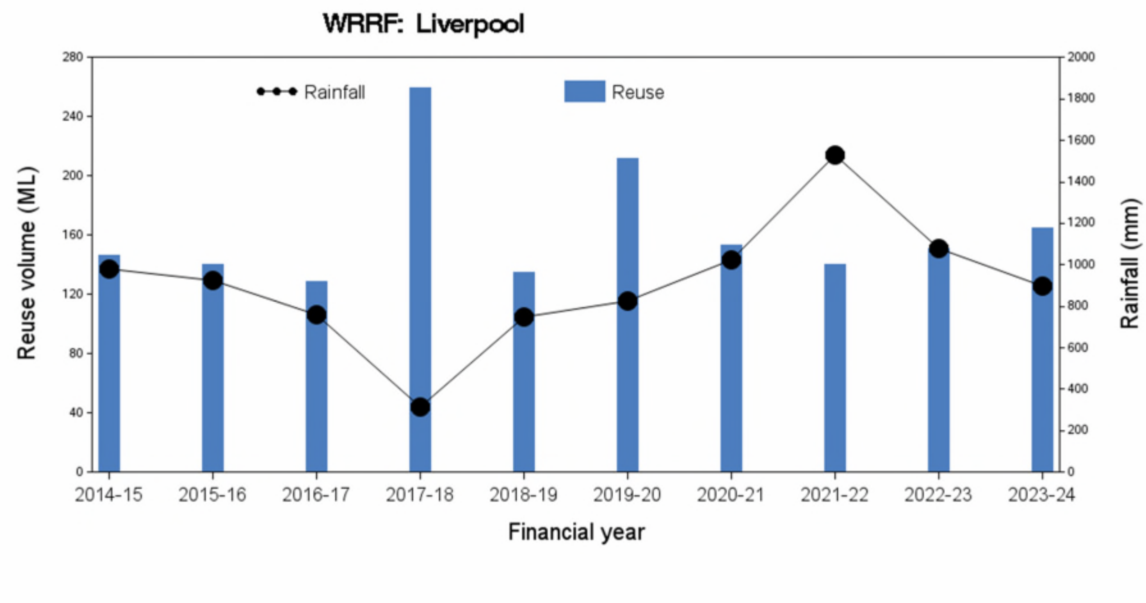


Figure 4-79 Liverpool WRRF discharge and reuse plots

Stressor – Water quality

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023).

Ecosystem Receptor – Phytoplankton

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023).

Ecosystem Receptor – Macroinvertebrates

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023).

4.3. Other monitoring – freshwater

4.3.1. Water quality and chlorophyll-a – Long-term Hawkesbury-Nepean River sites (SoE)

- Trends in nutrients, physico-chemical water quality and chlorophyll-a varied by site in 2023-24 compared to the previous nine years.
- Key nutrient analytes (both nitrogen and phosphorus) and chlorophyll-a concentrations increased at Nepean River at Yarramundi Bridge (N44).
- Total ammonia nitrogen concentrations increased at Hawkesbury River off Cattai SRA (N3001) and another at Lower Colo River (N2202). There was an increase in oxidised nitrogen and total nitrogen concentrations at two sites in the Hawkesbury River (N3001 and N26) and a decrease in filterable total phosphorus and total phosphorus at the lowermost site, Hawkesbury River at Leets Vale (N18).
- Most importantly, chlorophyll-a concentrations remained steady in the Hawkesbury River sites that are historically prone to phytoplankton blooms.

Receiving water quality and chlorophyll-a were monitored at ten long-term monitoring sites that aren't directly linked with the WRRF impact assessment. Five of these sites are situated along the mainstream river, from the upstream Nepean River at Yarramundi Bridge to the downstream Hawkesbury River at Leets Vale. Five other sites were monitored at four major tributaries: South Creek, Cattai Creek, Colo River and Berowra Creek (two sites). Key analytes including nutrients, physico-chemical analytes, trace metals and chlorophyll-a were routinely collected.

Monitoring data are assessed for the SoE. Each site is assessed individually for temporal trends statistically or for comparison against national guidelines and water quality objectives.

Temporal trend plots for all sites by each analyte are included in Volume 2 (Appendix C-1). The exception trend plots on water quality analytes (excluding trace metals) and chlorophyll- a for each site are presented in this section when:

- there was either a significant increasing or decreasing trend in the 2023-24 year or
- the yearly (2023-24) median results exceeded the relevant guideline limit.

A summary of Gate 1 Analysis outcomes is presented in Table 4-73. The 2023-24 period had an above average rainfall which mostly occurred between November 2023 and June 2024.

Table 4-73 Gate 1 Analysis outcome summary – water quality and chlorophyll-a of long-term SoE sites, Hawkesbury-Nepean River catchment

Analytes / SoE Sites	Nutrient analytes					Physico-chemical analytes						
	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity	Chlorophyll-α
Nepean River at Yarramundi Bridge (N44)	→	**→**	**↗**	↗	**↗**	↗	→	↗	↗	→	↗	**↗**
Lower South Creek at Fitzroy pedestrian bridge (NS04A)	→	**→**	**→**	→	**→**	→	→	**↗**	→	→	**→**	**→**
Hawkesbury River at Wilberforce (N35)	→	**→**	**→**	→	**→**	→	→	↗	→	→	→	**→**
Lower Cattai Creek at Cattai Road Bridge (NC11A)	→	**→**	**→**	→	**→**	→	→	**→**	→	→	→	**→**
Hawkesbury River Off Cattai SRA (N3001)	↗	**↗**	**↗**	→	**→**	↗	→	→	→	→	→	**→**
Hawkesbury River at Sackville Ferry (N26)	→	**↗**	**↗**	→	**→**	→	→	→	→	→	→	**→**
Lower Colo River at Putty Road Bridge (N2202)	↗	→	→	→	→	↗	→	→	→	→	**→**	↘
Hawkesbury River at Leets Vale (N18)	→	**→**	**→**	↘	↘	→	→	→	→	→	↘	**→**
Berowra Creek at Calabash Bay (NB13)	→	**→**	**→**	→	→	→	→	→	↘	→	**→**	↘
Berowra Creek, Off Square Bay (NB11)	→	→	**→**	→	→	→	→	→	→	→	→	**→**

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(bold)	Median value outside the guideline limit in 2023-24				

Nutrients and chlorophyll-a

- Statistical analysis confirmed that the oxidised nitrogen and total nitrogen concentrations increased at two Hawkesbury River sites, Off Cattai SRA (N3001) and Sackville Ferry (N26) in 2023-24 compared to the previous nine years.
- Total ammonia nitrogen concentration increased in the Hawkesbury River Off Cattai SRA (N3001) and at Lower Colo River site (N2202). Total nitrogen concentration increased significantly at Nepean River at Yarramundi Bridge (N44), in 2023-24 compared to the previous nine years.
- Filterable total phosphorus and total phosphorus concentrations increased in the Nepean River at Yarramundi (N44) and decreased in the Hawkesbury River at Leets Vale (N18) in 2023-24 compared to previous years.
- Chlorophyll-a concentrations increased in the Nepean River at Yarramundi Bridge (N44) and decreased at Lower Colo River (N2202) and Berowra Creek at Calabash Bay (NB13). It remained steady in the remaining seven sites in 2023-24.
- Median total ammonia nitrogen concentrations remained within the toxicant guideline for 95% species protection at all ten sites in 2023-24. Median oxidised nitrogen and total nitrogen concentrations exceeded the ANZG guideline at nine of the ten monitoring sites. The exceptions were both oxidised nitrogen and total nitrogen at Lower Colo River site (N2202) and oxidised nitrogen at Berowra Creek off Square Bay (NB11). Median total phosphorus concentrations exceeded the guideline at six upper catchment sites in the river or creek from Yarramundi to Sackville Ferry.
- Median chlorophyll-a concentrations exceeded the ANZG (2018) guideline at eight out of ten sites. The exceptions were the reference site at Lower Colo River (N2202) and Berowra Creek at Calabash Bay (NB13).

Physico-chemical water quality

- Conductivity levels increased significantly in the Nepean River at Yarramundi (N44), Hawkesbury River Off Cattai SRA (N3001) and Lower Colo River (N2202) in 2023-24 compared to the previous nine years. Conductivity levels at all eight freshwater sites were within the guideline.
- Dissolved oxygen saturation levels improved at three sites, Nepean River at Yarramundi (N44), Lower South Creek (NS04A) and Hawkesbury River at Wilberforce (N35).
- Median dissolved oxygen saturation concentrations remained below the ANZG (2018) lower guideline limit at Lower South Creek (NS04A) and Lower Cattai Creek (NC11A).
- pH decreased in the Berowra Creek at Calabash Bay (NB13) compared to previous nine years. pH and turbidity levels increased in Nepean River at Yarramundi Bridge (N44).
- Water clarity was good at most monitoring sites as indicated by low median turbidity levels. The only exception was Lower South Creek (NS04A) where turbidity was significantly higher than the ANZG (2018) upper guideline limit.
- Turbidity was below the lower guideline limit at two other sites, Lower Colo River (N2202) and Berowra Creek at Calabash Bay (NB13).

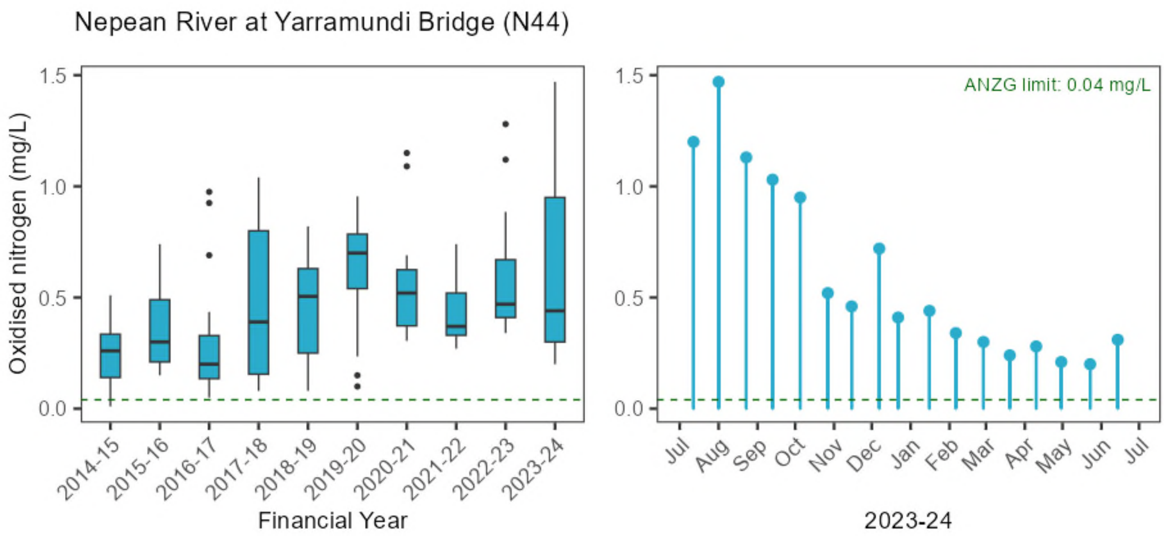
N44: Nepean River at Yarramundi Bridge

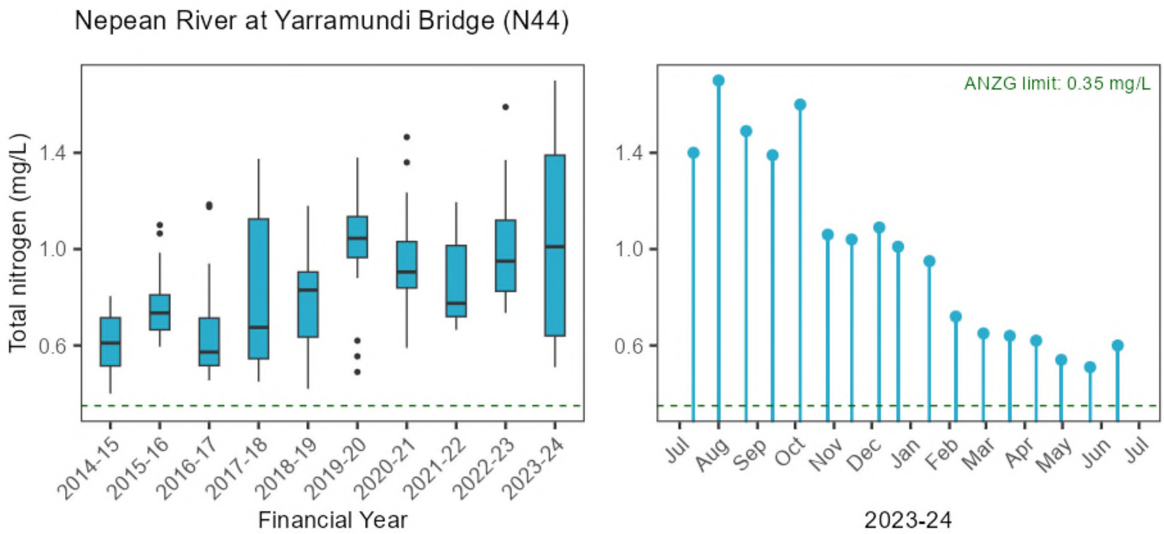
The Nepean River at Yarramundi Bridge (N44) is located just before the confluence with the Grose River. The site is situated downstream of Winmalee lagoon where Winmalee WRRF discharges treated wastewater. Yarramundi is the freshwater upper tidal limit for the Hawkesbury-Nepean River.

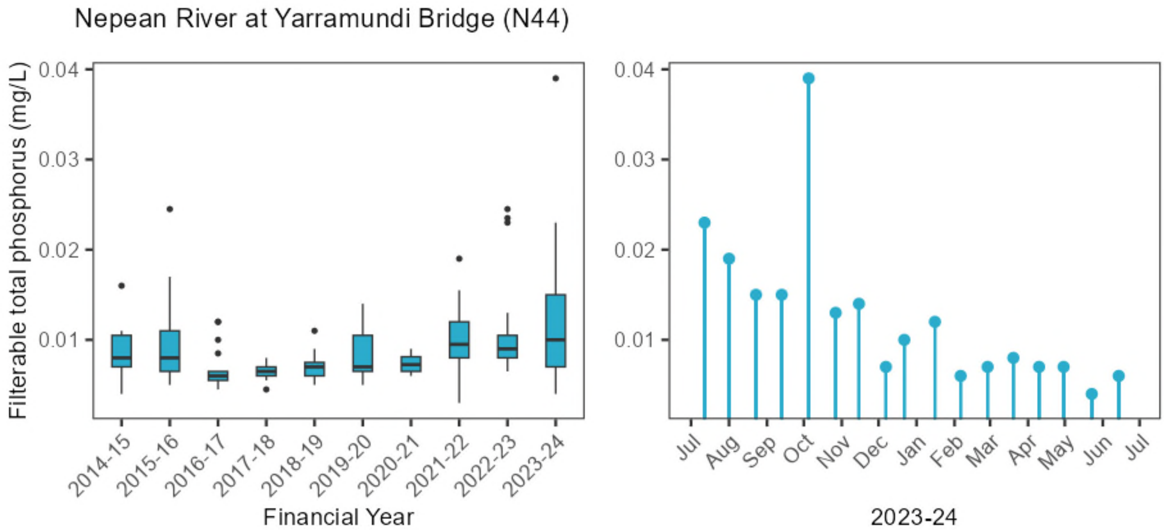
The water quality of the Nepean River at Yarramundi Bridge showed significantly increased concentrations of total nitrogen, filterable total phosphorus, total phosphorus and chlorophyll- a in 2023-24 compared to the previous nine years.

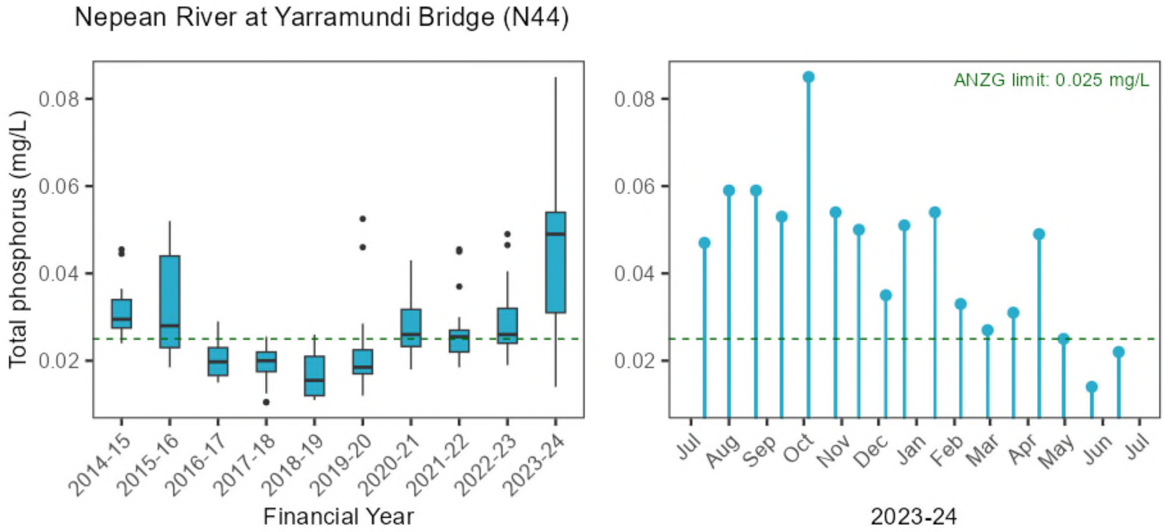
Among physico-chemical analytes, conductivity, dissolved oxygen saturation, pH and turbidity were also significantly higher in 2023-24.

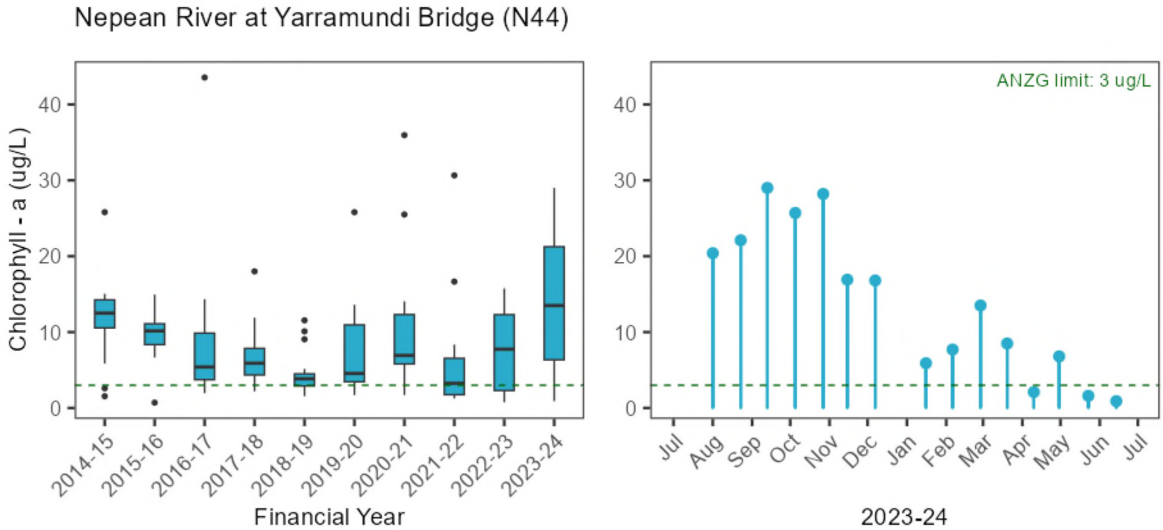
The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations exceeded the respective ANZG (2018) guidelines in 2023-24.

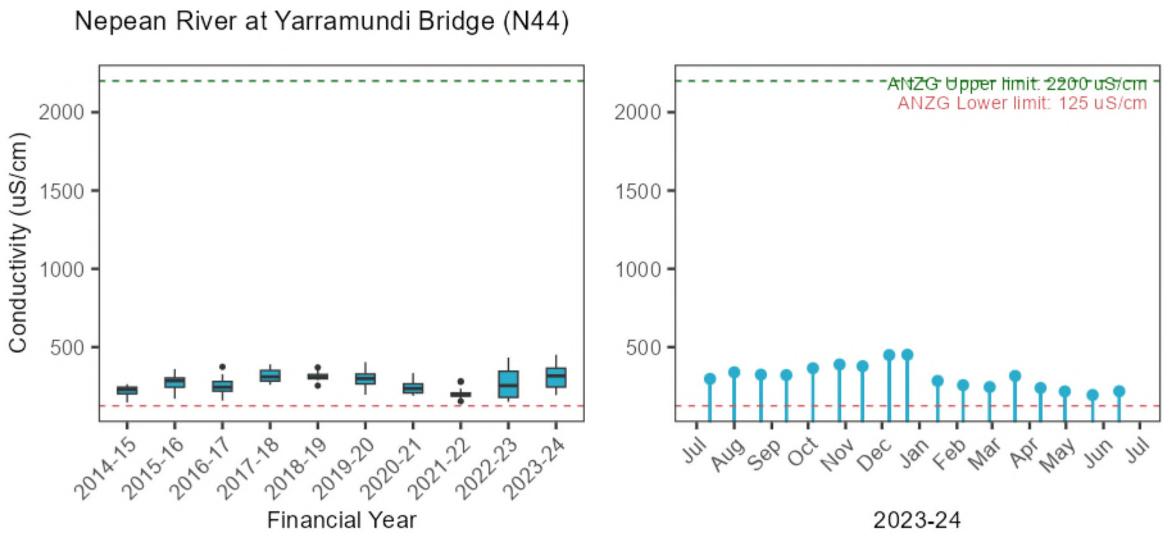

Nepean River at Yarramundi Bridge (N44)
Oxidised nitrogen (mg/L)
1.5
1.0
0.5
0.0
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.04 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Nepean River at Yarramundi Bridge (N44)
Total nitrogen (mg/L)
1.4
1.0
0.6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.35 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Nepean River at Yarramundi Bridge (N44)
Filterable total phosphorus (mg/L)
0.04
0.03
0.02
0.01
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Nepean River at Yarramundi Bridge (N44)
Total phosphorus (mg/L)
0.08
0.06
0.04
0.02
2014-15 2015-16 2016-17 2017-18 2018-19 2019-20 2020-21 2021-22 2022-23 2023-24
Financial Year
ANZG limit: 0.025 mg/L
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
2023-24


Nepean River at Yarramundi Bridge (N44)
Chlorophyll - a (ug/L)
40
30
20
10
0
2014-15 2015-16 2016-17 2017-18 2018-19 2019-20 2020-21 2021-22 2022-23 2023-24
Financial Year
ANZG limit: 3 ug/L
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
2023-24


Nepean River at Yarramundi Bridge (N44)
Conductivity (uS/cm)
2000
1500
1000
500
2014-15 2015-16 2016-17 2017-18 2018-19 2019-20 2020-21 2021-22 2022-23 2023-24
Financial Year
ANZG Upper limit: 2200 uS/cm
ANZG Lower limit: 125 uS/cm
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul
2023-24

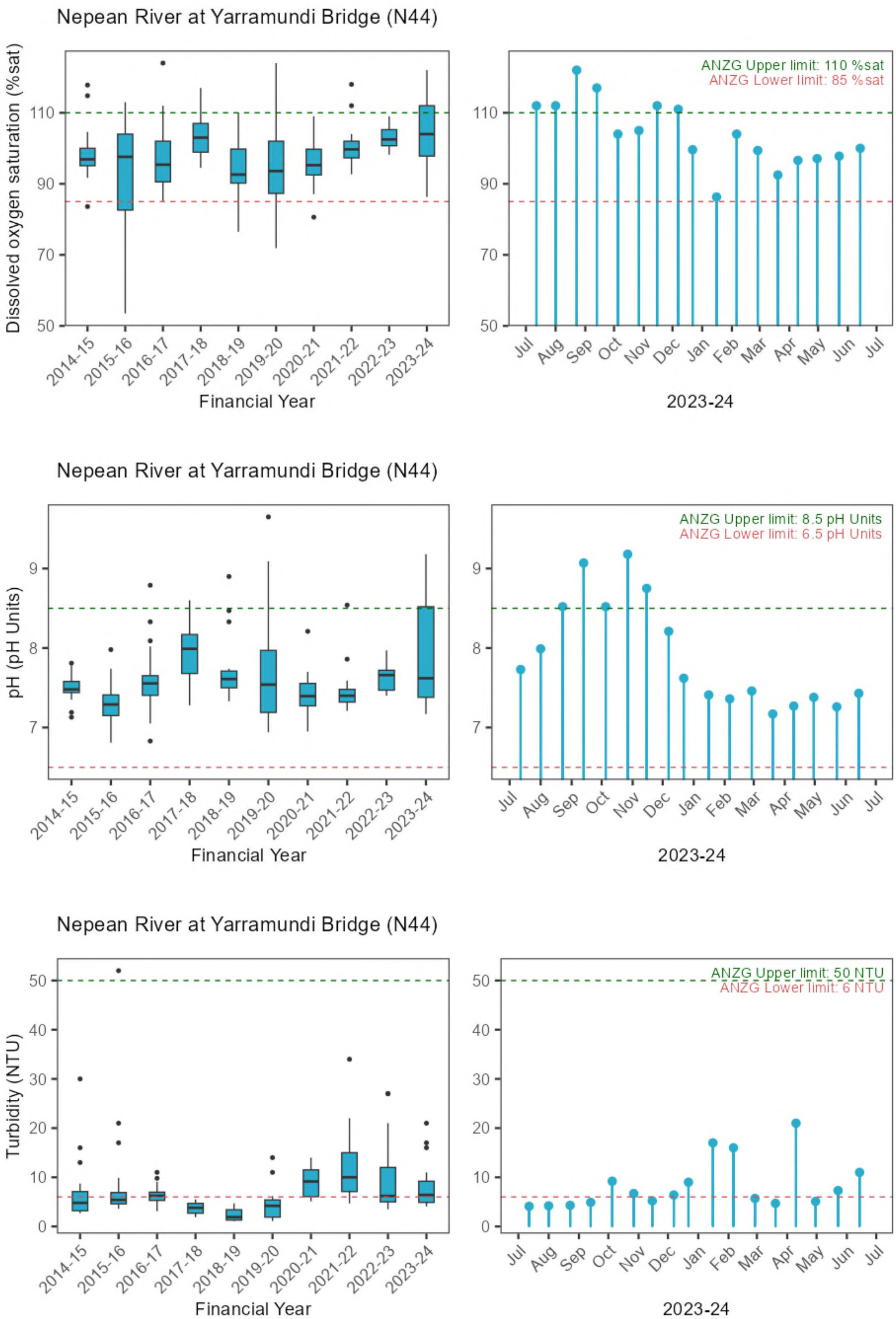


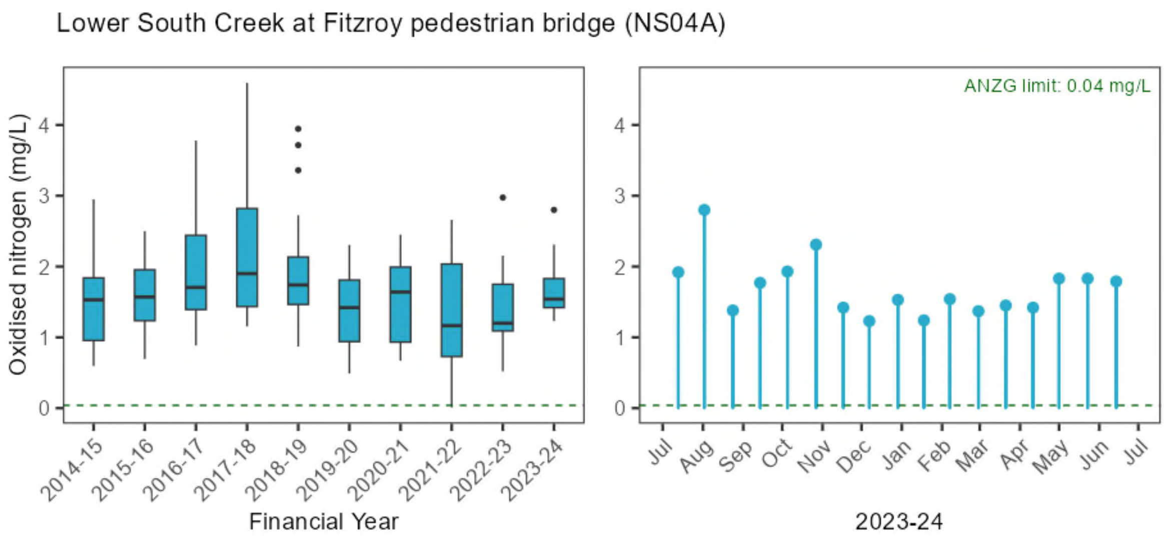
Figure 4-80 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Nepean River at Yarramundi Bridge (N44)

NS04A: Lower South Creek at Fitzroy Bridge

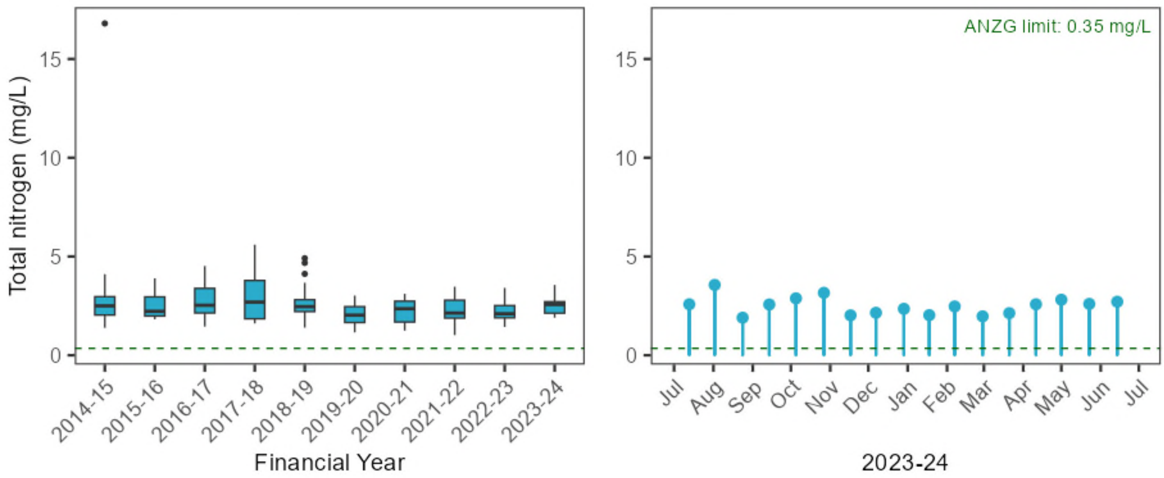
South Creek is one of the major tributaries to the Hawkesbury River. It originates at Narellan and travels 64 km before entering the Hawkesbury River at Windsor. The land along South Creek is used for rural applications including grazing and market gardening, and intensive agriculture such as poultry farming. It also has both residential and industrial land uses that have increased in recent years. South Creek and its tributaries receive tertiary treated wastewater discharges from three Sydney Water WRRFs (St Marys, Riverstone and Quakers Hill) and two council Sewage Treatment Plants (STPs, McGraths Hill and South Windsor). The lower South Creek water quality monitoring site (NS04A) is located at Fitzroy Bridge, about 2 km upstream of the confluence with the Hawkesbury River. Although the lower part of the creek is tidal, the water quality at this site is expected to represent overall quality of South Creek before joining the river.

Concentrations of nutrient analytes and chlorophyll-a were steady at NS04A in 2023-24 compared to the previous nine years. Among physico-chemical water quality analytes, dissolved oxygen saturation levels were higher or improved in the 2023-24 year.

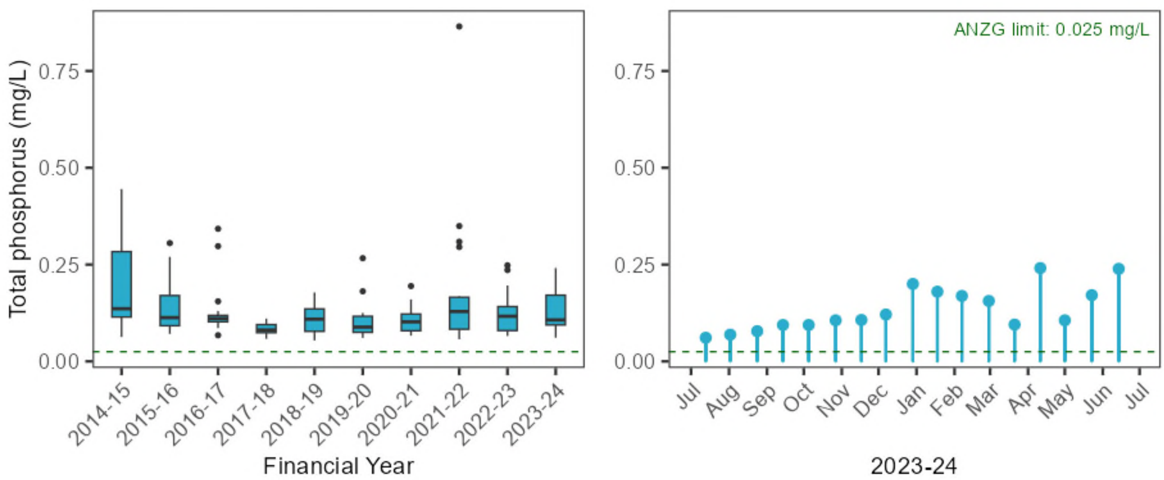
The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations in South Creek exceeded the respective ANZG (2018) guidelines in 2023-24. Dissolved oxygen saturation was less than the ANZG (2018) lower guideline limit. The creek was turbid with the median level exceeding the higher guideline limit in 2023-24 (median = 60 NTU).



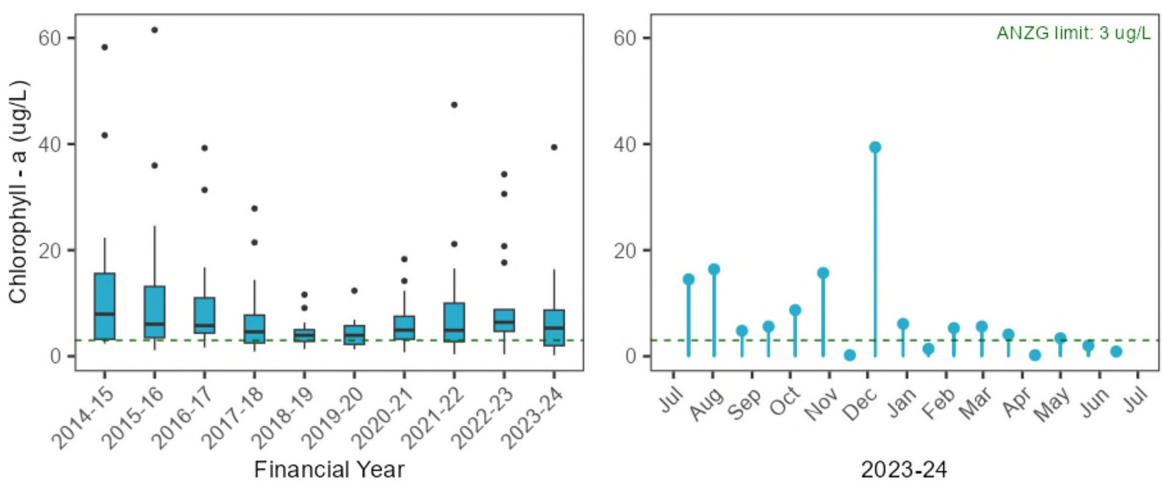
Lower South Creek at Fitzroy pedestrian bridge (NS04A)



Lower South Creek at Fitzroy pedestrian bridge (NS04A)



Lower South Creek at Fitzroy pedestrian bridge (NS04A)



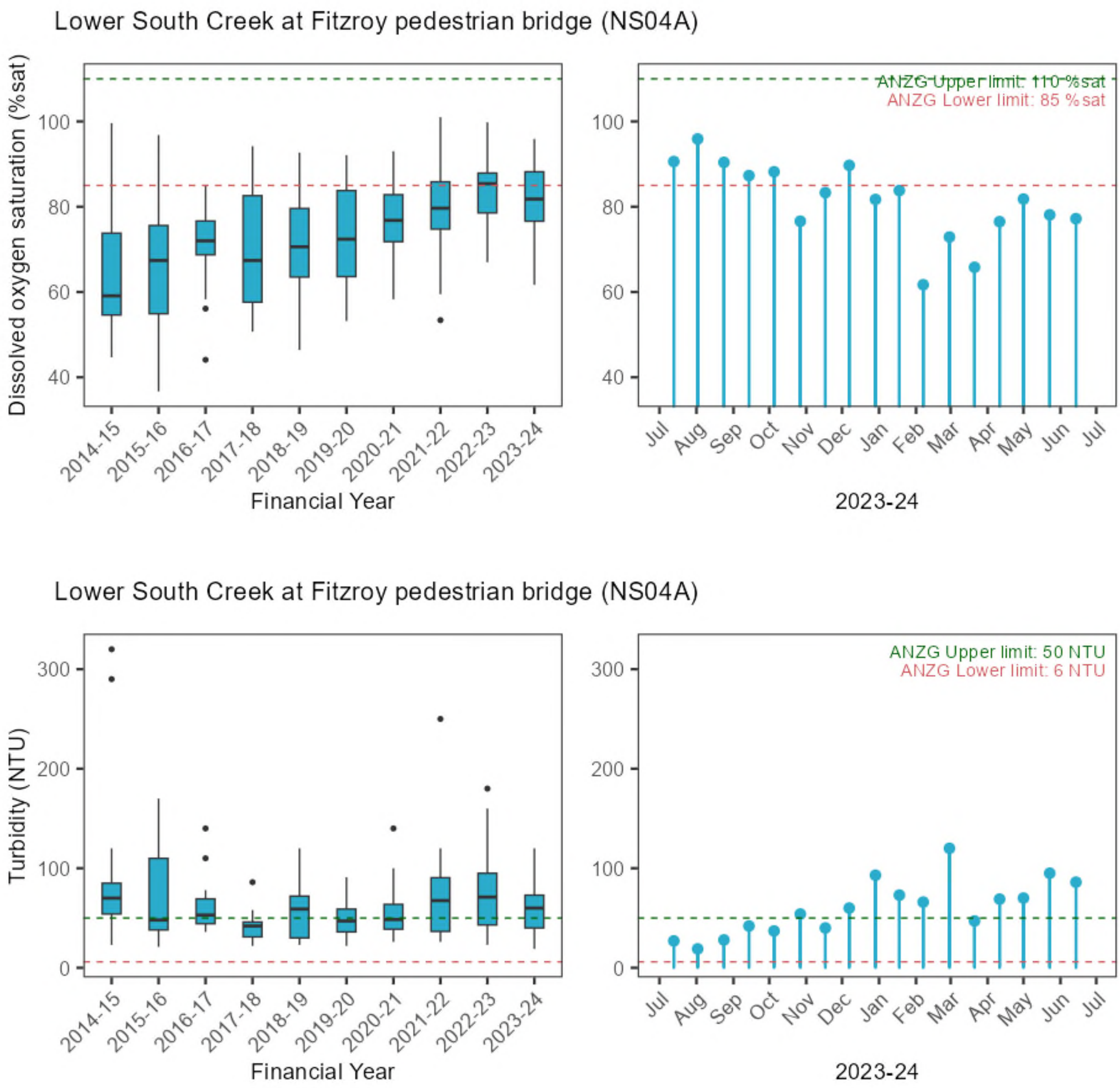


Figure 4-81 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Lower South Creek at Fitzroy Bridge (NS04A)

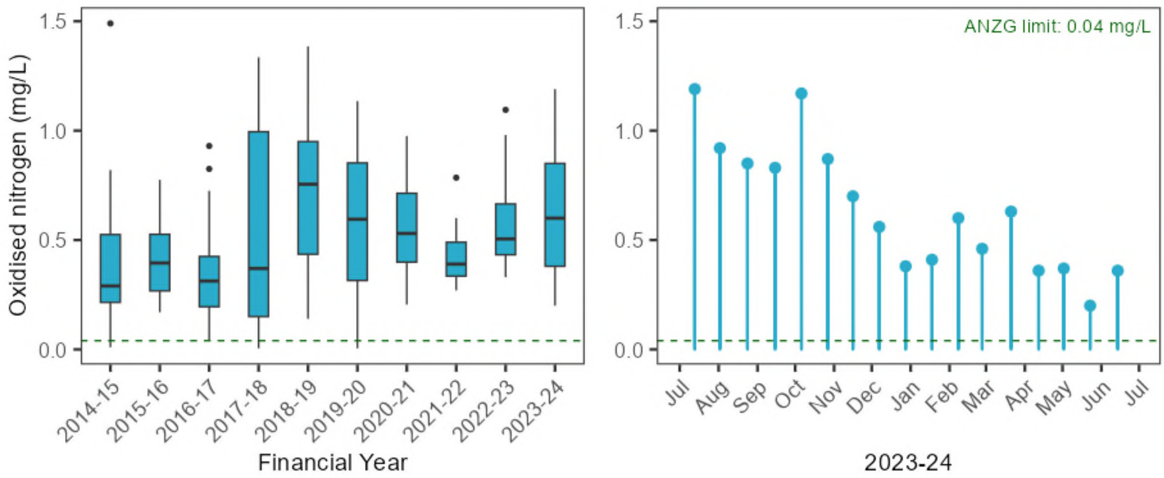
N35: Hawkesbury River at Wilberforce

Hawkesbury River at Wilberforce (N35) is located about 5 km downstream of the confluence with South Creek. Water quality at this site is affected by the quality and magnitude of flows coming from South Creek. Historically, there have been water quality concerns at this site due to elevated nutrient concentrations, chlorophyll-a and phytoplankton blooms, especially potentially toxic blue-green species. The width and depth of the river, combined with the high nutrients, tidal influence and long residence time has made it prone to phytoplankton blooms in the past.

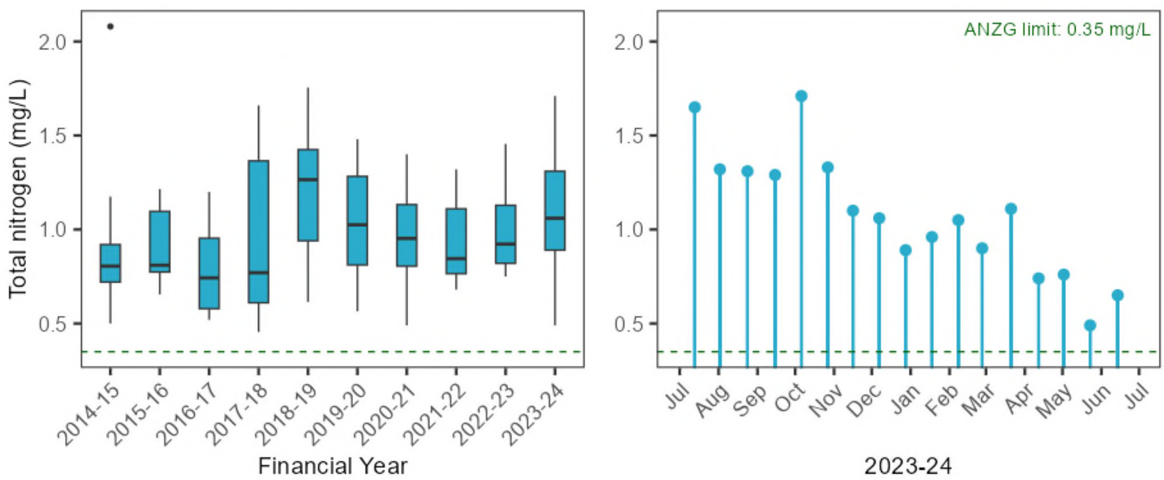
Concentrations of nutrient analytes and chlorophyll-a were steady at N35 in 2023-24 compared to the previous nine years. Among physico-chemical water quality analytes, dissolved oxygen saturation was higher/improved in the 2023-24 year.

The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations at N35 exceeded the respective ANZG (2018) guidelines in 2023-24.

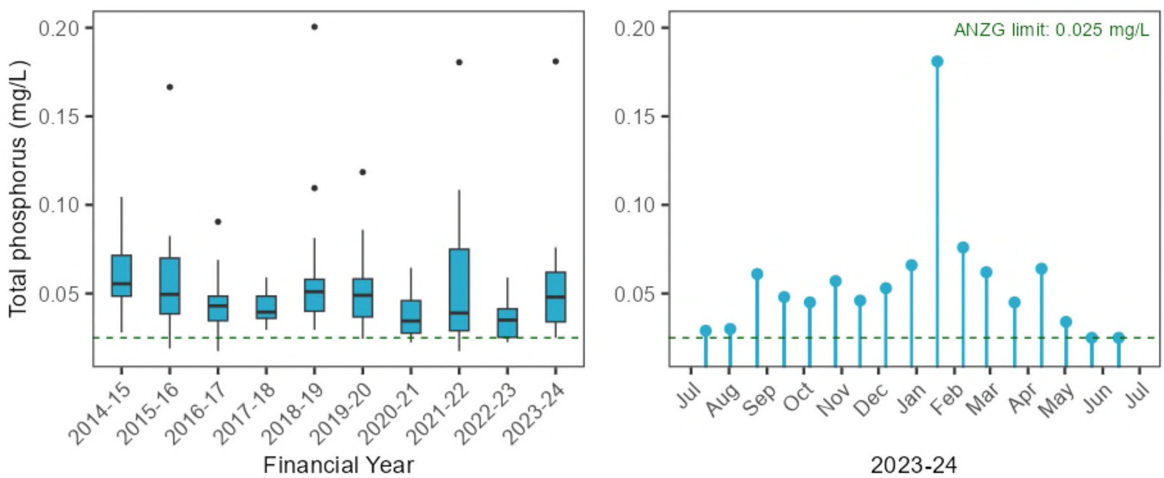
Hawkesbury River at Wilberforce (N35)

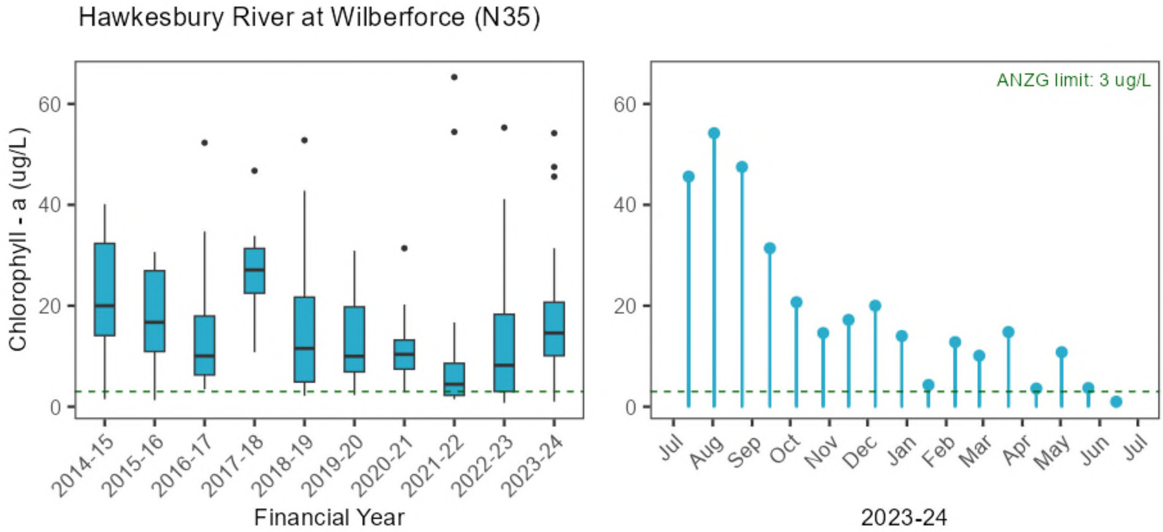


Hawkesbury River at Wilberforce (N35)



Hawkesbury River at Wilberforce (N35)





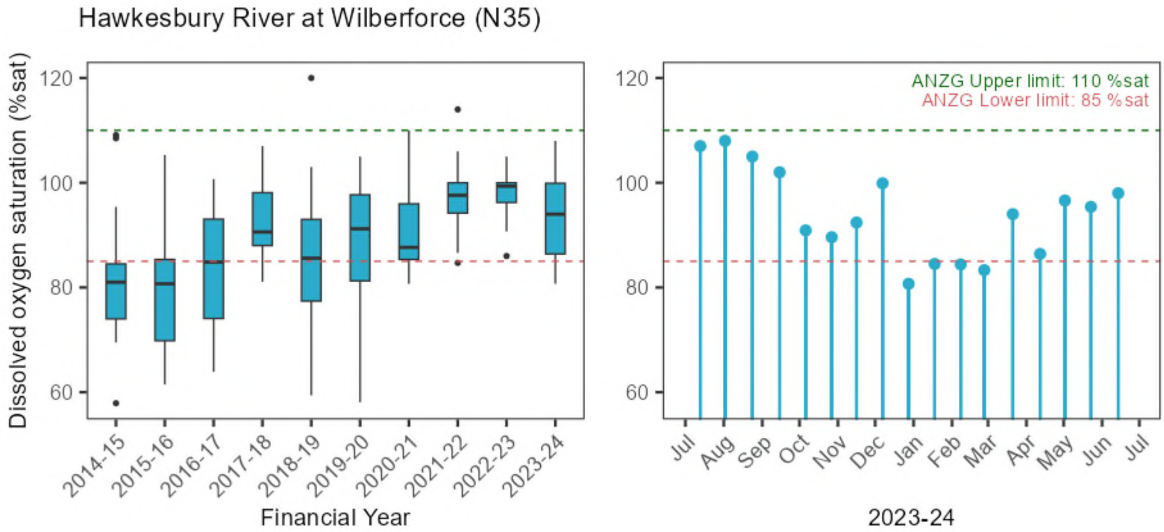


Figure 4-82 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Hawkesbury River at Wilberforce (N35)

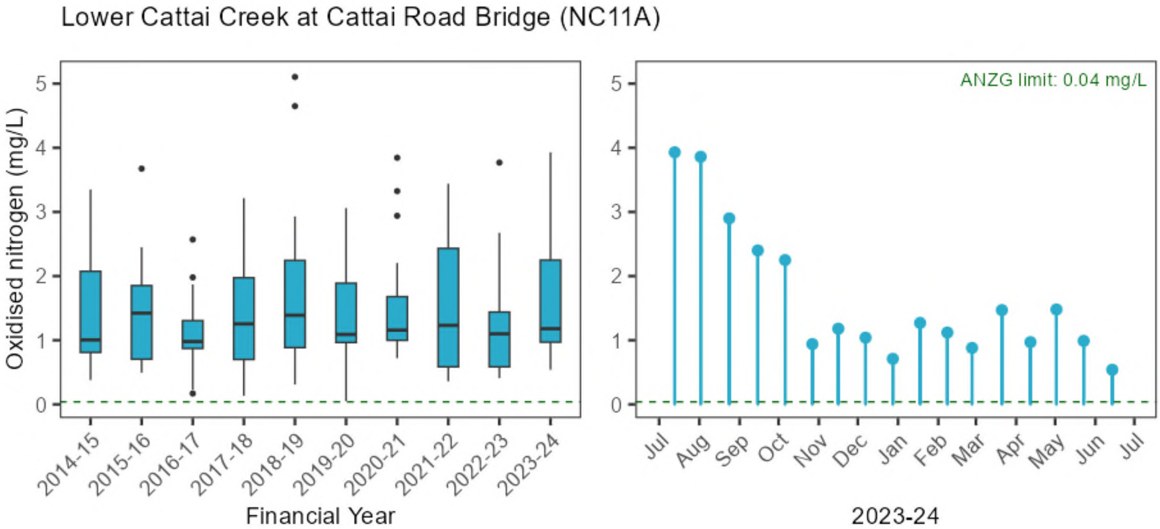
NC11A: Lower Cattai Creek at Cattai Ridge Road

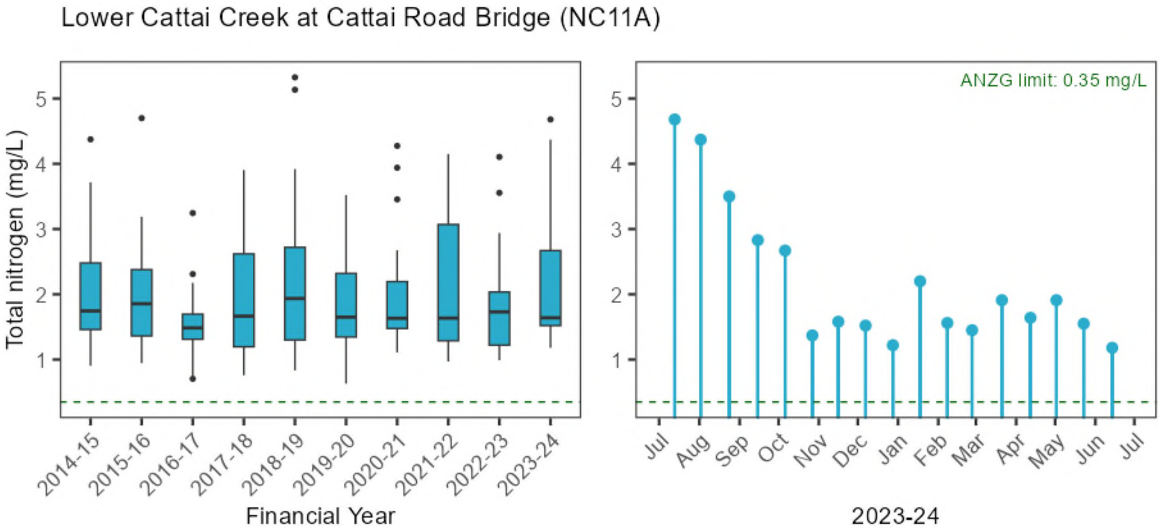
Lower Cattai Creek at Cattai Ridge Road (NC11A) is a major tributary of the Hawkesbury River, draining one of the fastest growing urban catchments of Sydney. The upper Cattai Creek catchment land use influences are new urban development and light industrial activities. Further down the catchment, land uses are mainly rural and agricultural. Two Sydney Water WRRFs (Castle Hill and Rouse Hill) operate in the Cattai Creek catchment. The Rouse Hill WRRF discharges via a constructed wetland or bypassing directly to Second Ponds Creek, a tributary of Cattai Creek. Castle Hill WRRF discharges directly to the upper Cattai Creek. This water quality monitoring site is located at Cattai Ridge Road, about 7 km upstream of the confluence with the Hawkesbury River.

There were no significantly increasing trends identified in any of the nutrients and physico-chemical analytes or chlorophyll-a at Lower Cattai Creek (NC11A) in 2023-24 compared to the previous nine years.

The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations in Cattai Creek exceeded the respective ANZG (2018) guidelines in 2023-24.

Among physico-chemical water quality analytes, the median dissolved oxygen saturation remained below ANZG (2018) lower guideline limit.





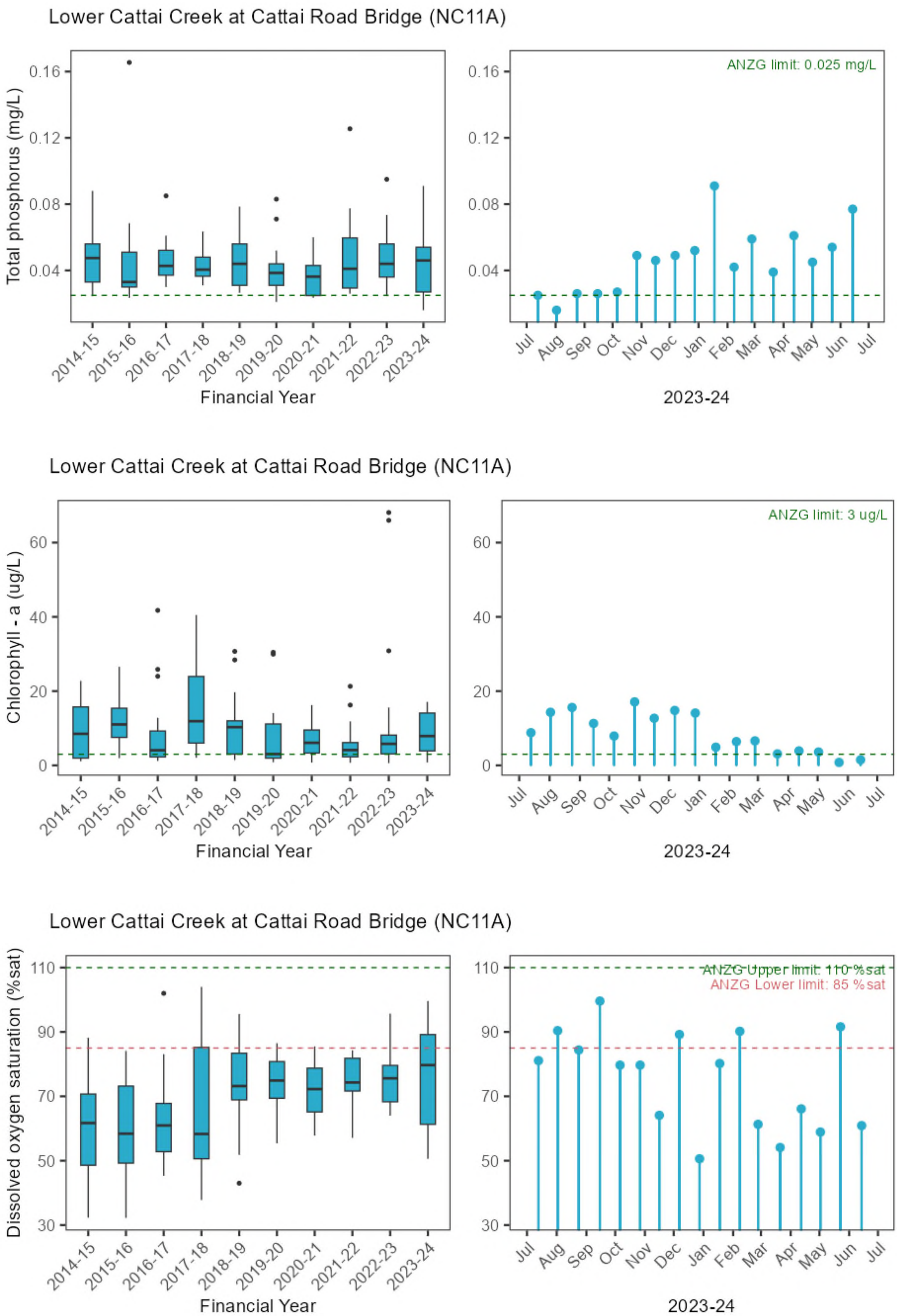


Figure 4-83 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Lower Cattai Creek at Cattai Ridge Road (NC11A)

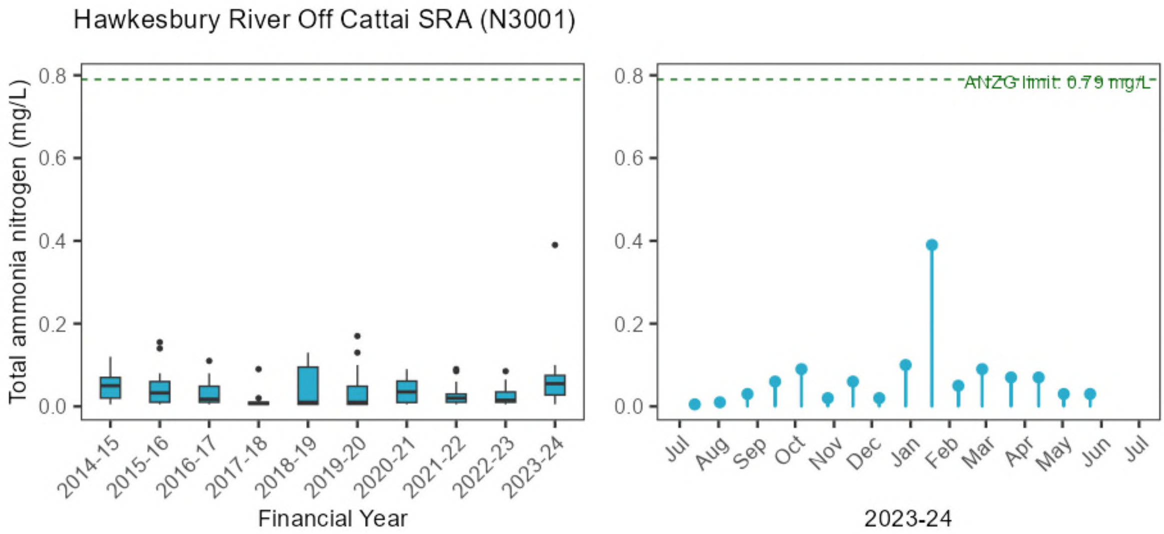
N3001: Hawkesbury River off Cattai SRA

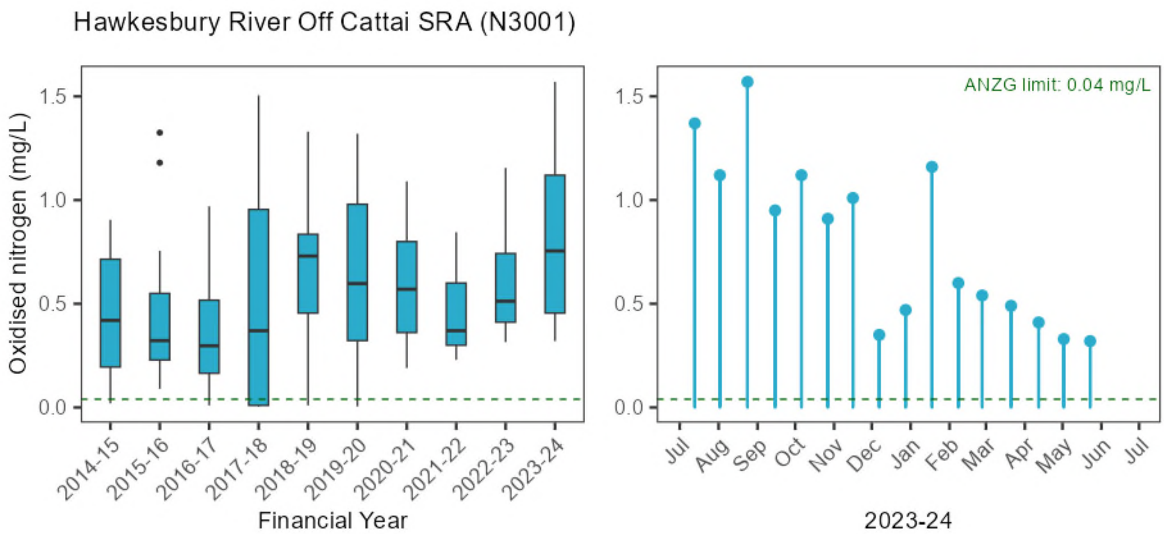
Hawkesbury River off Cattai SRA (N3001) is located about 2 km downstream of the confluence with Cattai Creek. The water quality at this site is influenced by flows from both South Creek and Cattai Creek. Historically, this site has exhibited high nutrients, high chlorophyll-a concentrations and phytoplankton blooms.

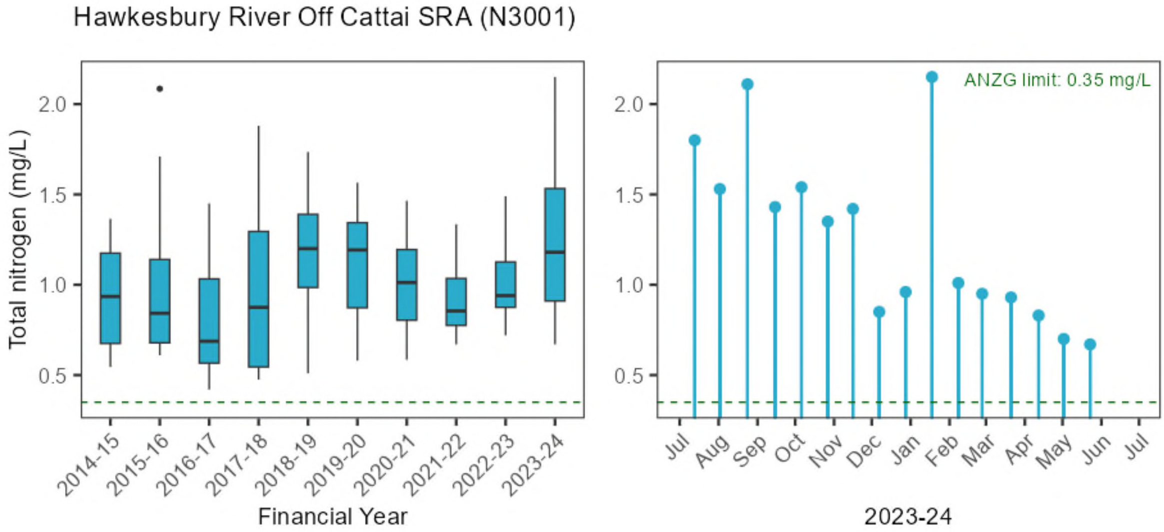
The water quality at this site showed significantly increased concentrations of total ammonia nitrogen, oxidised nitrogen and total nitrogen in 2023-24 compared to the previous nine years.

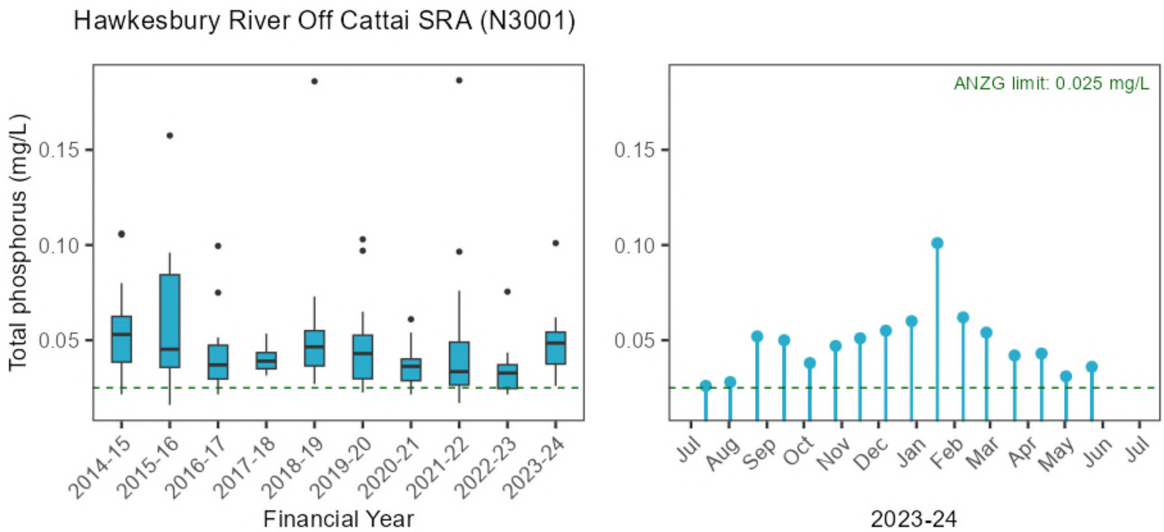
Among physico-chemical analytes, conductivity was significantly higher in 2023-24.

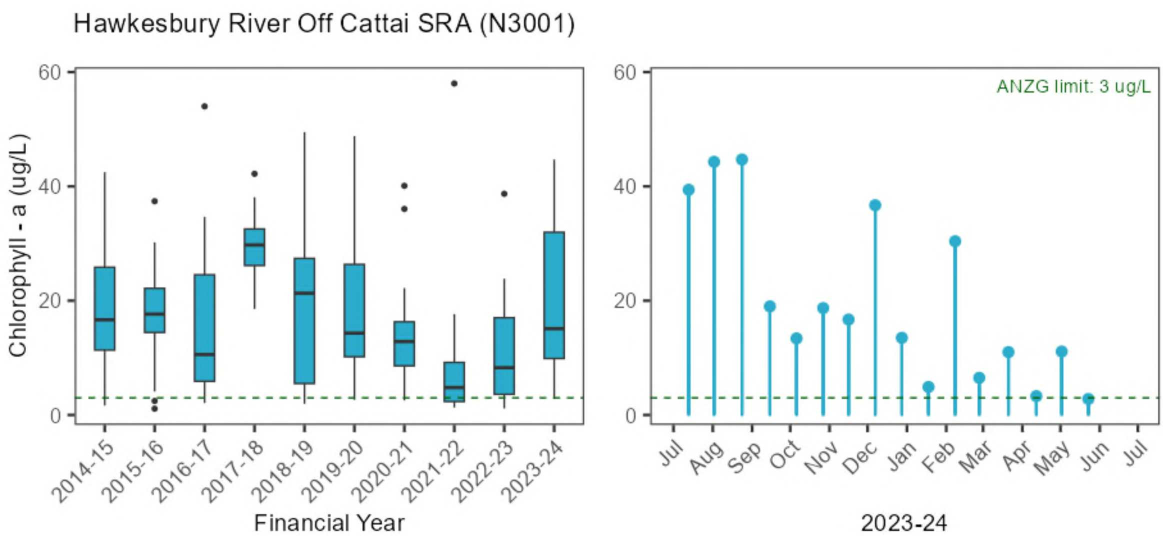
The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations at N3001 exceeded the respective ANZG (2018) guidelines in 2023-24.






Hawkesbury River Off Cattai SRA (N3001)
Total nitrogen (mg/L)
ANZG limit: 0.35 mg/L
Financial Year
2023-24


Hawkesbury River Off Cattai SRA (N3001)
Total phosphorus (mg/L)
ANZG limit: 0.025 mg/L
Financial Year
2023-24


Hawkesbury River Off Cattai SRA (N3001)
Chlorophyll - a (ug/L)
ANZG limit: 3 ug/L
Financial Year
2023-24

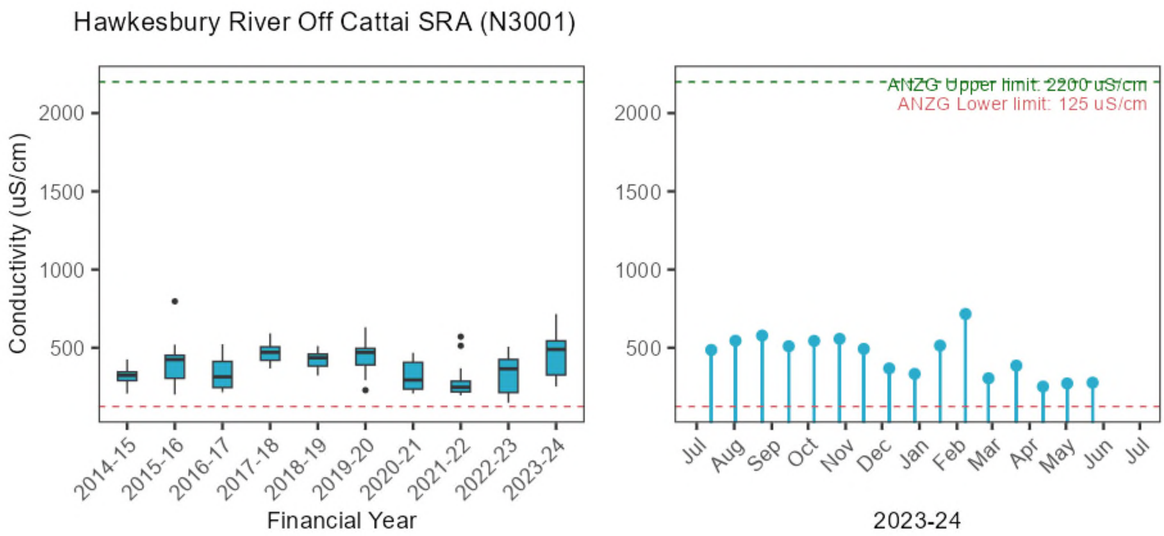


Figure 4-84 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Hawkesbury River off Cattai SRA (N3001)

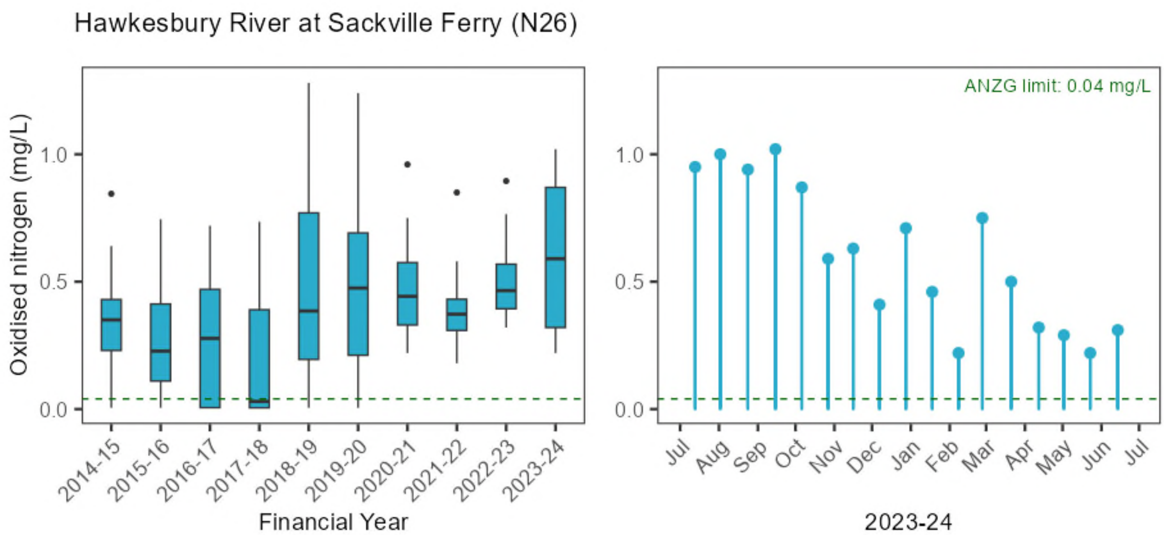
N26: Hawkesbury River at Sackville Ferry

Hawkesbury River at Sackville Ferry (N26) is located about 18 km downstream of the Cattai Creek confluence with the Hawkesbury River. Historically, this site has had the highest incidences of phytoplankton blooms, especially toxic blue-green species.

Oxidised nitrogen and total nitrogen concentrations increased significantly in 2023-24 compared to the previous nine years.

There were no other significant statistical trends for any physico-chemical analytes at N26 in 2023-24.

The median oxidised nitrogen, total nitrogen, total phosphorus and chlorophyll-a concentrations at N26 exceeded the respective ANZG (2018) guidelines in 2023-24.



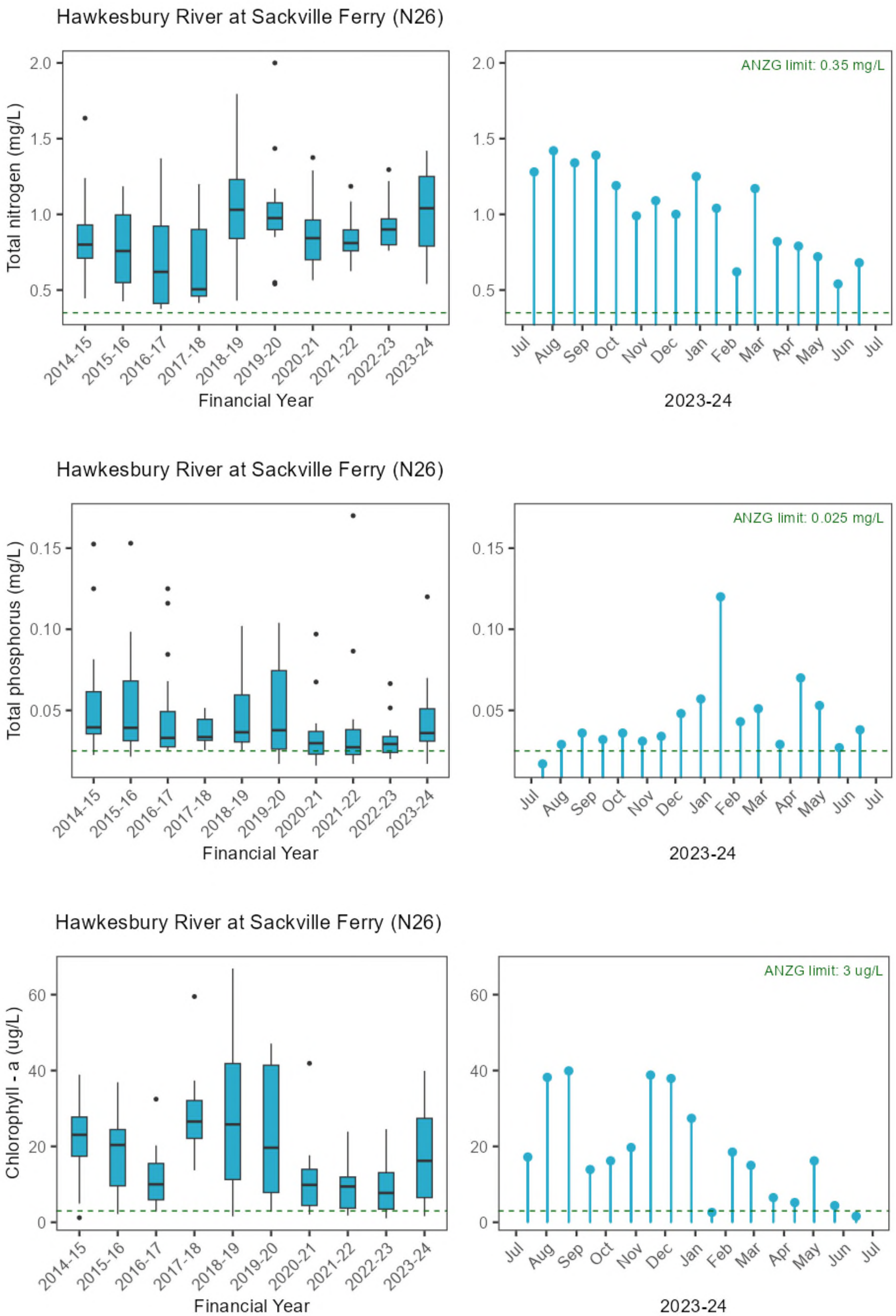


Figure 4-85 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Hawkesbury River at Sackville Ferry (N26)

N2202: Lower Colo River at Putty Road

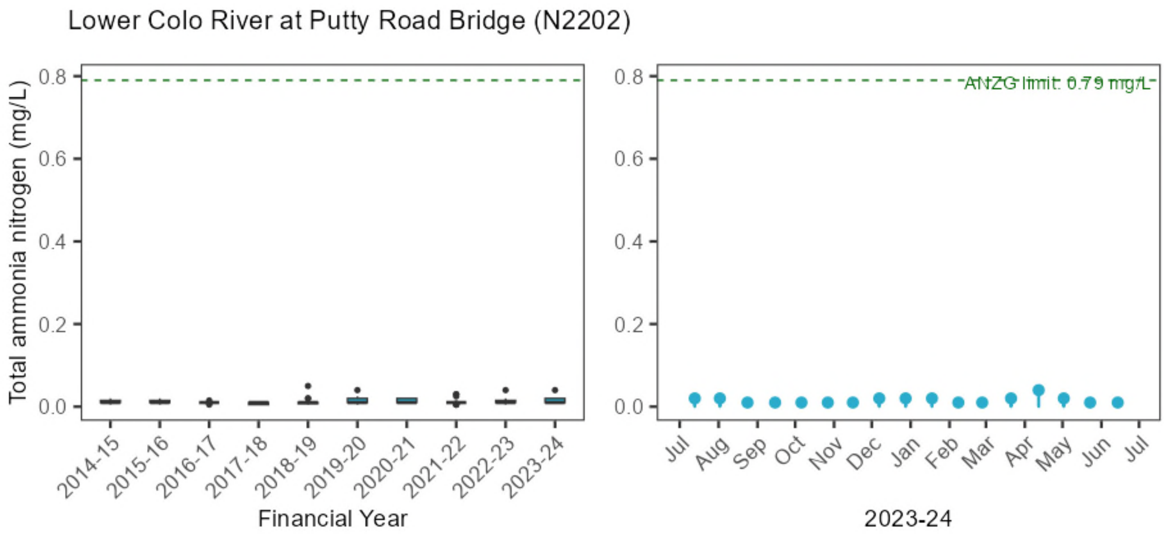
The Colo River is one of the major tributaries of the Hawkesbury River, joining at Lower Portland. The Colo River catchment consists of mostly pristine and undisturbed areas. About 80% of the catchment is comprised of the Greater Blue Mountain's World Heritage Area. Lower Colo River at Putty Road Bridge (N2202) is located at Putty Road, about 12 km upstream of the confluence with the Hawkesbury River and is considered a reference site.

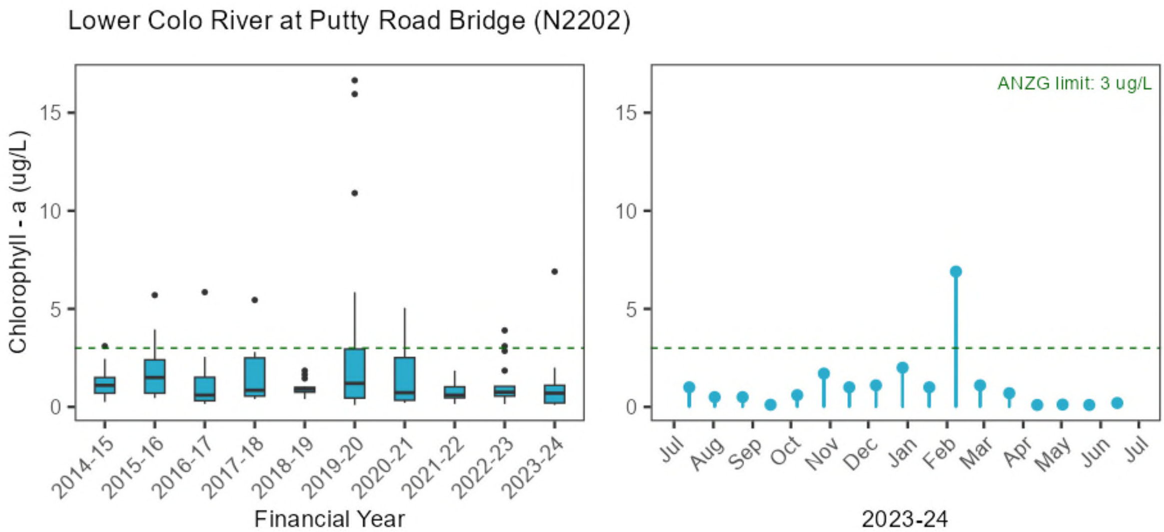
Total ammonia nitrogen concentrations at this site were very low but increased significantly in 2023-24 compared to the previous nine years.

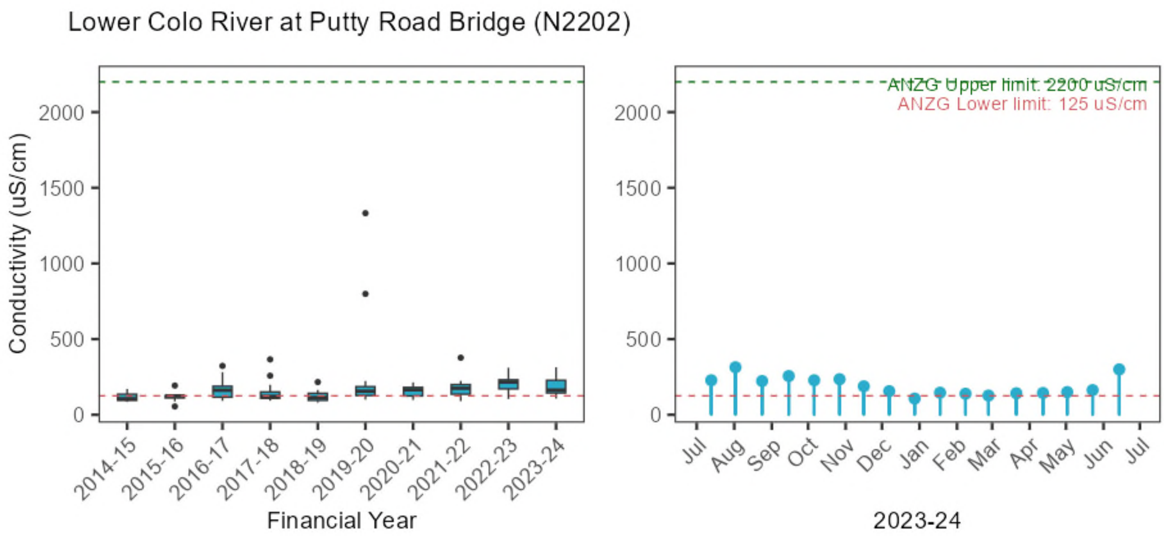
Chlorophyll-a concentrations decreased significantly in 2023-24 compared to the previous nine years.

Among physico-chemical analytes, conductivity was significantly higher in 2023-24.

Median turbidity for this site was below the ANZG (2018) lower guideline limit.







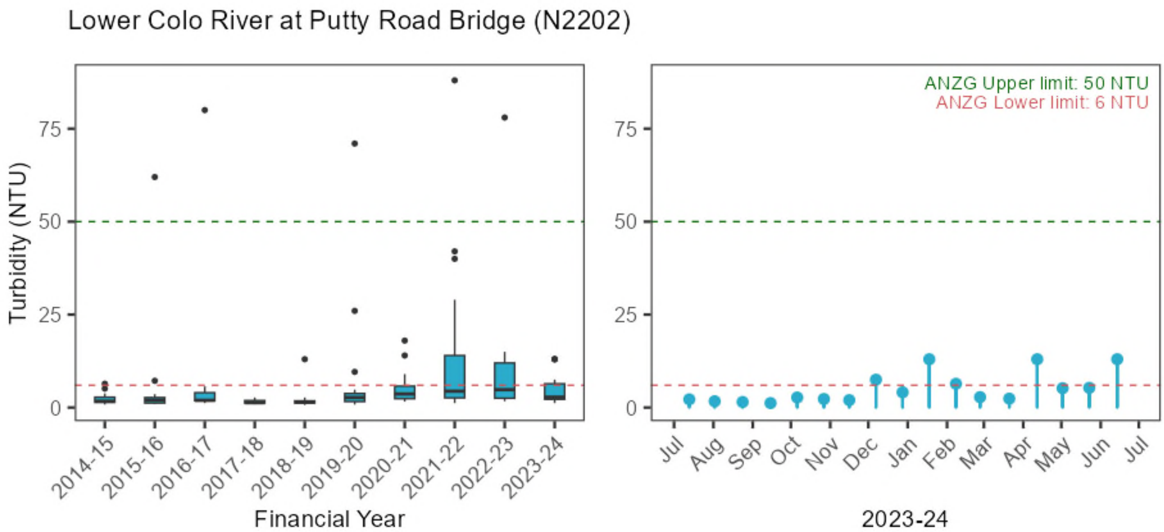


Figure 4-86 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Lower Colo River at Putty Road (N2202)

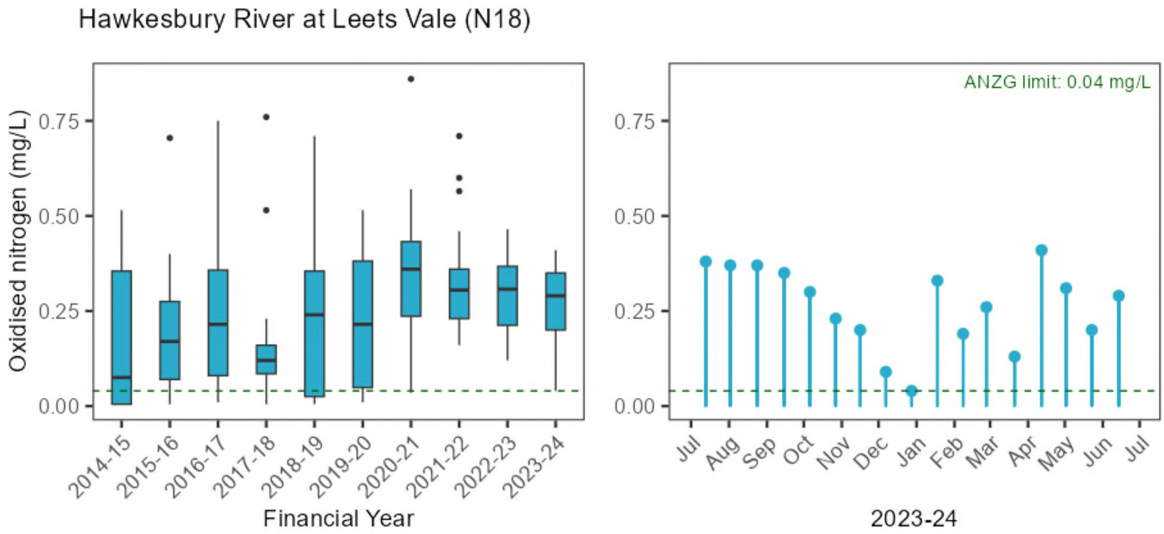
N18: Hawkesbury River at Leets Vale

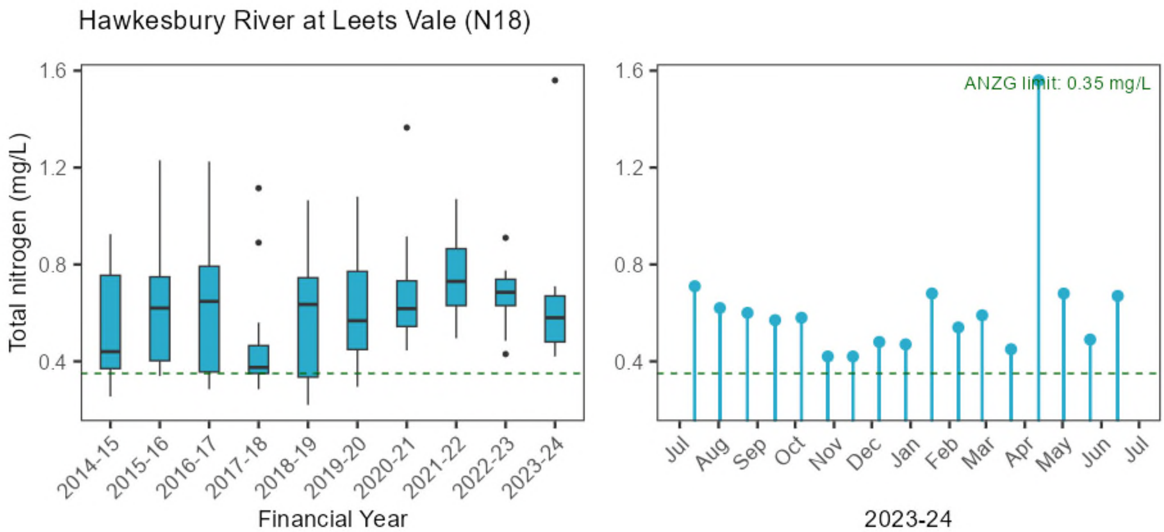
The Hawkesbury River at Leets Vale (N18) is located about 12 km downstream of the Colo River confluence. N18 receives relatively high-quality inflows from the Colo River as well as occasional strong tidal influences causing periodic high salinity levels.

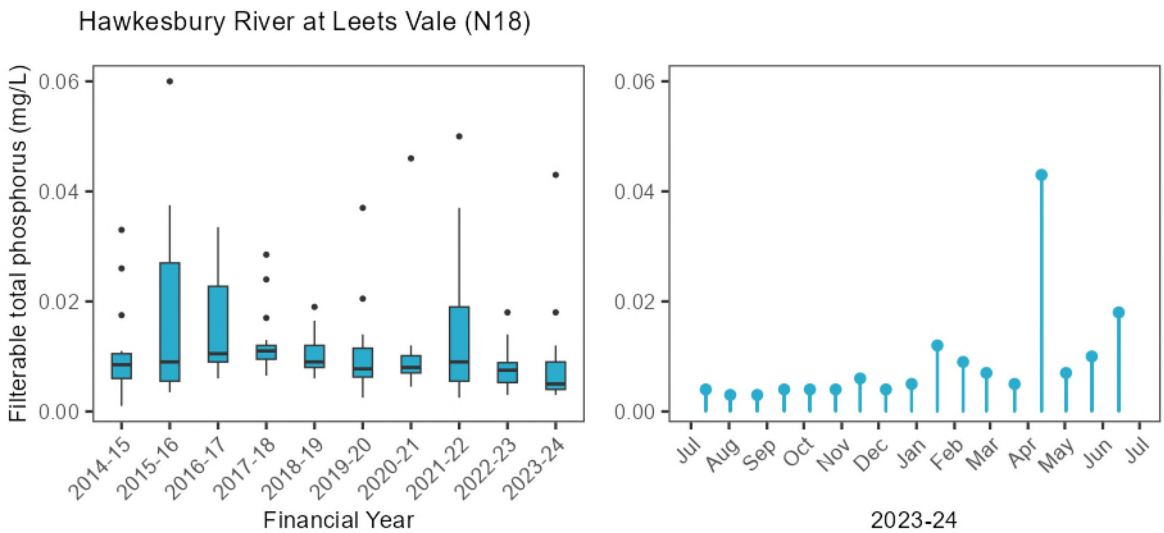
The water quality of the Hawkesbury River at Leets Vale (N18 showed significantly decreased concentrations of filterable total phosphorus and total phosphorus in 2023-24 compared to the previous nine years.

Among physico-chemical water quality analytes, turbidity decreased significantly in 2023-24.

The median oxidised nitrogen, total nitrogen and chlorophyll-a concentrations at N18 exceeded the respective ANZG (2018) guidelines in 2023-24.


Hawkesbury River at Leets Vale (N18)
Oxidised nitrogen (mg/L)
0.00
0.25
0.50
0.75
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.04 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Hawkesbury River at Leets Vale (N18)
Total nitrogen (mg/L)
0.4
0.8
1.2
1.6
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
ANZG limit: 0.35 mg/L
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24


Hawkesbury River at Leets Vale (N18)
Filterable total phosphorus (mg/L)
0.00
0.02
0.04
0.06
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24

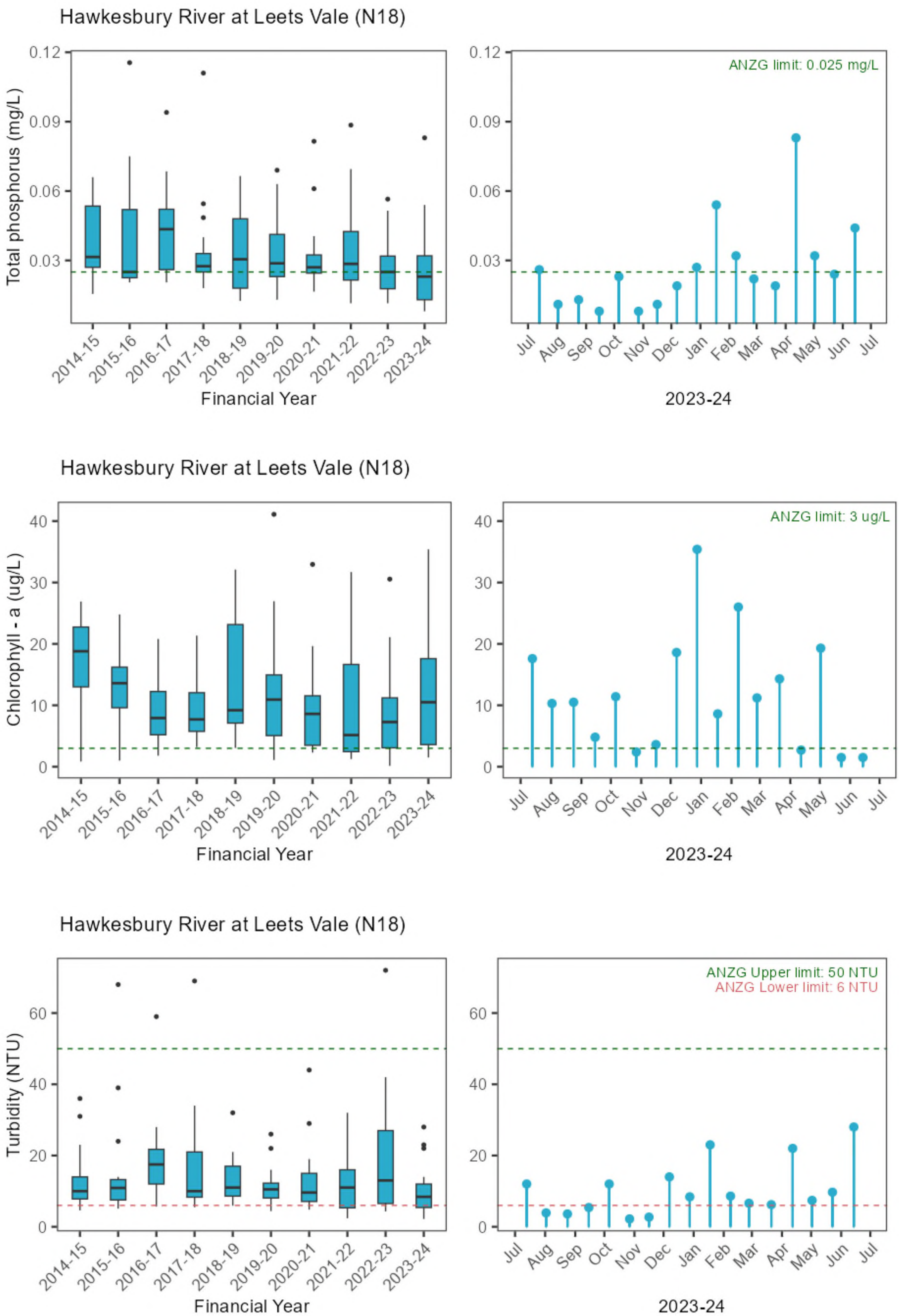


Figure 4-87 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Hawkesbury River at Leets Vale (N18)

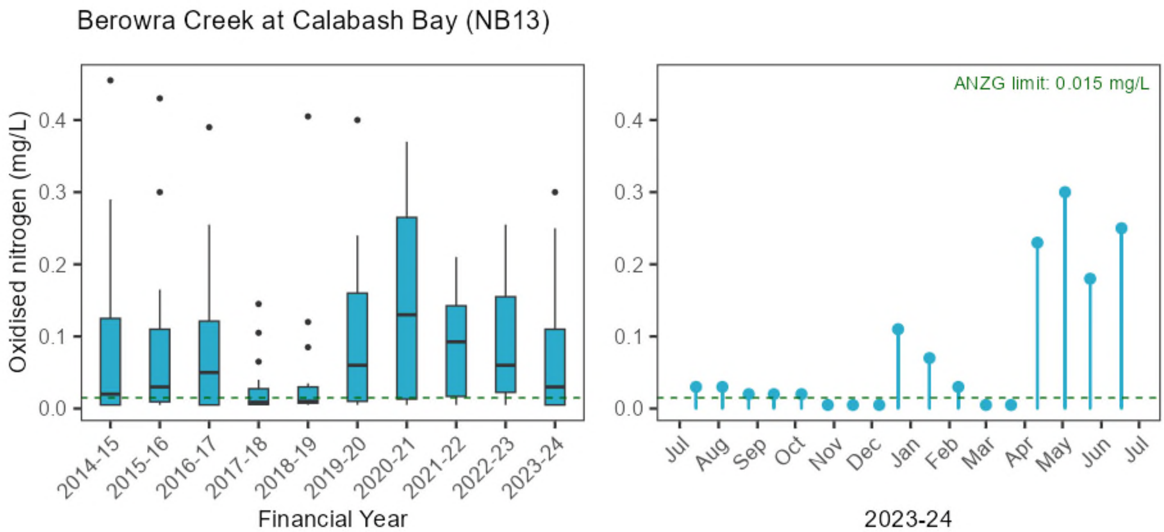
NB13: Berowra Creek at Calabash Bay

Berowra Creek at Calabash Bay (NB13) is located at Cunio Point in the Berowra estuary of the Hawkesbury River. This site has strong tidal influence, and the water quality is affected by various sources of pollution from the upstream Berowra Creek catchment. This includes urban run-off, run-off from unsewered areas, agricultural cultivation involving fertiliser use, bushland and two licensed Sydney Water WRRF discharge points. Hornsby Heights WRRF discharges to Calna Creek, a tributary of Berowra Creek, while West Hornsby WRRF discharges to Waitara Creek, also a tributary of Berowra Creek.

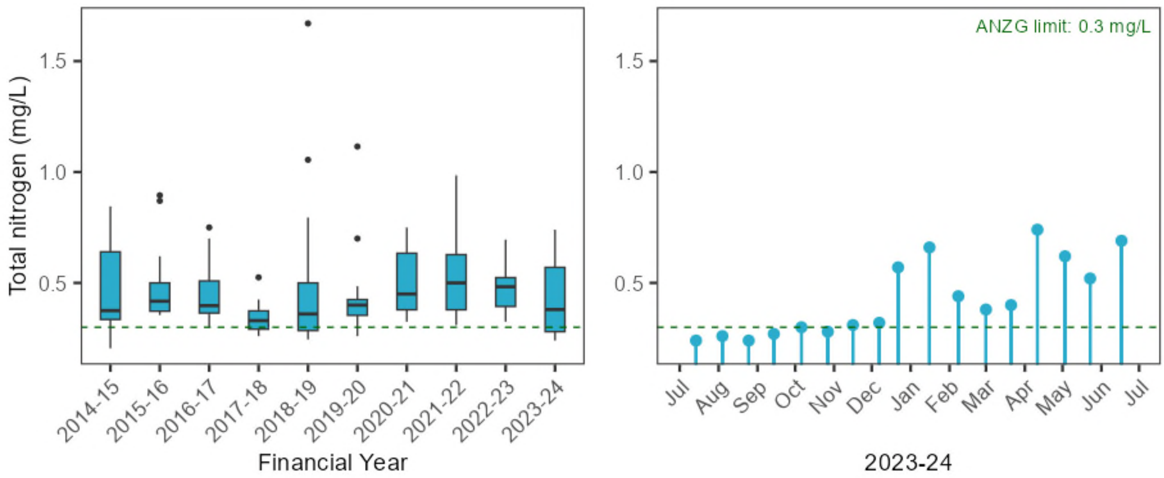
Concentrations of nutrient analytes were steady at Berowra Creek at Calabash Bay (NB13) in 2023-24 compared to the previous nine years. Chlorophyll-a concentrations decreased significantly in 2023-24 compared to the previous nine years.

Among physico-chemical water quality analytes, pH was significantly lower in 2023-24.

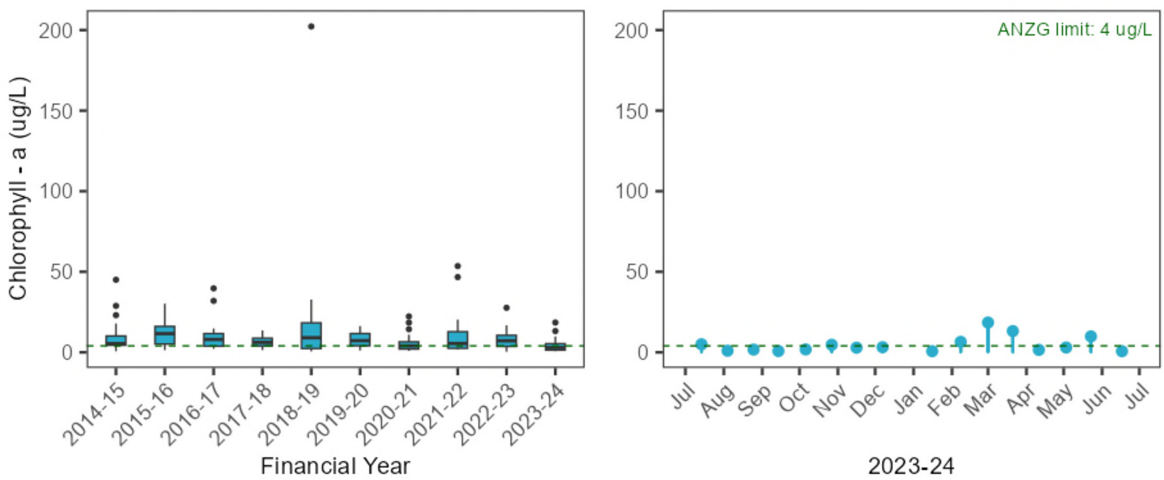
The median oxidised nitrogen and total nitrogen exceeded the respective ANZG (2018) guidelines in 2023-24. Median turbidity was below the ANZG (2018) lower guideline limit.



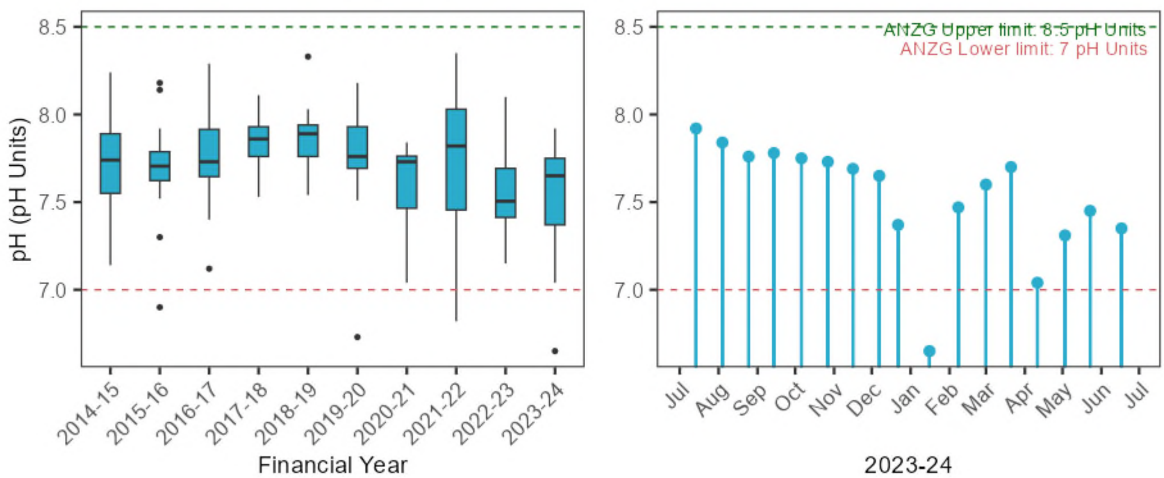
Berowra Creek at Calabash Bay (NB13)



Berowra Creek at Calabash Bay (NB13)



Berowra Creek at Calabash Bay (NB13)



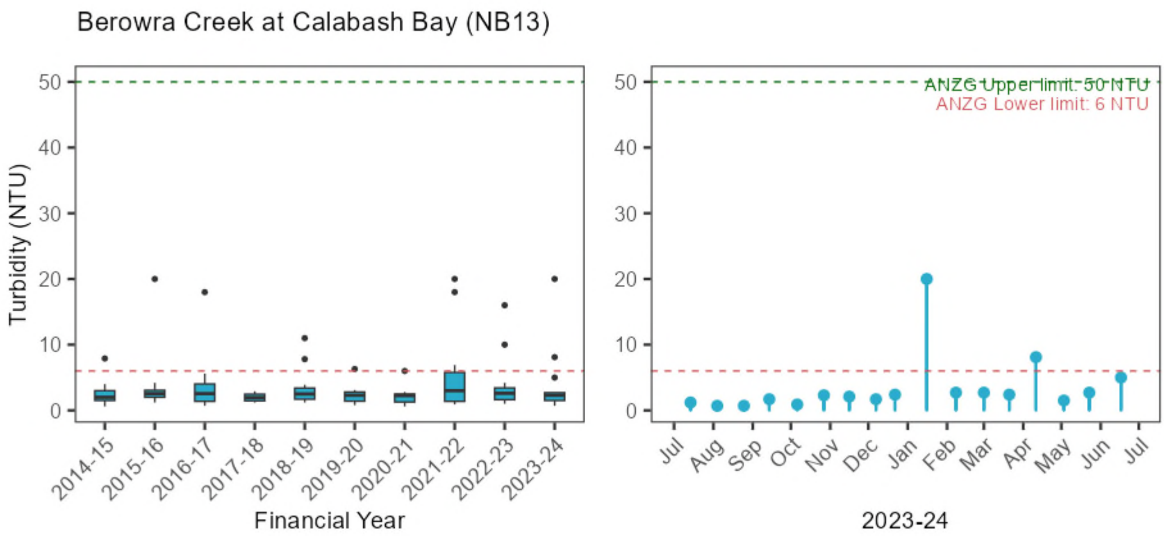


Figure 4-88 Nutrients. Chlorophyll-a and physico-chemical water quality exception plots, Berowra Creek at Calabash Bay (NB13)

NB11: Berowra Creek off Square Bay

Berowra Creek site off Square Bay (NB11) is located at Oaky Point in the Berowra estuary of the Hawkesbury River. This site is strongly influenced by tidal movement and cycles. The catchment influences at this site are the same as for the nearby Calabash Bay site (NB13), the only difference being this site is further away from wastewater discharges. Catchment influences include urban run-off, run-off from unsewered areas, agricultural cultivation involving fertiliser use, bushland and two Sydney Water WRRFs.

There were no significantly increasing or decreasing trends identified in any of the nutrients and chlorophyll-a and physico-chemical analytes at Berowra Creek site off Square Bay (NB11) in 2023-24 compared to the previous nine years.

The median total nitrogen concentrations and chlorophyll-a exceeded the respective ANZG (2018) guidelines in 2023-24.

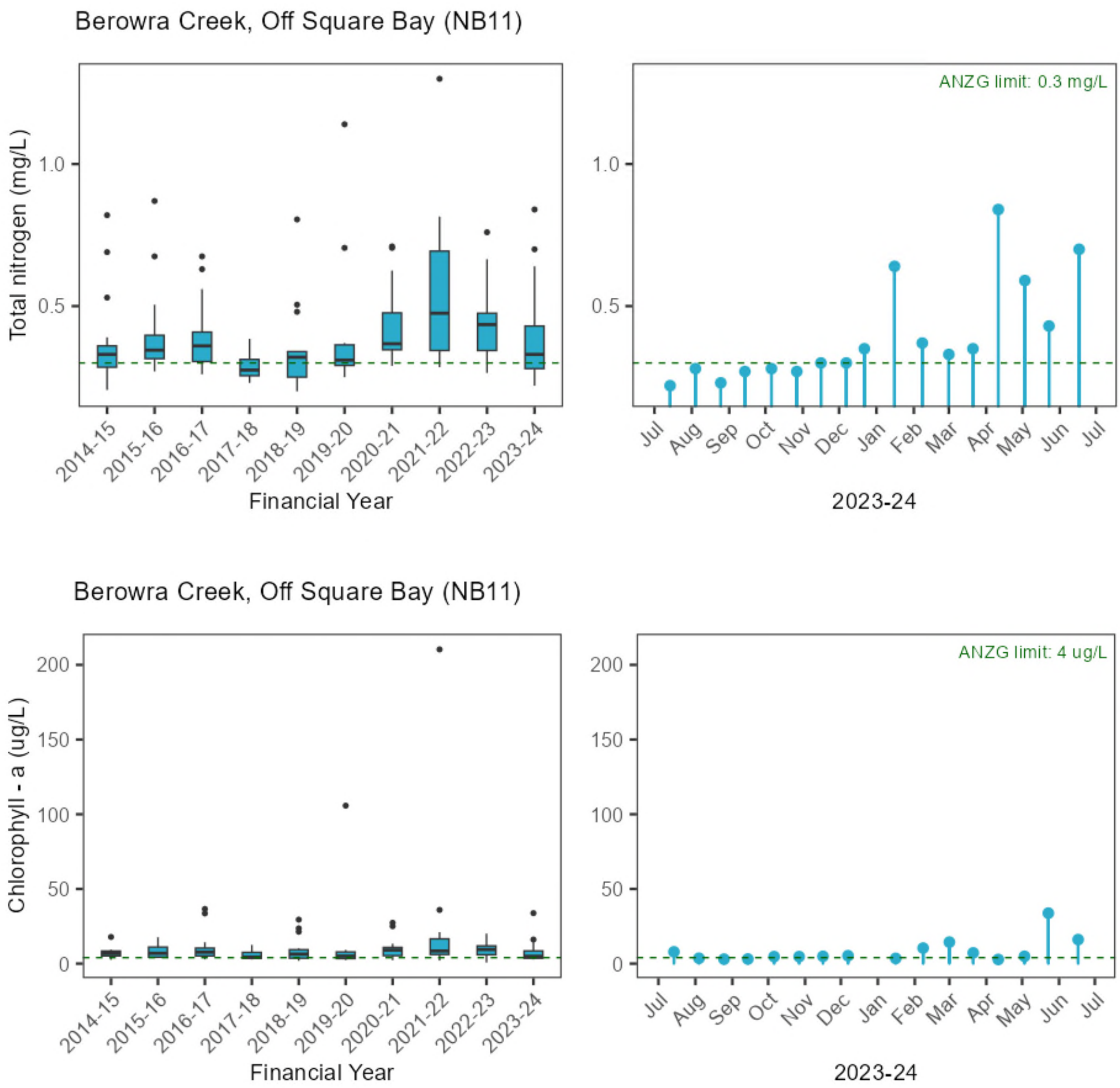


Figure 4-89 Nutrients, chlorophyll-a and physico-chemical water quality exception plots, Berowra Creek off Square Bay (NB11)

4.3.2. Phytoplankton dynamics – long-term Hawkesbury-Nepean River sites (SoE)

- Trends in phytoplankton biovolume and counts were varied by site in 2023-24 period. Blue-green biovolumes exceeded the NHMRC (2008) amber alert level once or more at four of the ten sites:
  - Nepean River at Sharpes Weir and Penrith Weir (N75 and N57); and
  - Hawkesbury River at Wilberforce and Sackville Ferry (N35 and N26).
- Potentially toxic blue-green species counts exceeded the NHMRC (2008) amber alert level once or more at three of the ten sites:
  - Nepean River at Shares Weir and Penrith Weir (N75 and N57) and
  - Hawkesbury River at Sackville Ferry (N26).
- At Sackville, the phytoplankton counts were close to the red alert level, when high numbers of toxic taxa were present (49,393 cells/mL).
- Diatoms were the most dominant group of phytoplankton at most sites, while South Creek and to some extant Cattai Creek were exceptions, where flagellated monads dominated for most of the 2023-24 period.

Phytoplankton community structure and abundances were monitored at ten long-term monitoring sites. Seven of these sites are along the mainstream river from the upstream Nepean River at Maldon Weir to the downstream Hawkesbury River at Sackville Ferry. Three other sites were monitored at three major tributaries, South Creek, Cattai Creek and Berowra Creek. The analytes included phytoplankton biovolume by individual taxa and cell counts that can be combined as key taxonomic groups of significance.

Monitoring data for these sites are presented for assessing the SoE in terms of phytoplankton dynamics or species succession at each site or, comparison of phytoplankton biovolume or counts against national guidelines for two selective analytes. The 2023-24 phytoplankton monitoring data was not comparable with previous years' monitoring data, as historically, phytoplankton was only counted when chlorophyll-a levels exceeded 7 µg/L. Therefore, statistical analysis will follow from 2024-25 to determine the year-to-year trends in phytoplankton abundance.

Volume 1 provides a general discussion on phytoplankton for the 2023-24 data based on needle plots or area plots and exceedances of the NHMRC (2008) guideline for two selective analytes. No further information of data summary or plots are included in the Volume 2 report.

N92: Nepean River at Maldon Weir

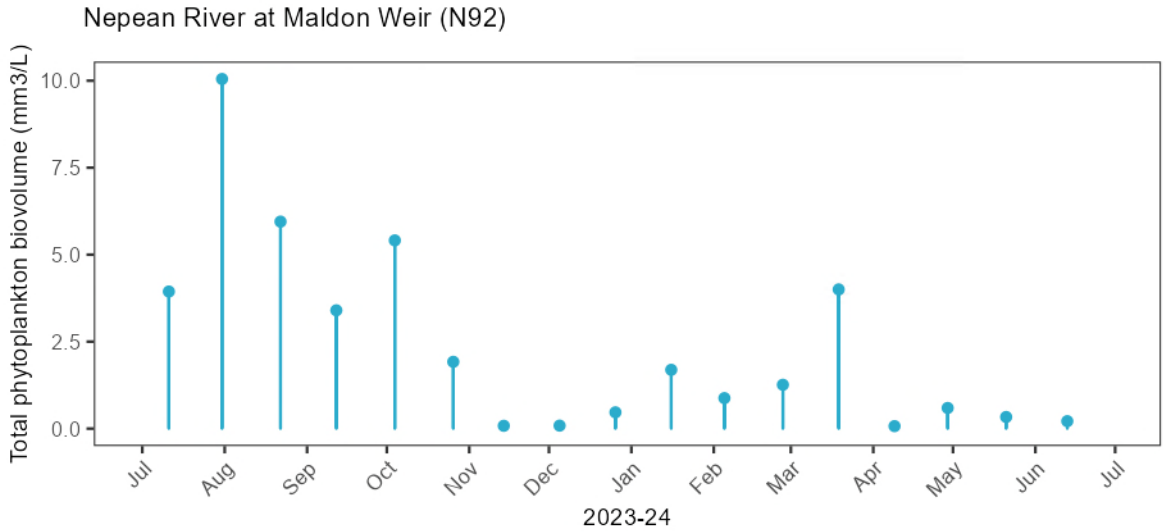
The Nepean River at Maldon Weir (N92) also serves as the upstream control site for the Picton WRRF discharge impact assessment. The water quality and phytoplankton at Maldon Weir is influenced by upstream catchment factors including mining from Tahmoor Colliery and environmental flows released from the upstream water storage dams (Nepean, Avon and Cordeaux).

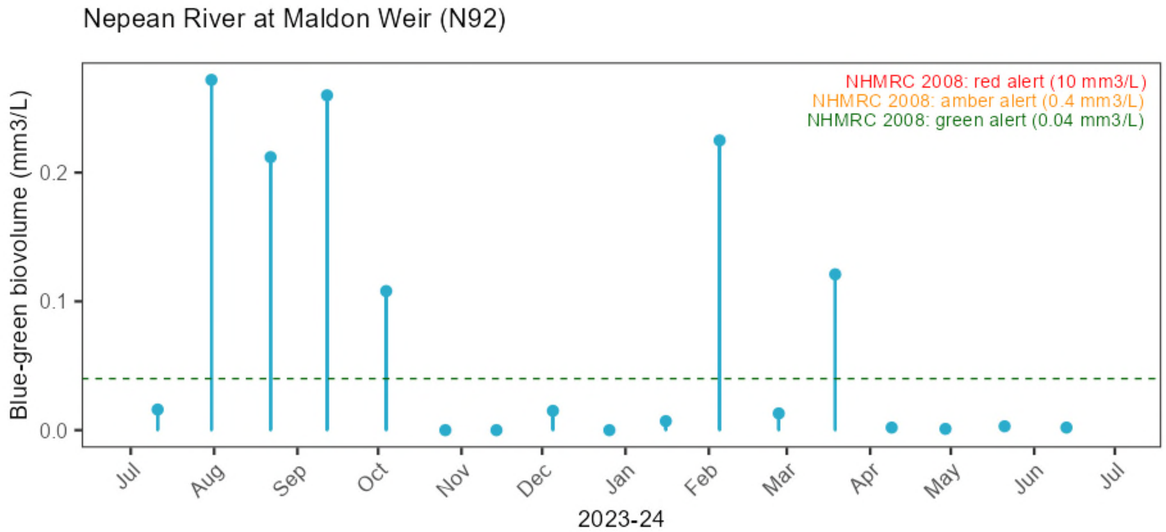
Total phytoplankton biovolume at Maldon Weir (N92) was generally elevated at the beginning of 2023-24 (July to October) and later eased, possibly due to periodic washout by intermittent rainfall or wet weather.

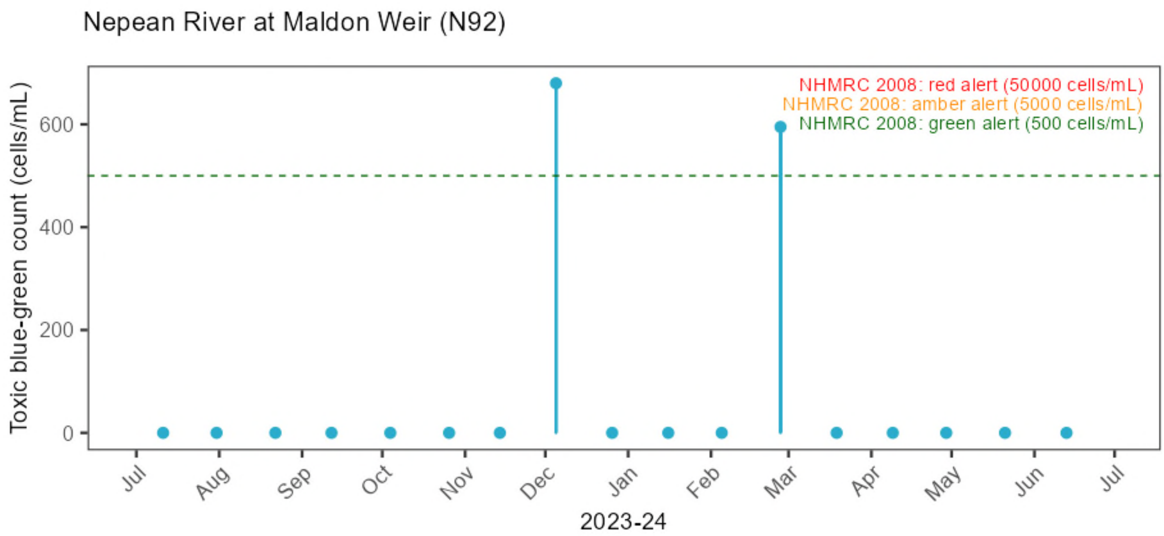
Total phytoplankton biovolume reached a maximum of 10.05 mm^3/L on 31 July 2023 when miscellaneous diatoms (Bacillariophyta) were dominant.

Diatoms (Bacillariophyta) were the dominant group of phytoplankton taxa that sustained at Maldon Weir for most of 2023-24. Although flagellated monads were co-dominant at times, which usually favour fresh nutrient inputs after storm events. Blue-greens (Cyanophyte) were rarely present at this site.

Blue-green (Cyanophyta) biovolume or toxic blue-green counts were low, and did not exceed the NHMRC (2008) Amber alert level on any occasion. Potentially toxic blue-green taxa *Phormidium* was found at this site twice (5 December 2023 and 27 February 2024) in low numbers (<1000 cells/mL), although this exceeds the NHMRC (2008) green alert level.







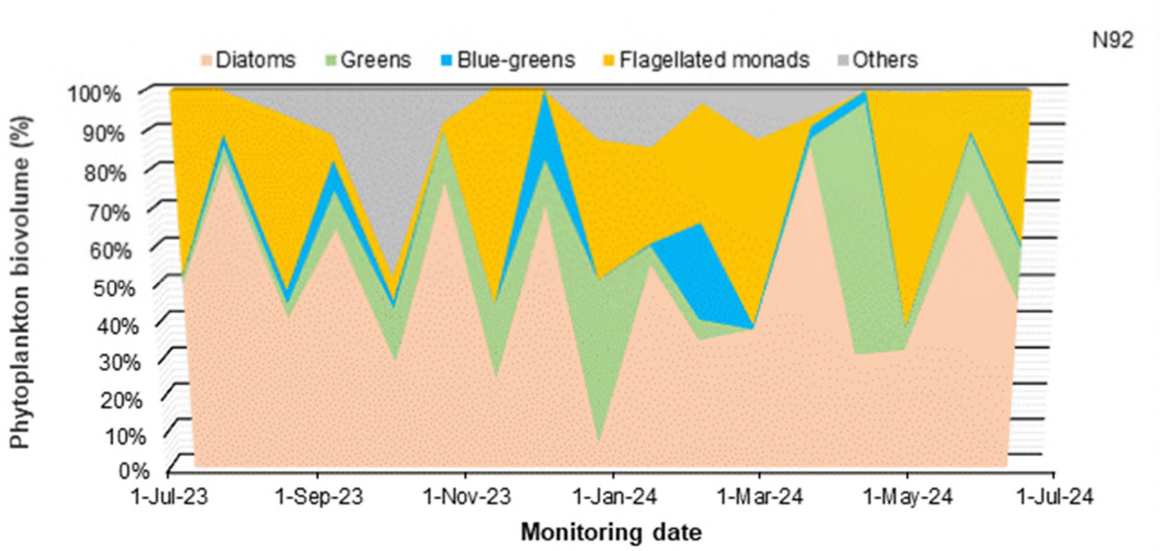


Figure 4-90 Phytoplankton biovolume and count plots, Nepean River at Maldon Weir (N92)

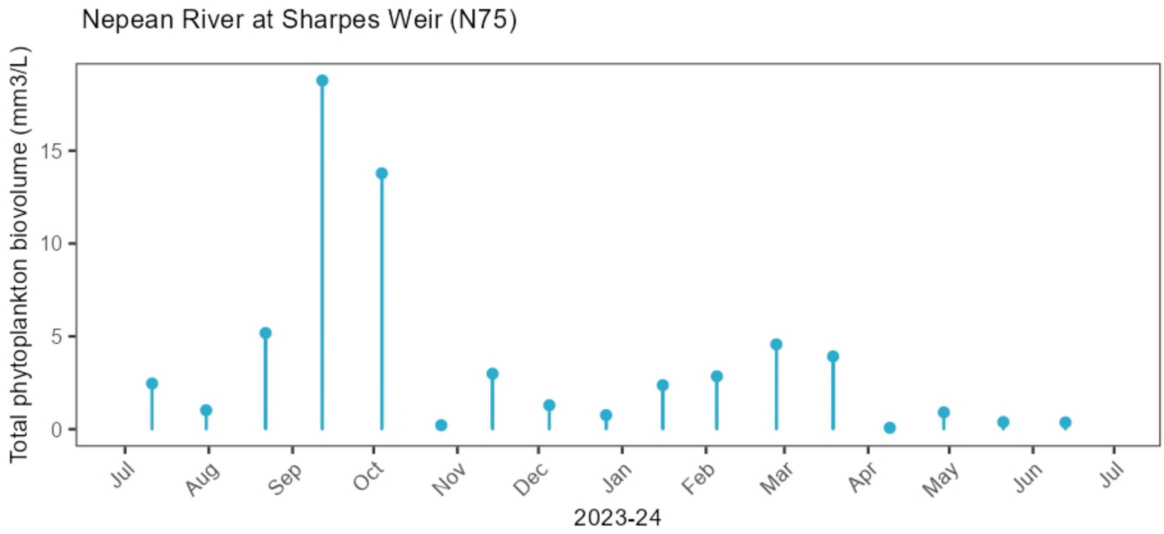
N75: Nepean River at Sharpes Weir

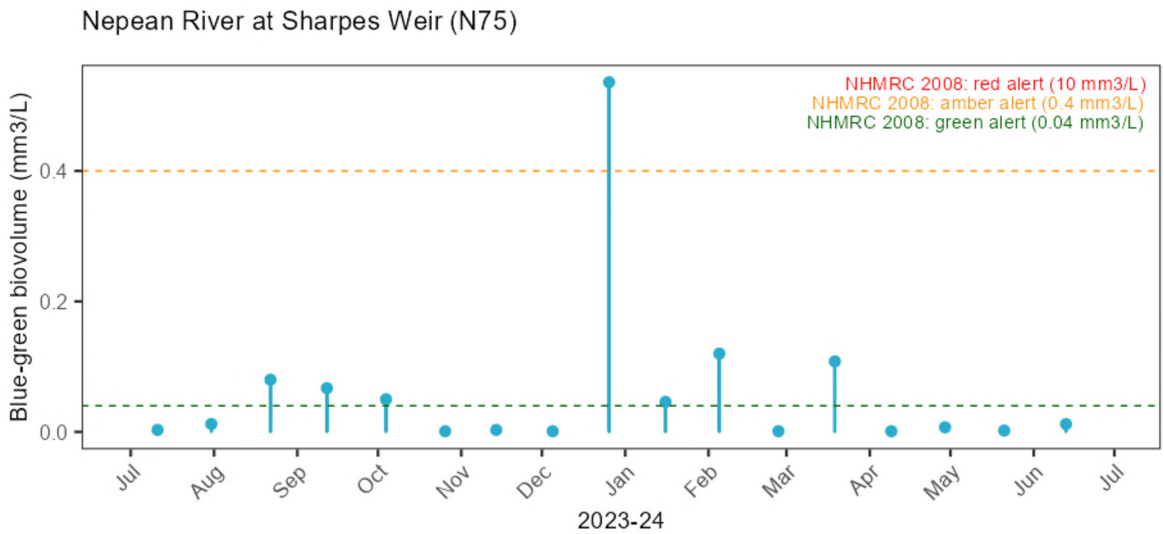
The Nepean River at Sharpes Weir (N75) site also serves as the downstream impact site for the West Camden WRRF. It is located immediately downstream of Matahil Creek, which receives the treated wastewater from West Camden WRRF. Other upstream catchment factors such as agricultural run-off, increased urbanisation and resultant run-offs may also govern the water quality and phytoplankton at this site.

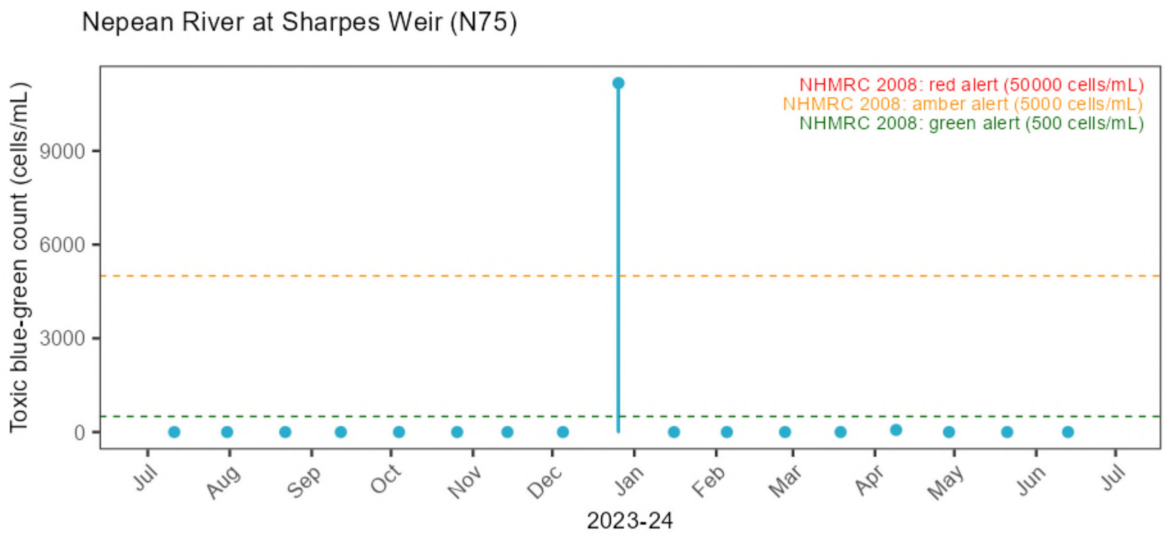
Total phytoplankton biovolumes at Sharpes Weir (N75) were elevated during September-October 2023 but later eased, possibly due to periodic washout by intermittent rainfall or wet weather.

Total phytoplankton biovolume reached a maximum of 18.78 mm^3/L on 12 September 2023 when miscellaneous Diatoms (Bacillariophyta) were present in high numbers. With the onset of summer, Greens (Chlorophyta), Blue-greens (Cyanophyta) and flagellated monads replaced the Diatoms. Flagellated monads and other types of phytoplankton also dominated the assemblage in the second half of the year.

Blue-greens (Cyanophyta) biovolume and toxic blue-green counts exceeded the NHMRC (2008) amber alert level on 26 December 2023, when the potentially toxic blue-green taxa *Microcystis* and *Dolichospermum circinale* were found in moderate numbers (8,227 cells/mL and 2,939 cells/mL, respectively).







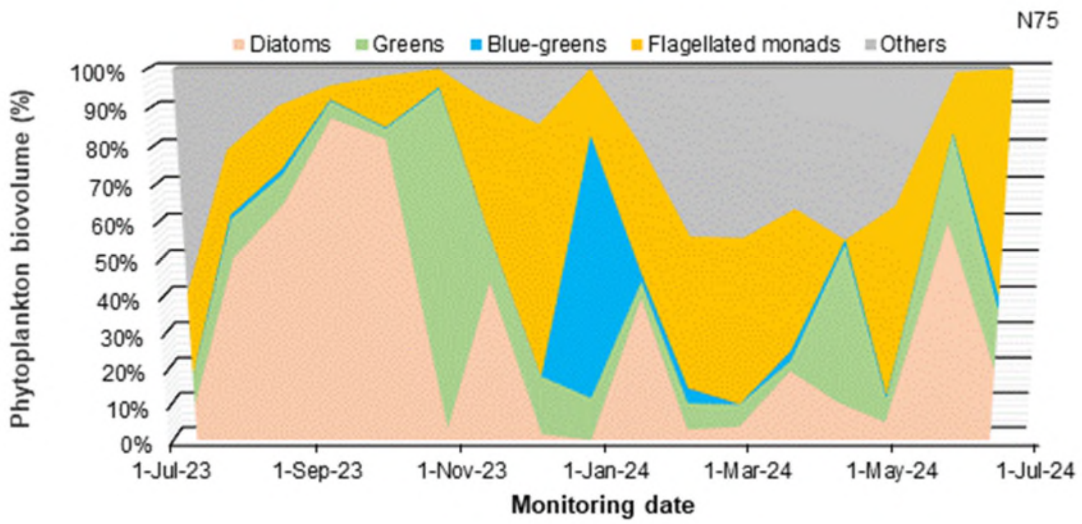


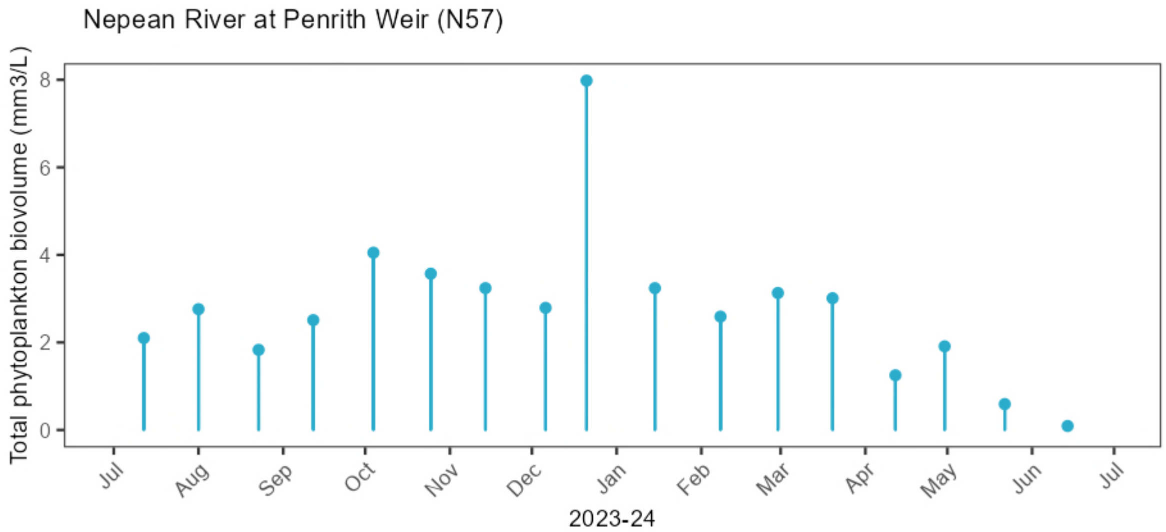
Figure 4-91 Phytoplankton biovolume and count plots, Nepean River at Sharpes Weir (N75)

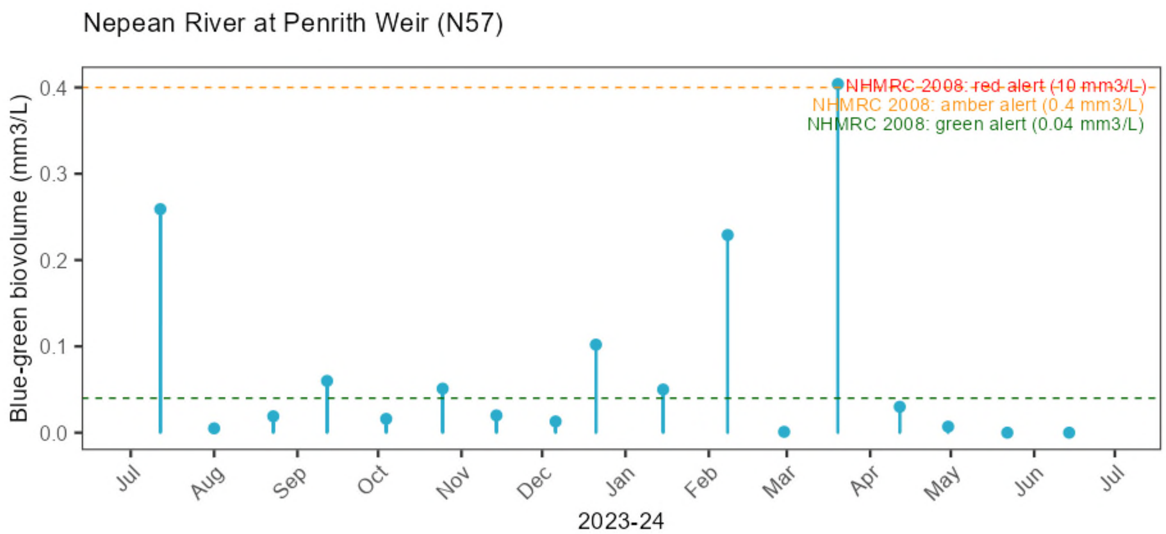
N57: Nepean River at Penrith Weir

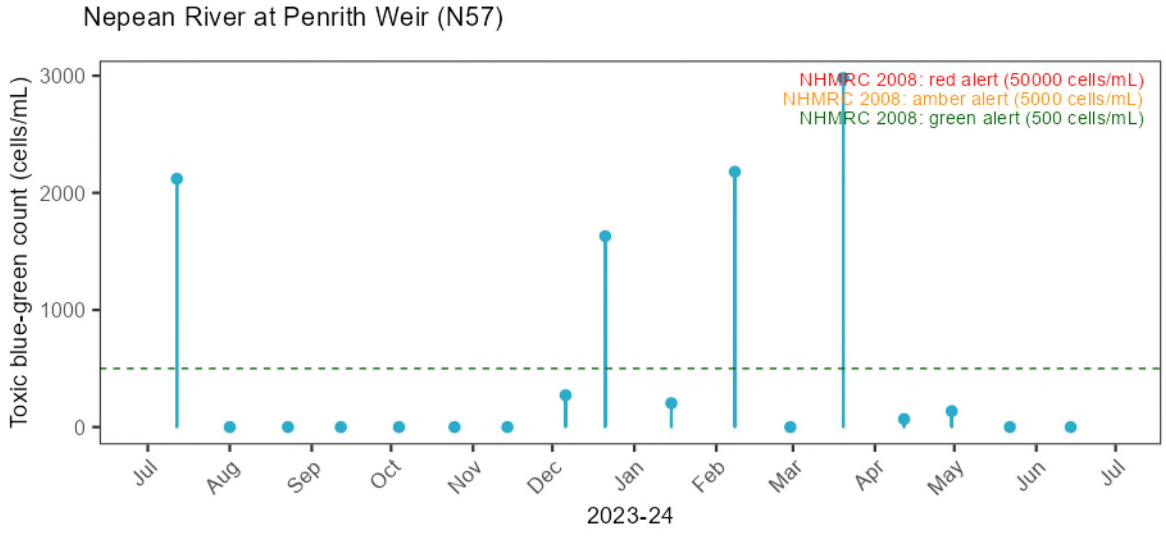
The Nepean River at Penrith Weir (N57) site also serves as the upstream control site for Penrith WRRF discharges. The Warragamba River joins the Nepean River about 18 km upstream of Penrith Weir. This site receives discharges from Wallacia WRRF and environmental flow releases from Warragamba Dam. The immediate upstream catchment of Penrith Weir is mixed including new urban residential housings, rural, agricultural and protected catchment/national park. Submerged macrophyte beds with the occasional floating macrophyte species are also present at this site, which may compete for nutrients with phytoplankton species.

Total phytoplankton biovolume at Penrith Weir (N57) reached a maximum of 7.98 mm^3/L on 21 December 2023 when miscellaneous diatoms (Bacillariophyta) were present in high numbers. Diatoms were the dominant group in phytoplankton composition for most of the 2023-24 period. Blue-greens (Cyanophyte) were rarely present at this site.

Blue-green (Cyanophyta) biovolume marginally exceeded the NHMRC (2008) amber alert level on 20 March 2024. Toxic blue-green counts also exceeded the amber alert level on the same day when *Microcystis* and *Radiocystis* were found in moderate numbers (531 cells/mL and 2,450 cells/mL, respectively).







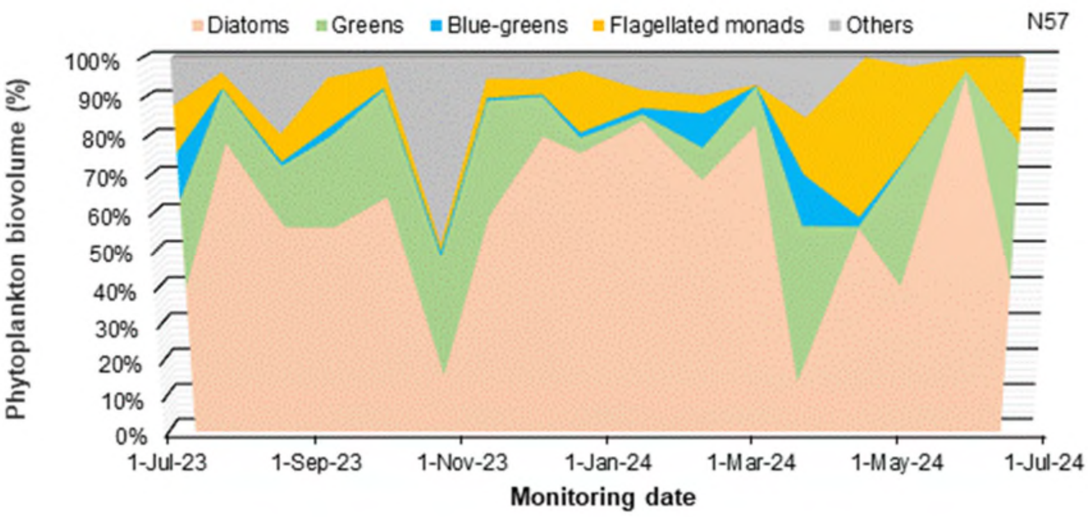


Figure 4-92 Phytoplankton biovolume and count plots, Nepean River at Penrith Weir (N57)

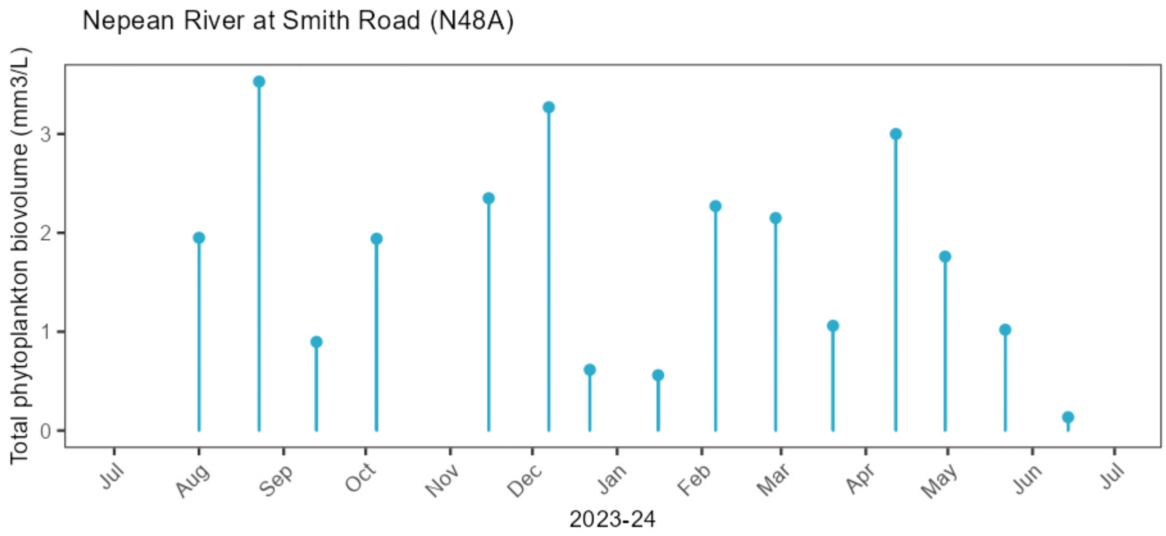
N48A: Nepean River at Smith Road

The Nepean River at Smith Road (N48A) also served as the upstream control site for Winmalee WRRF discharges. This site often contains submerged macrophyte beds with the occasional floating macrophyte species which may compete for nutrients with phytoplankton species.

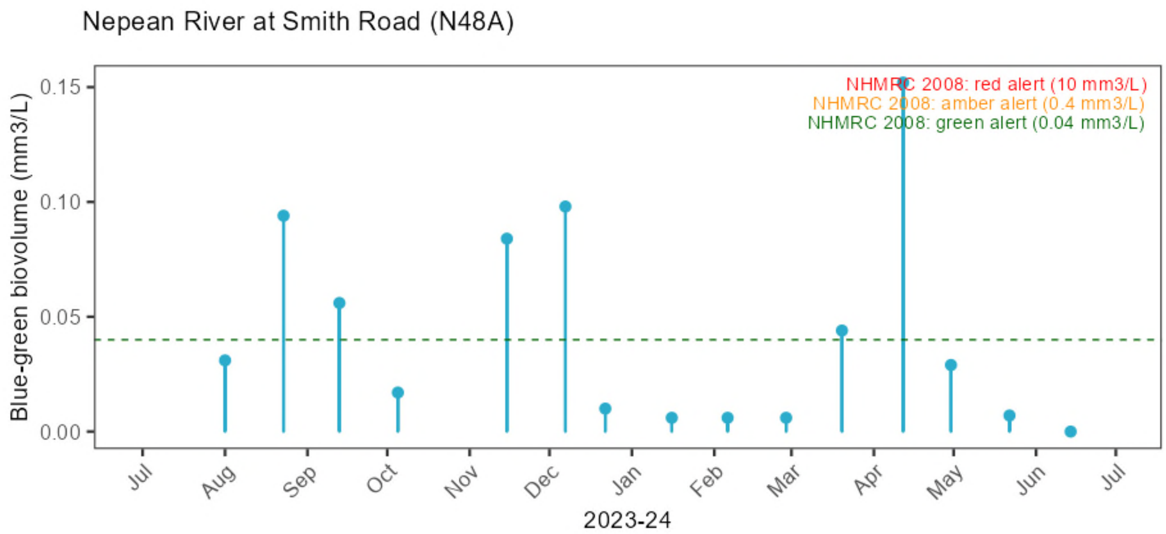
Total phytoplankton biovolumes at Smith Road Nepean River (N48A) were low to moderate with a maximum of 3.53 mm^3/L on 23 August 2023.

Diatoms were the dominant group in phytoplankton composition for most of 2023-24. Greens (Chlorophyta) and flagellated monads were also co-dominant. Blue-greens (Cyanophyte) were rarely present at this site.

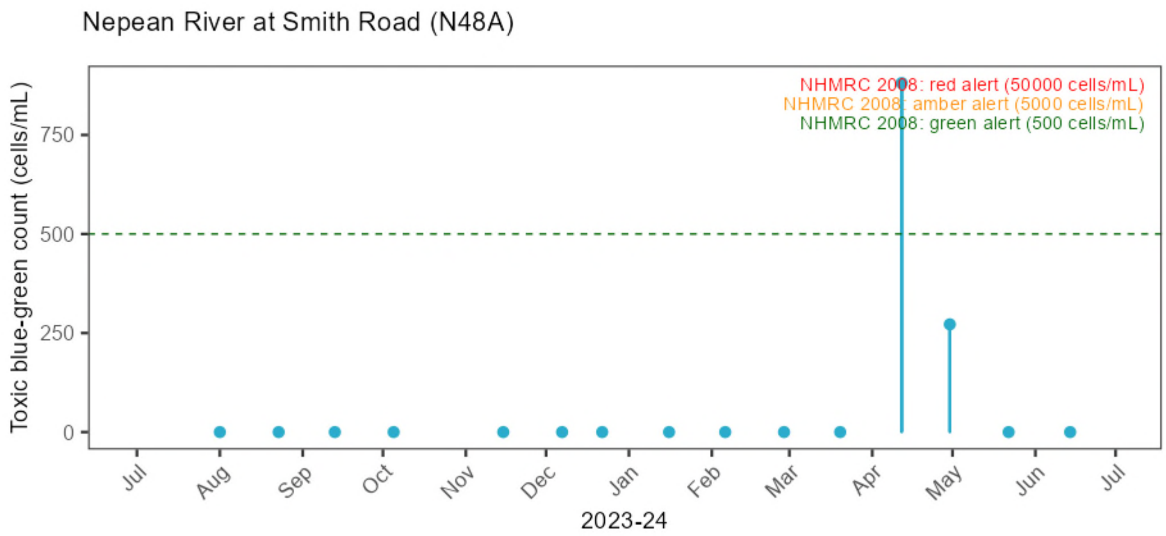
Blue-green (Cyanophyta) biovolume or toxic blue-green counts were low, not exceeding the NHMRC (2008) amber alert level on any occasion. Potentially toxic blue-green taxa *Microcystis* was found at this site twice (12 April 2024 and 30 April 2024) in low numbers (<1000 cells/mL).



Nepean River at Smith Road (N48A)
Total phytoplankton biovolume (mm3/L)
0
1
2
3
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24



Nepean River at Smith Road (N48A)
Blue-green biovolume (mm3/L)
0.00
0.05
0.10
0.15
NHMRC 2008: red alert (10 mm3/L)
NHMRC 2008: amber alert (0.4 mm3/L)
NHMRC 2008: green alert (0.04 mm3/L)
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
2023-24



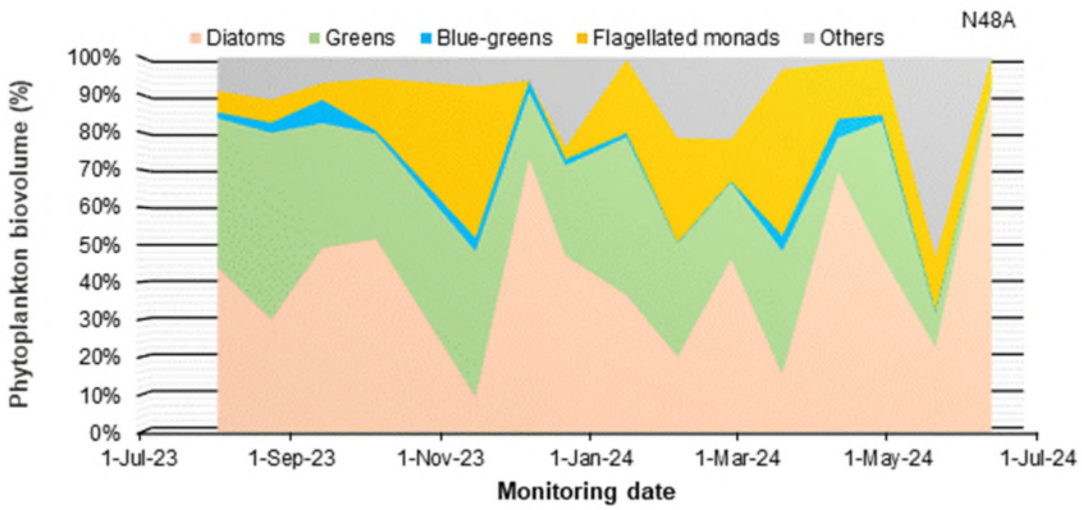


Figure 4-93 Phytoplankton biovolume and count plots, Nepean River at Smith Road (N48A)

N42: Hawkesbury River at North Richmond

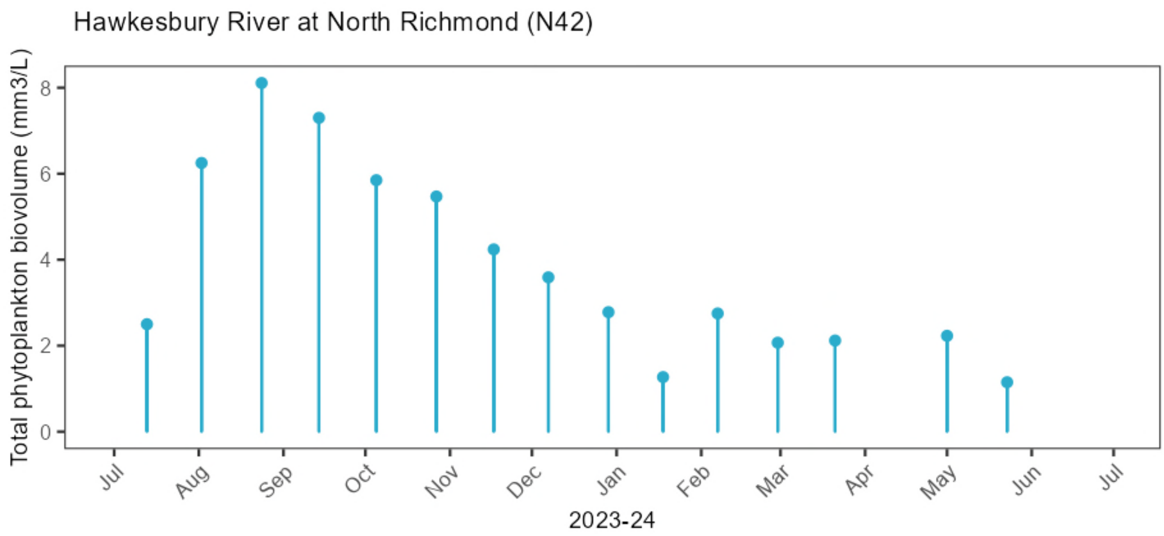
The Hawkesbury River at North Richmond (N42) also serves as the upstream control site for North Richmond WRRF discharges. It is the uppermost site on the Hawkesbury River, located immediately downstream of the confluence with the Grose River. The river widens and deepens from this point.

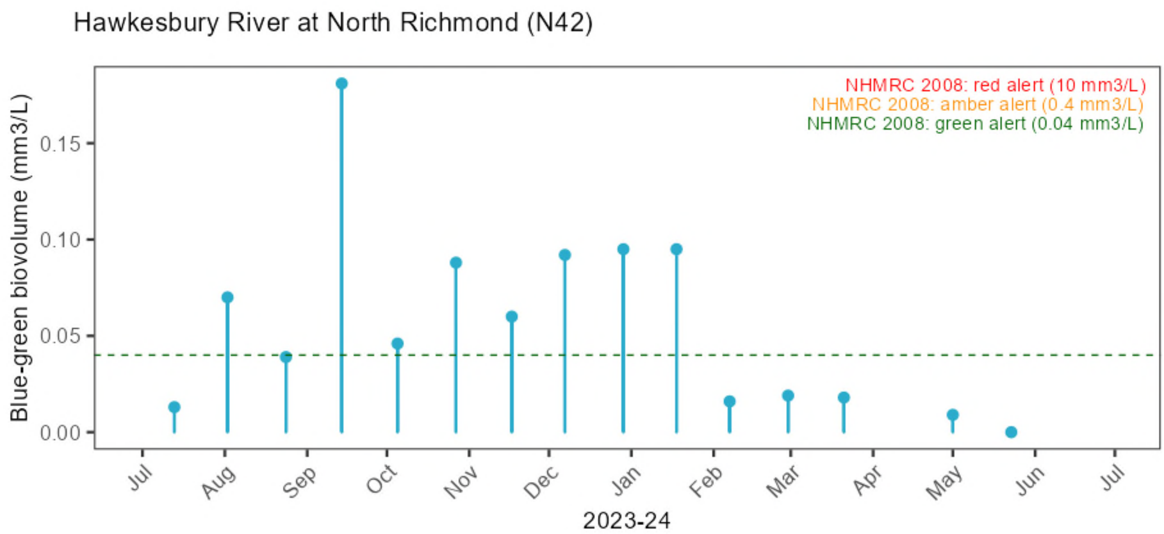
Total phytoplankton biovolume at North Richmond (N42) were generally elevated at the beginning of 2023-24 (July to October) and later eased, likely due to periodic washout by intermittent rainfall or wet weather.

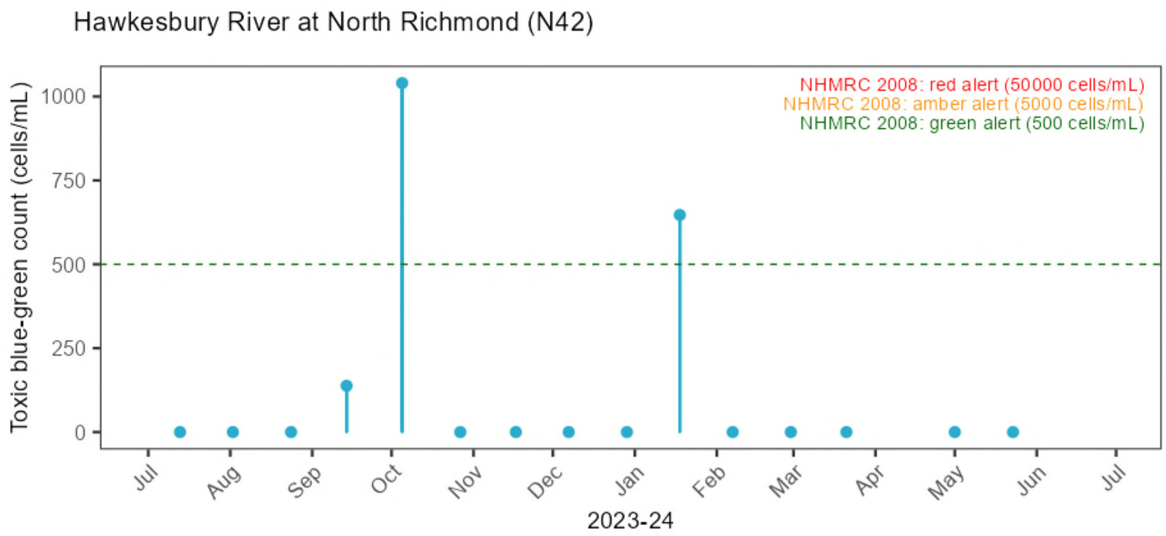
Total phytoplankton biovolume reached a maximum of 8.11 mm^3/L on 24 August 2023 when miscellaneous diatoms (Bacillariophyta) taxa were dominant.

Phytoplankton composition at N42 was mixed, mostly diatoms (Bacillariophyta) were dominant, but sometimes other groups succeeded intermittently. Blue-greens (Cyanophyte) were rarely present at this site.

Blue-green (Cyanophyta) biovolume or toxic blue-green counts were low, not exceeding the NHMRC (2008) amber alert level on any occasion. The potentially toxic blue-green taxa *Microcystis* reached a maximum of 1,037 cells/mL on 5 October 2023.







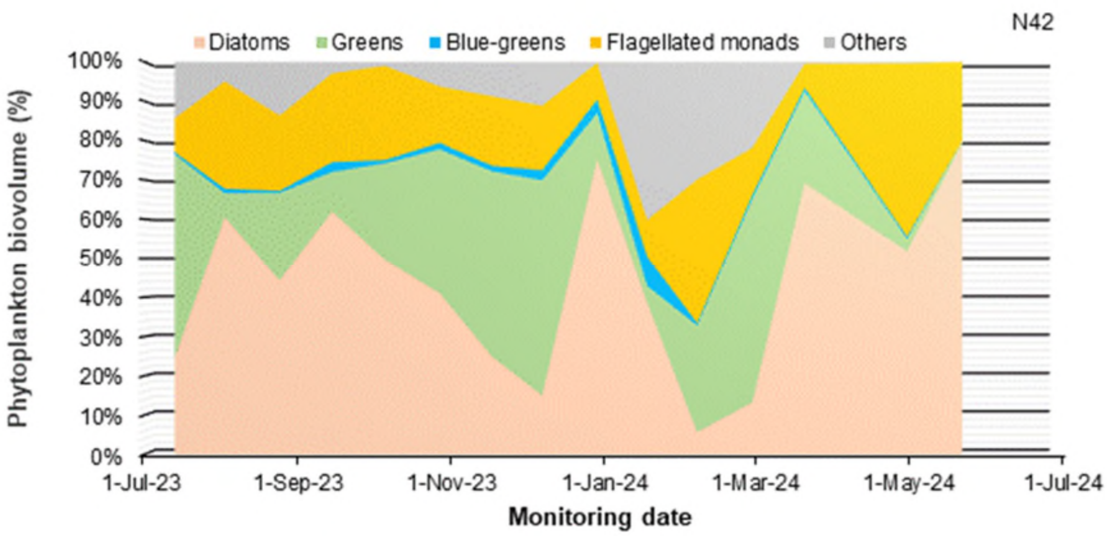


Figure 4-94 Phytoplankton biovolume and count plots, Hawkesbury River at North Richmond (N42)

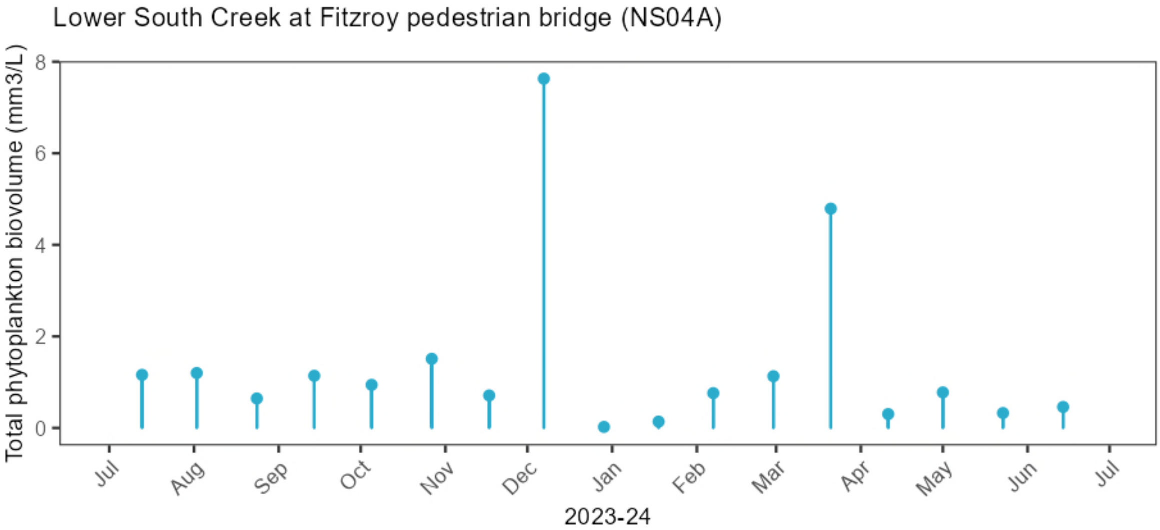
NS04A: Lower South Creek at Fitzroy Bridge

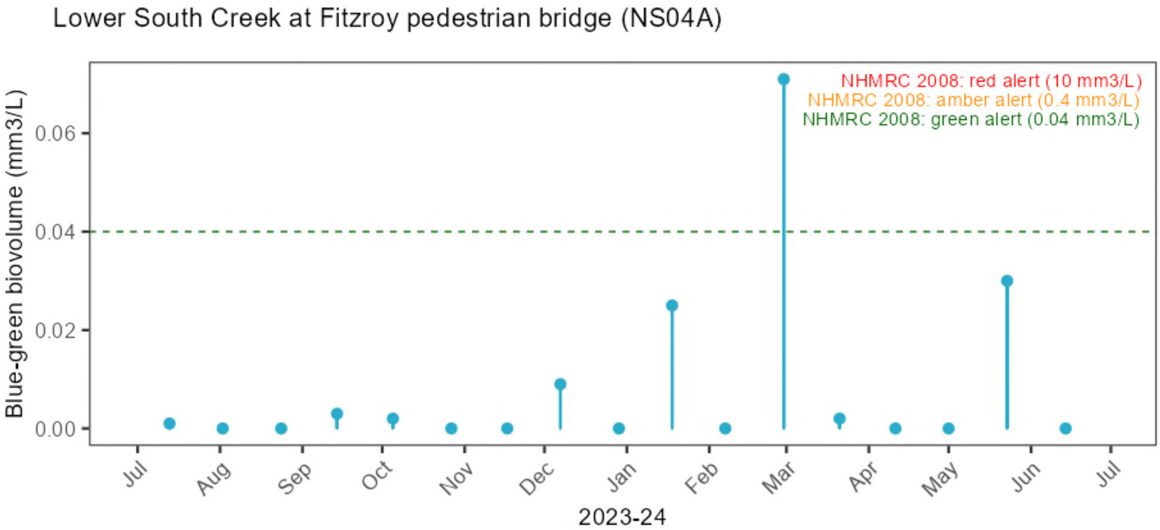
Lower South Creek (NS04A) is located at Fitzroy Bridge, about 2 km upstream of the confluence with the Hawkesbury River. Although the lower part of the creek is tidal, the water quality at this site is expected to represent the overall quality of South Creek before joining the river. The land along South Creek is used for rural applications, including grazing and market gardening, and intensive agriculture such as poultry farming. It also has both residential and industrial land uses that have increased in recent years. South Creek and its tributaries receive tertiary treated wastewater discharges from three Sydney Water WRRFs (St Marys, Riverstone and Quakers Hill) and two council STPs (McGraths Hill and South Windsor).

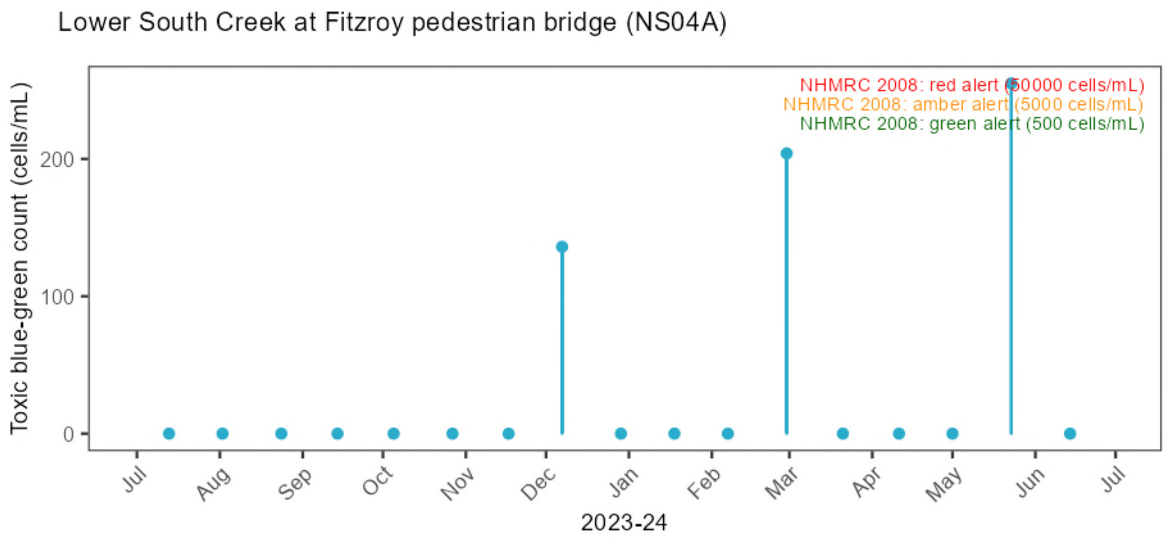
Total phytoplankton biovolume at Lower South Creek (NS04A) reached a maximum of 7.63 mm^3/L on 21 December 2023 when flagellated monads *Chroomonas* and *Cryptomonas* were present in moderate numbers (68 cells/mL and 3,743 cells/mL, respectively).

Flagellated monads were the dominant group of phytoplankton at this site for most of 2023-24. This creek site was usually more turbid than any other main river or creek site, thus giving an advantage to these motile phytoplankton taxa that can position themselves on the surface for light or move around the water column to scavenge nutrients. Blue-greens (Cyanophyte) were rarely present at this site.

Blue-green (Cyanophyta) biovolume or toxic blue-green counts were low, not exceeding the NHMRC (2008) amber alert level on any occasion. Potentially toxic blue-green taxa were found at this site on three occasions in low numbers: *Microcystis* on 7 December 2023 (136 cells/mL), *Planktothrix* on 29 February 2024 (204 cells/mL) and *Aphanizomenonaceae* on 23 May 2024 (255 cells/mL).







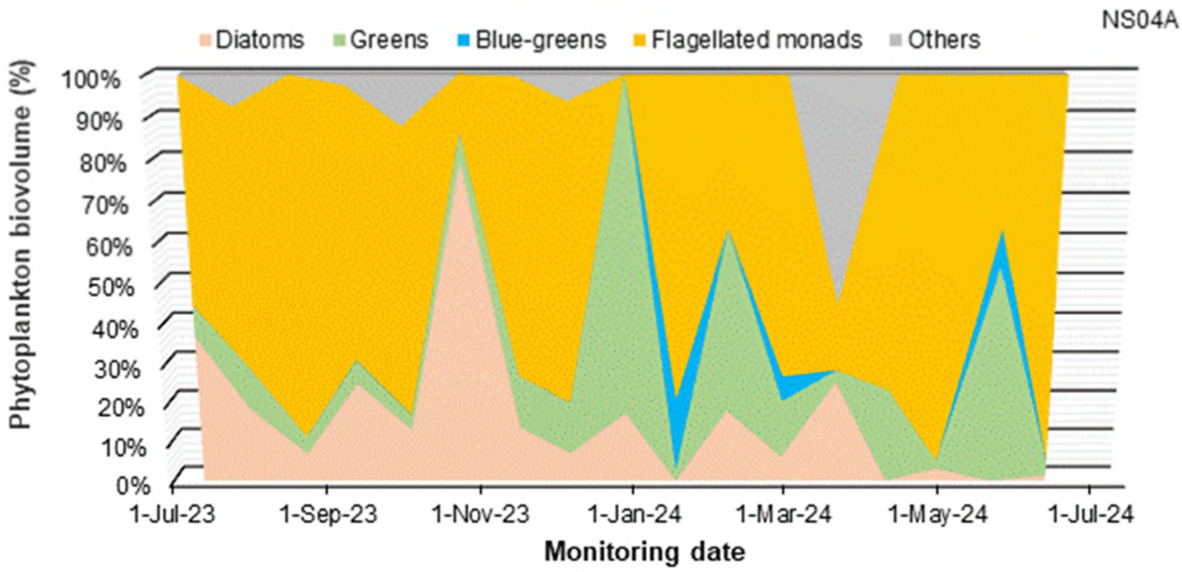


Figure 4-95 Phytoplankton biovolume and count plots, Lower South Creek (NS04A)

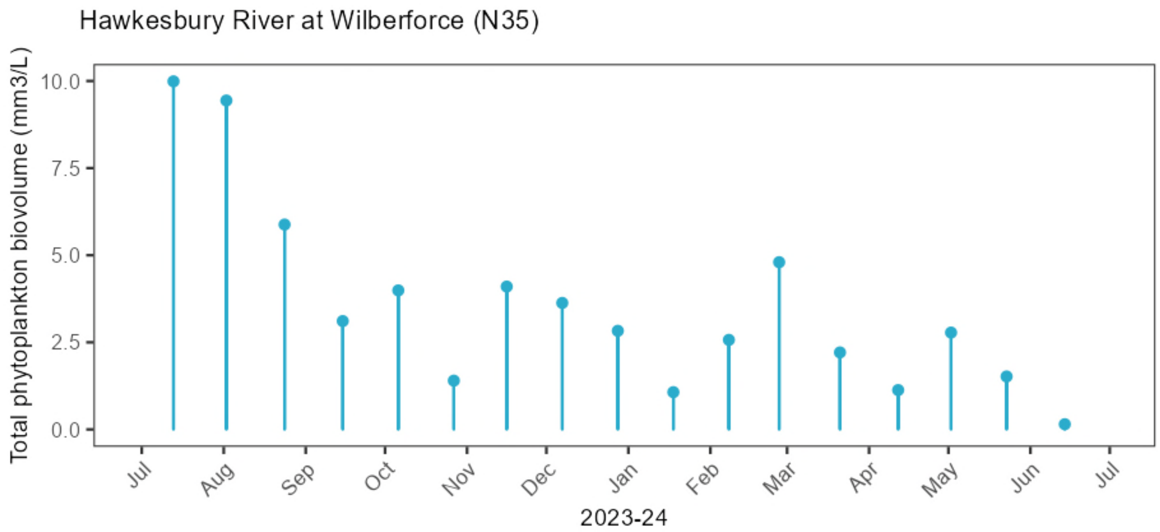
N35: Hawkesbury River at Wilberforce

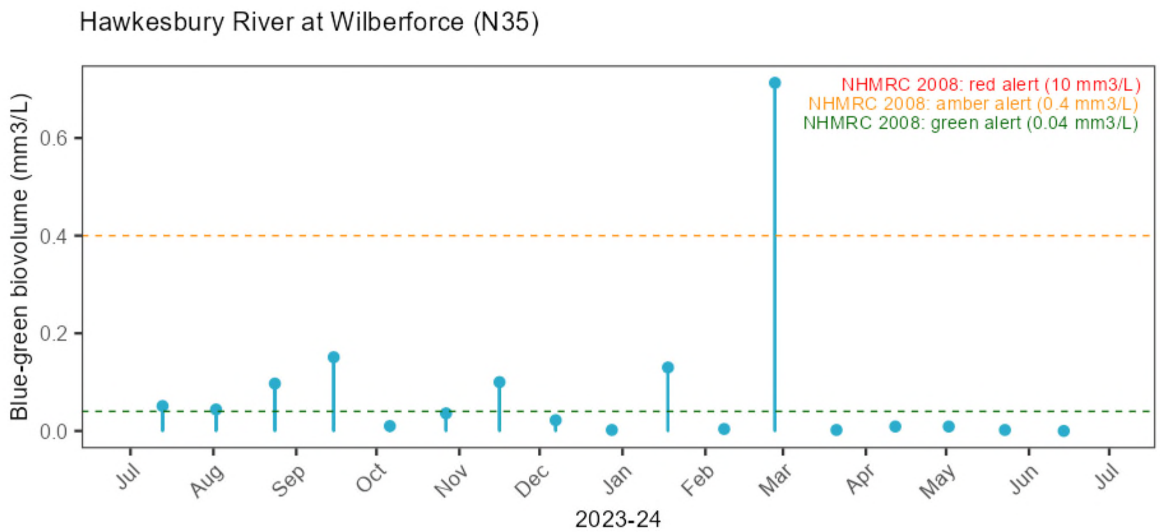
The Hawkesbury River site at Wilberforce (N35) is located about 5 km downstream of the confluence with South Creek. Water quality at this site is affected by the quality and magnitude of flows coming from South Creek. Historically, there have been water quality concerns at this site due to elevated nutrient concentrations, chlorophyll-a and phytoplankton blooms, especially potentially toxic blue-green blooms. The width and depth of the river, combined with the high nutrients, tidal influence and long residence time has made it prone to phytoplankton blooms in the past.

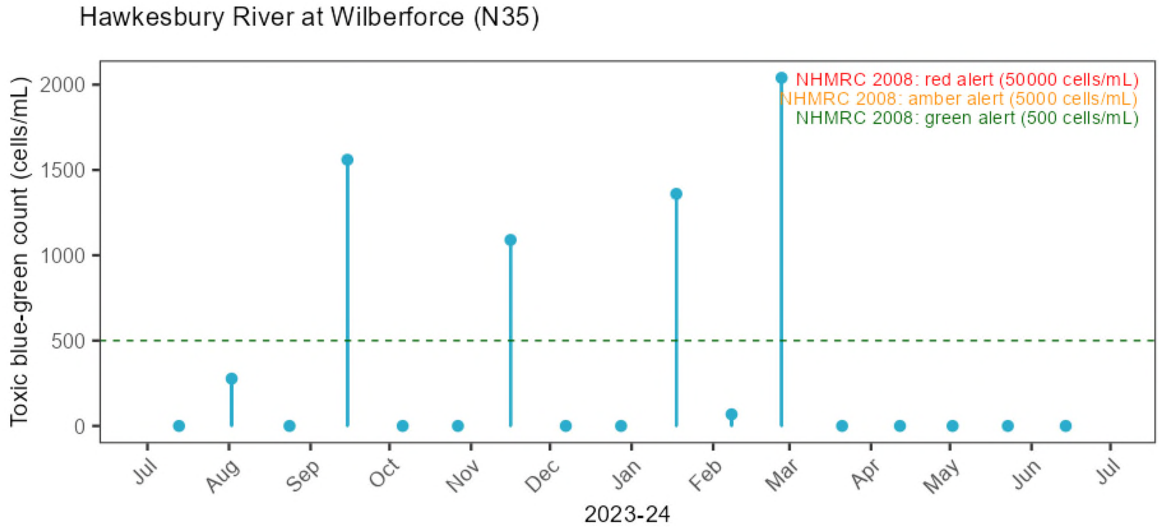
Total phytoplankton biovolumes at Hawkesbury River at Wilberforce (N35) were elevated at the beginning of 2023- 24, reaching a maximum of 9.99 mm^3/L on 13 July 2023 when miscellaneous diatoms (Bacillariophyta) taxa were dominant.

Phytoplankton taxa composition at this site was mixed, mostly diatoms (Bacillariophyta) were dominant, and other groups succeeded intermittently. Blue-greens (Cyanophyte) were present but not dominating in terms of phytoplankton biovolume.

Blue-greens (Cyanophyta) biovolume exceeded the NHMRC (2008) amber alert level on 27 February 2024. The amber alert level was not exceeded for toxic blue-green counts, but potentially toxic taxa were present in moderate numbers on four of 17 occasions: *Aphanizomenonaceae* and *Microcystis* on 15 September 2023 (1,571 cells/mL), *Microcystis* on 16 November 2023 (1,089 cells/mL), *Dolichospermum* on 18 January 2024 (1,361 cells/mL) and *Planktothrix* on 27 February 2024 (2,039 cells/mL).







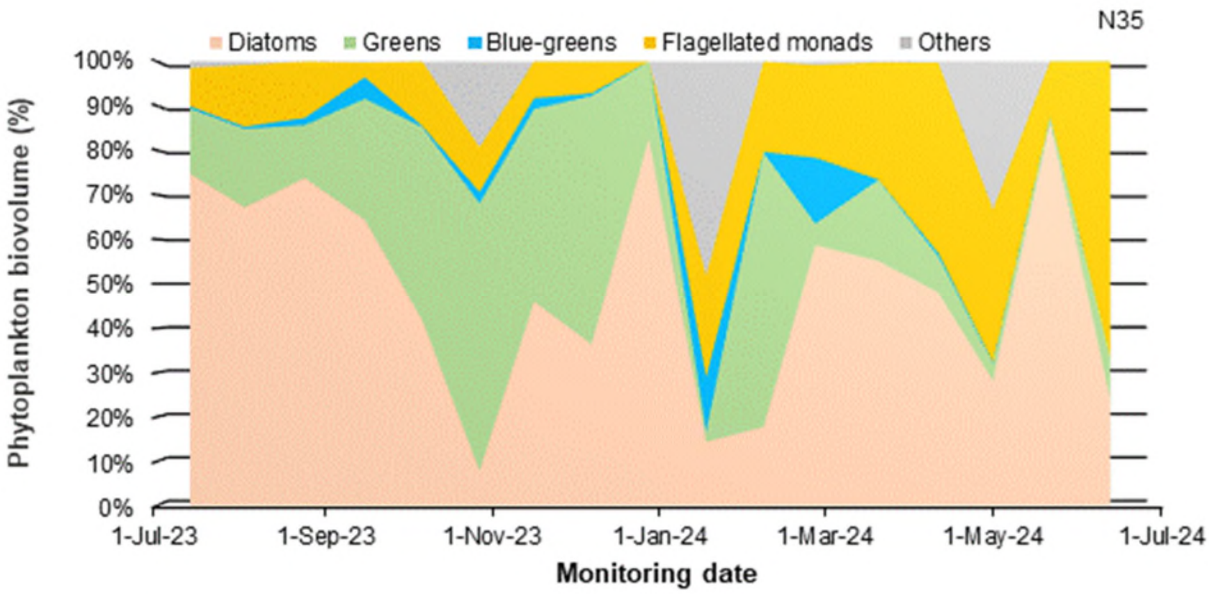


Figure 4-96 Phytoplankton biovolume and count plots, Hawkesbury River at Wilberforce (N35)

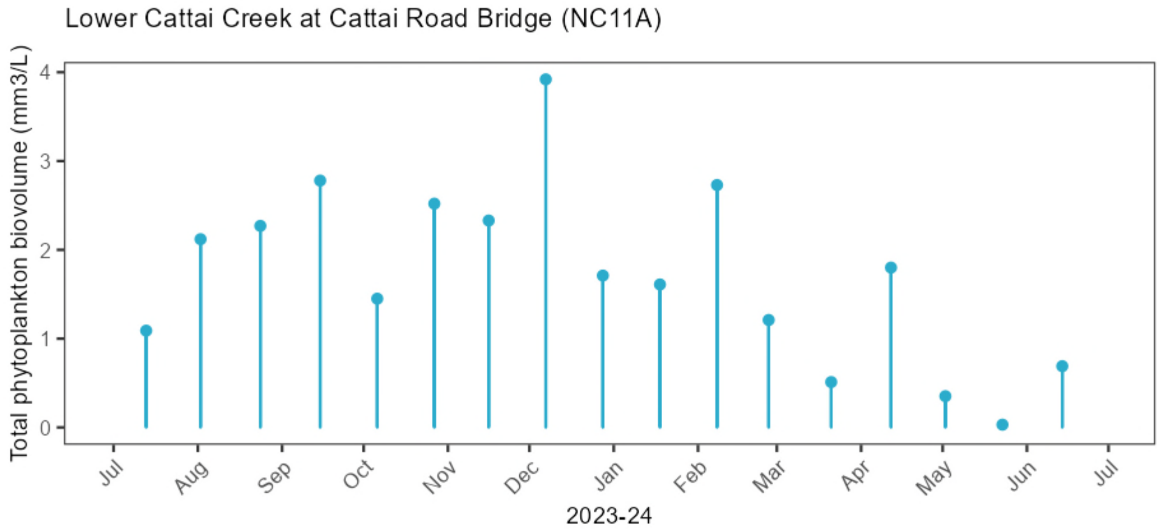
NC11A: Lower Cattai Creek at Cattai Ridge Road

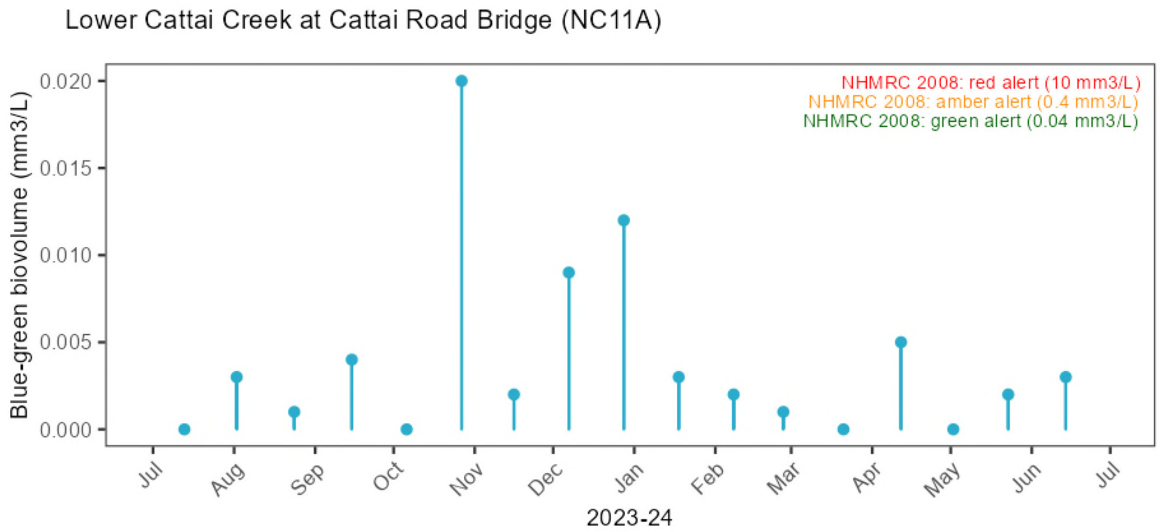
Lower Cattai Creek at Cattai Ridge Road (NC11A) is a major tributary of the Hawkesbury River, draining one of the fastest growing urban catchments of Sydney. The upper Cattai Creek catchment land use influences consist of new urban development and light industrial activities. Further down the catchment, land is used for rural and agricultural purposes. Two Sydney Water WRRFs (Castle Hill and Rouse Hill) operate in the Cattai Creek catchment. The Rouse Hill WRRF discharges via a constructed wetland or bypassing directly to Second Ponds Creek, a tributary of Cattai Creek. Castle Hill WRRF discharges directly to upper Cattai Creek. This water quality monitoring site is located at Cattai Ridge Road, about 7 km upstream of the confluence with the Hawkesbury River.

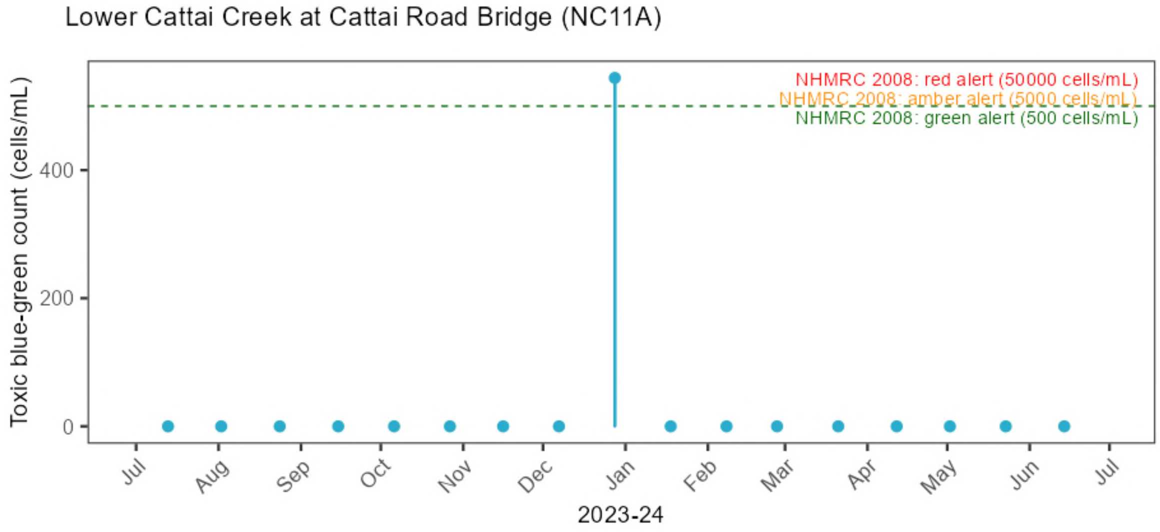
Total phytoplankton biovolumes at Cattai Creek (NC11A) were low to moderate and reached a maximum of 3.92 mm^3/L on 7 December 2023 when flagellated monads *Chroomonas* and *Cryptomonas* were present in moderate numbers (5,172 cells/mL and 885 cells/mL, respectively).

Flagellated monads were the dominant group of phytoplankton at this site for most of the 2023-24 period. This site is more turbid than any other main river site, thus giving an advantage to these motile phytoplankton taxa that can position themselves at the surface for light or move around the water column to scavenge nutrients. Diatoms (Bacillariophyta) and Greens (Chlorophyta) were also co-dominant. Blue-greens (Cyanophyte) were rarely present at this site.

Blue-green (Cyanophyta) biovolume or toxic blue-green counts were low, not exceeding the NHMRC (2008) amber alert level on any occasion. Potentially toxic blue-green taxa *Microcystis* reached a maximum of 544 cells/mL.







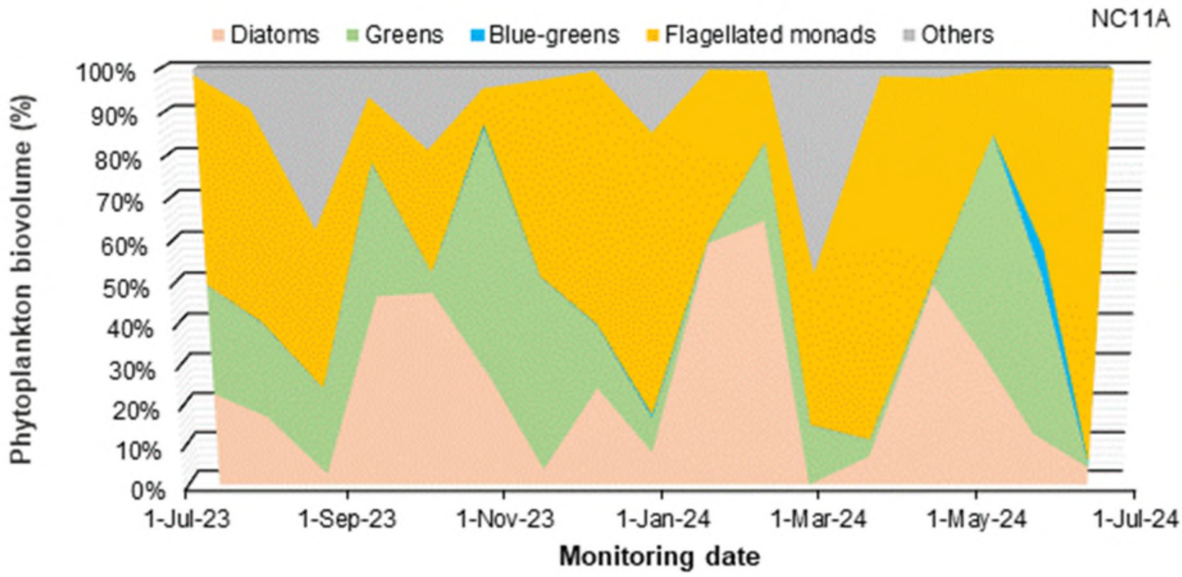


Figure 4-97 Phytoplankton biovolume and count plots, Lower Cattai Creek (NC11A)

N26: Hawkesbury River at Sackville Ferry

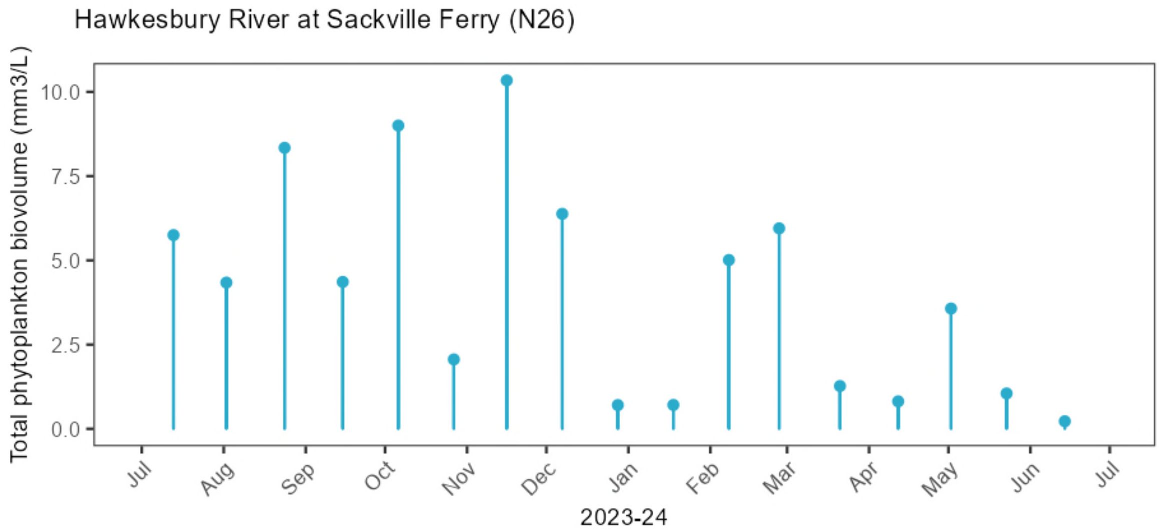
Hawkesbury River at the Sackville Ferry (N26) is located about 18 km downstream of the Cattai Creek confluence with the Hawkesbury River. Historically, this site has had the highest incidences of phytoplankton blooms, especially toxic blue-greens species.

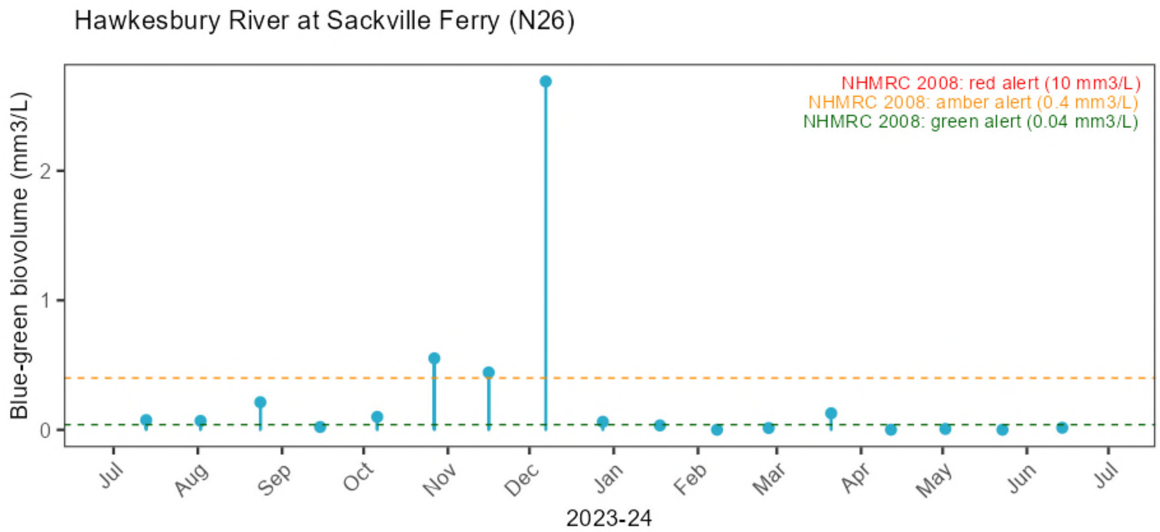
Total phytoplankton biovolume at Hawkesbury River at Sackville Ferry (N26) was generally elevated during the first half of 2023-24, reaching a maximum of 10.34 mm^3/L on 16 November 2023 when miscellaneous Greens (Chlorophyta) taxa were dominant.

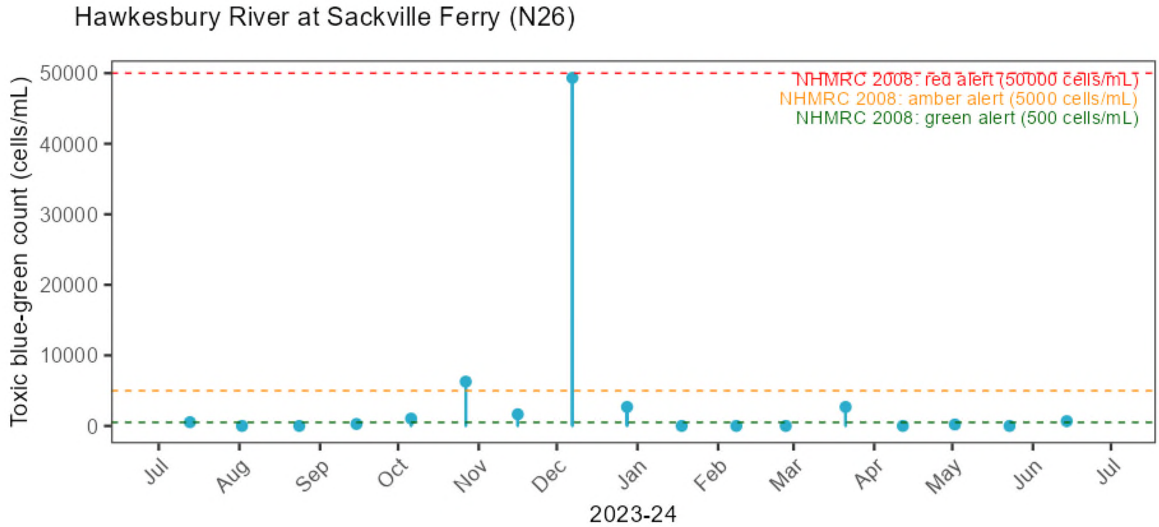
Phytoplankton composition was mixed, mostly diatoms (Bacillariophyta) or Greens (Cyanophyta) were dominant, and other groups succeeded intermittently. Blue-greens (Cyanophyte) were moderately present at this site.

Blue-green (Cyanophyta) biovolumes exceeded the NHMRC (2008) amber alert level on three occasions, reaching a maximum of 2.69 mm^3/L on 7 December 2023 when miscellaneous phytoplankton including toxic taxa were present.

Potentially toxic blue-green counts exceeded the NHMRC (2008) amber alert level twice and reached close to the red alert level on 7 December 2023 (49,393 cells/mL), when potentially toxic blue-green taxa *Dolichospermum circinale* (391 cells/mL), *Microcystis* (38,501 cells/mL), *Phormidium* (714 cells/mL) and *Radiocystis* (9,737 cells/mL) were present.







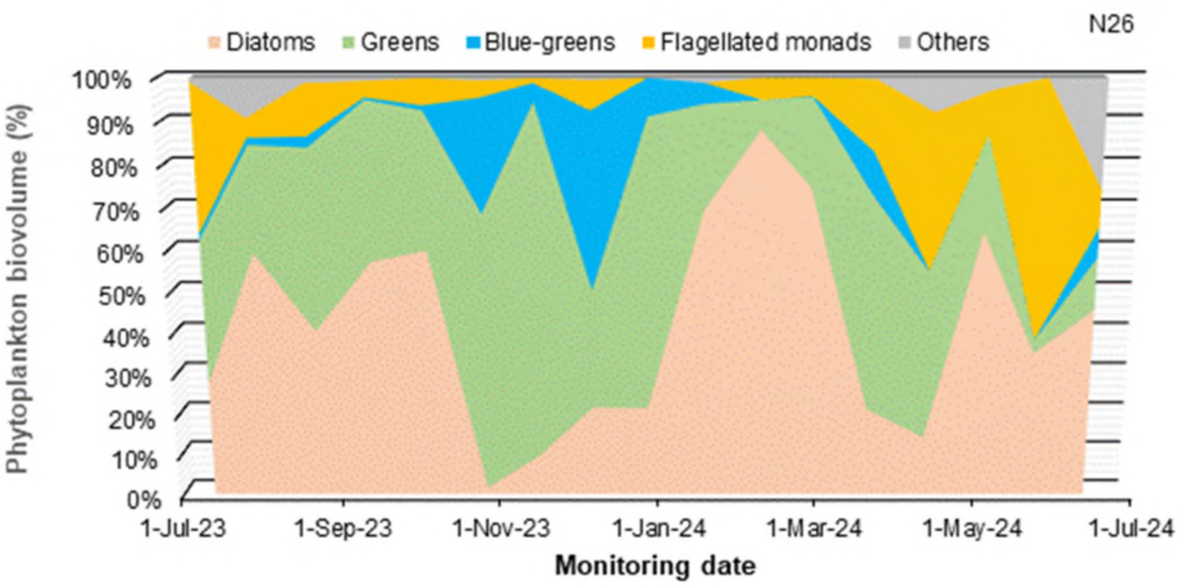


Figure 4-98 Phytoplankton biovolume and count plots, Hawkesbury River at Sackville Ferry (N26)

NB11: Berowra Creek off Square Bay

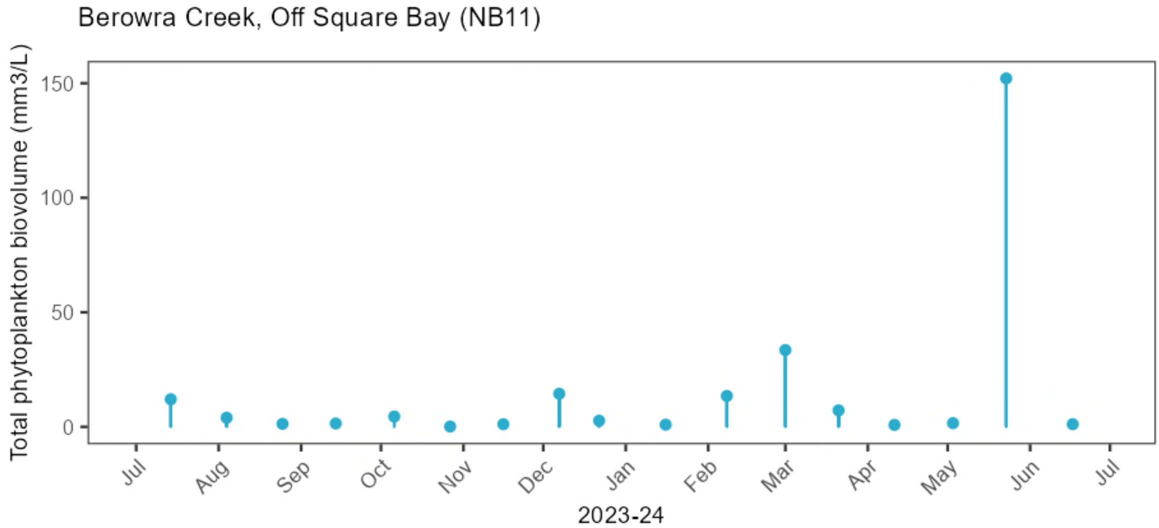
Berowra Creek off Square Bay (NB11) is located at Oaky Point in the Berowra estuary of the Hawkesbury River. This site is strongly influenced by tidal movement and cycles. The other influences include urban run-off, run-off from unsewered areas, agricultural cultivation involving fertiliser use, bushland and two Sydney Water WRRFs (West Hornsby and Hornsby Heights).

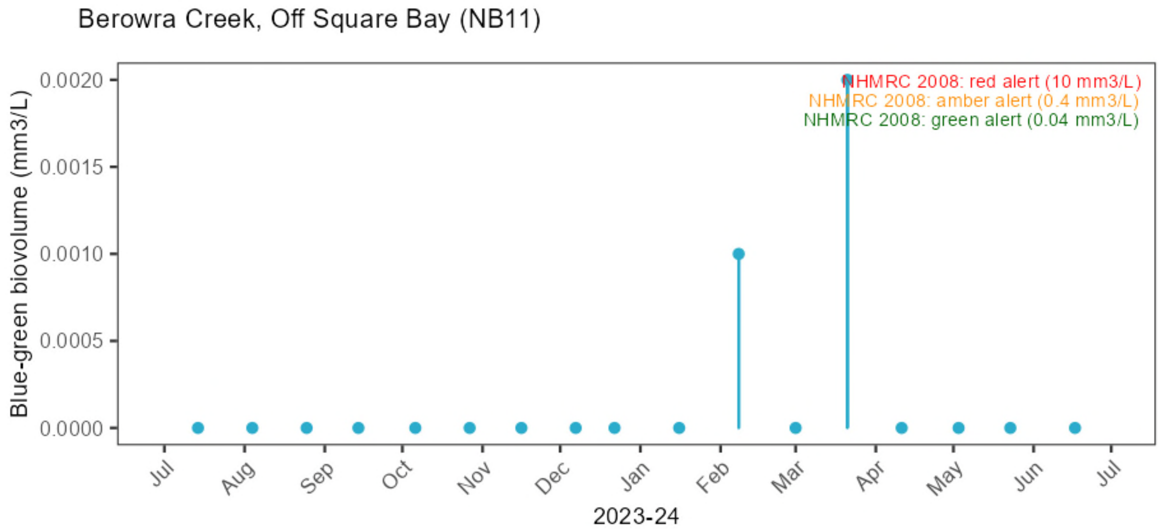
Total phytoplankton biovolumes at the estuarine site of Berowra Creek (NB11) were often much higher than any other freshwater site, with corresponding larger sized phytoplankton taxa present. Total phytoplankton biovolumes reached a maximum of 152.14 mm^3/L on 23 May 2024 when Diatoms (Bacillariophyta) *Chaetoceros* was present in high numbers (77,736 cells/mL).

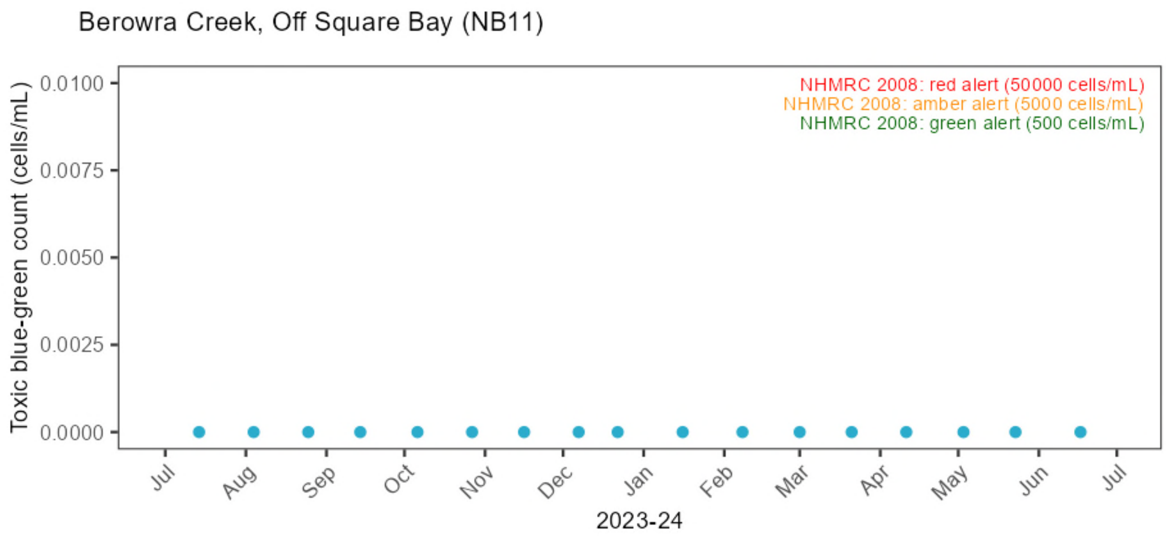
Diatoms (Bacillariophyta) were the dominant group of phytoplankton taxa that sustained at Berowra Creek and were sometimes succeeded by other types of phytoplankton e.g.

Dinoflagellates (Dinophyta). Some species of diatoms and dinoflagellates are potentially toxic when phytoplankton blooms form. These toxic taxa were present in 11 of 17 samples analysed in 2023-24. The highest number of these toxic species were identified on 1 March 2024, *Heterocapsa* (726 cells/mL) and *Prorocentrum minimum* (68 cells/mL).

Blue-green algae (Cyanophyta) were found in two of 17 samples in very low numbers.







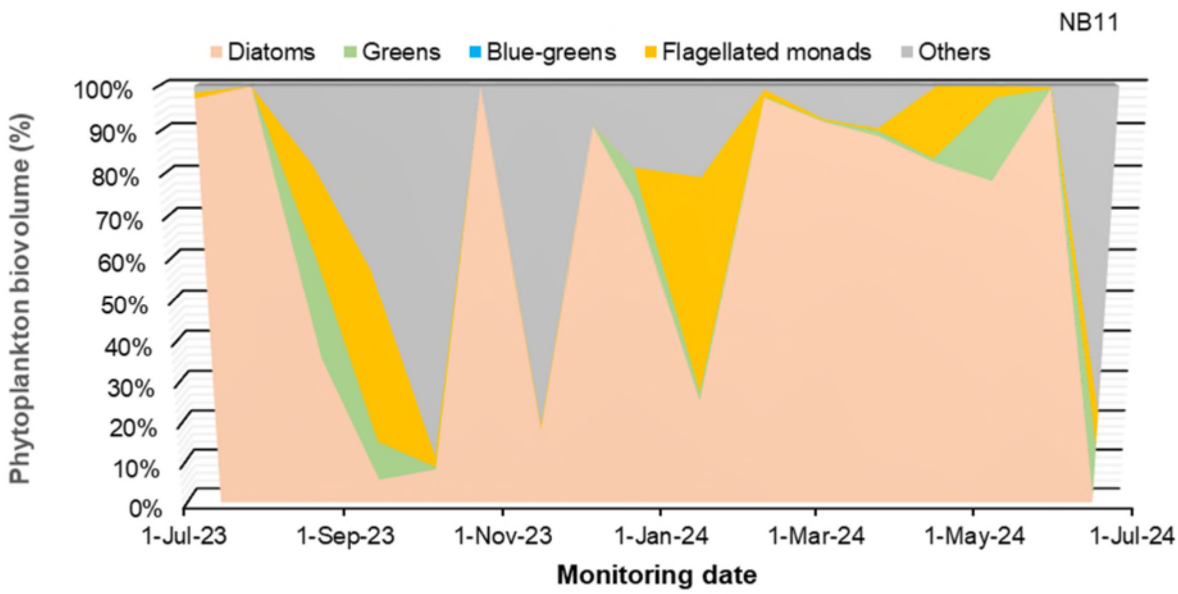


Figure 4-99 Phytoplankton biovolume and count plots at Berowra Creek off Square Bay (NB11)

4.3.3. Freshwater reference sites – Water quality and ecosystem health

For macroinvertebrates, almost all sites across the reference sites of Port Jackson and Georges River were within the 'natural water quality' range for ecosystem health. All sites were also typical of the stream health that has been recorded for these sites over the previous 1995 to 2024 period (Volume 2, Appendix C-3).

Water quality plots for these sites are included in Volume 2, Appendix C-3.

4.4. Nearshore marine environment

The treated wastewater discharged from the nearshore, cliff face and shoreline marine environment discharging WRRFs in 2023-24 and the population serviced by these WRRFs are shown in Table 4-74.

This section contains a summary of exceptions for the nearshore marine environment discharging WRRFs.

Trend plots of discharge volume and catchment specific rainfall are presented first, and then reuse volume where applicable. This is followed by load limit plot where there was an exceedance of an annual EPL limit during the 2023-24 monitoring period.

Trend plots showing the concentration of analytes in the discharge are only presented where they exceeded the respective annual EPL limit for a WRRF during the 2023-24 monitoring period, or there was a significant increase/decrease in concentrations in 2023-24 in comparison to earlier years.

All trend plots showing the analyte concentration and load data for nearshore marine WRRFs, including applicable EPL limits, can be found in Volume 2 Appendix D.

An electronic appendix file which includes a summary of results for all nearshore marine WRRFs by year has been provided to the EPA (December 2024).

Plots and multivariate statistical outcomes for nearshore macroalgae and macroinvertebrates (Shellharbour WRRF outfall) can be found in Volume 2 Appendix D-5.5. Macroinvertebrate community data have been provided to the EPA in electronic appendix files (December 2024).

Table 4-74 Nearshore marine environment WRRFs operated by Sydney Water

WRRFs	Treatment level	Discharge 2023-24 (ML/year)[a]	Projected population 2023-24[b]	Discharge location
Warriewood	Secondary with disinfection	7,417	74,859	Ocean outfall Turimetta Head
Vaucluse & Diamond Bay (Bondi)	No treatment	1,615	0*	Cliff face outfalls
Cronulla	Tertiary with disinfection	24,545	245,564	Ocean outfall Potter Point, Kurnell
Wollongong	Tertiary with disinfection	18,433	211,601	Ocean outfall Coniston Beach
Bellambi**	Primary	1,262	0*	Near shore
Port Kembla**	Primary	1,279	0*	Shoreline
Shellharbour	Secondary with disinfection	9,343	82,452	Ocean outfall 130 m from Barrack Point with diffuser zone
Bombo	Secondary, denitrification with disinfection	2,142	16,112	Ocean outfall Bombo Point

a Discharge volume excludes onsite and offsite reuse.
b Projected populations (at 30 June 2023) are based on forecasts by the Australian Bureau of Statistics and the DCCEEW.
**WRRFs not directly servicing any households.*
***Part of Wollongong system. Treated wastewater is discharged during wet weather only.*

4.4.1. Warriewood WRRF

- All parameters (concentrations and loads) in the discharge from Warriewood WRRF were within EPL limits in 2023-34. There were no significant trends observed in pollutant concentrations in the discharge compared to the previous nine years.

Pressure – Wastewater discharge

Table 4-75 Gate 1 Analysis outcome summary – Warriewood WRRF

Analytes / Warriewood WRRF	Nutrients		Conventional analytes					Trace Metals		Other	
	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Cyanide	Nonyl phenol ethoxylate
Concentration				→		→	→	→	→	→	→
Load											

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the Warriewood WRRF discharge were within the EPL limits during the 2023-24 reporting period.

Statistical analysis identified no significant trends in pollutant concentrations in 2023-24 compared to the previous nine years.

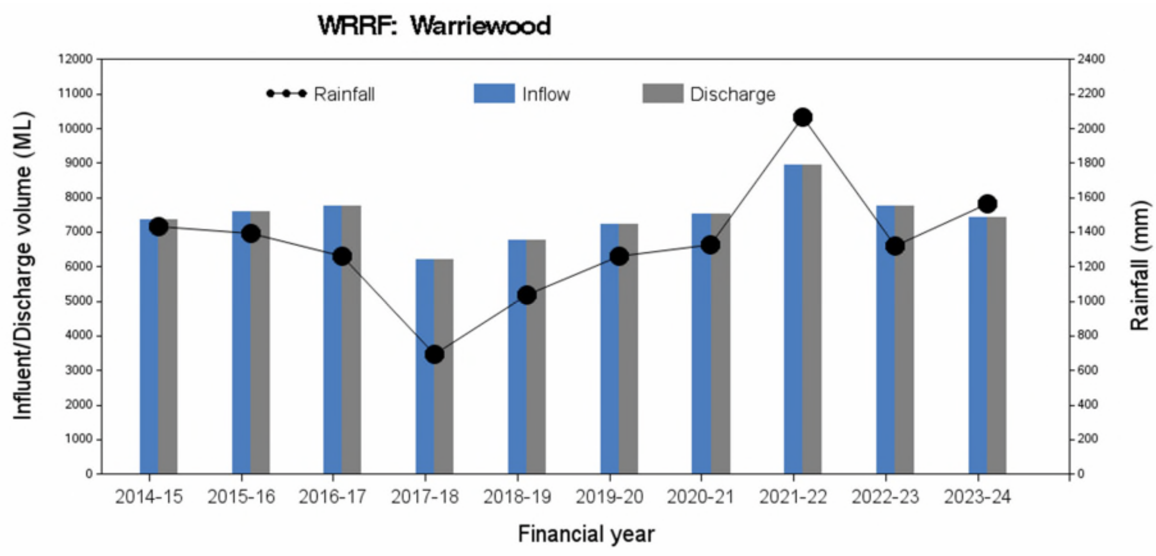
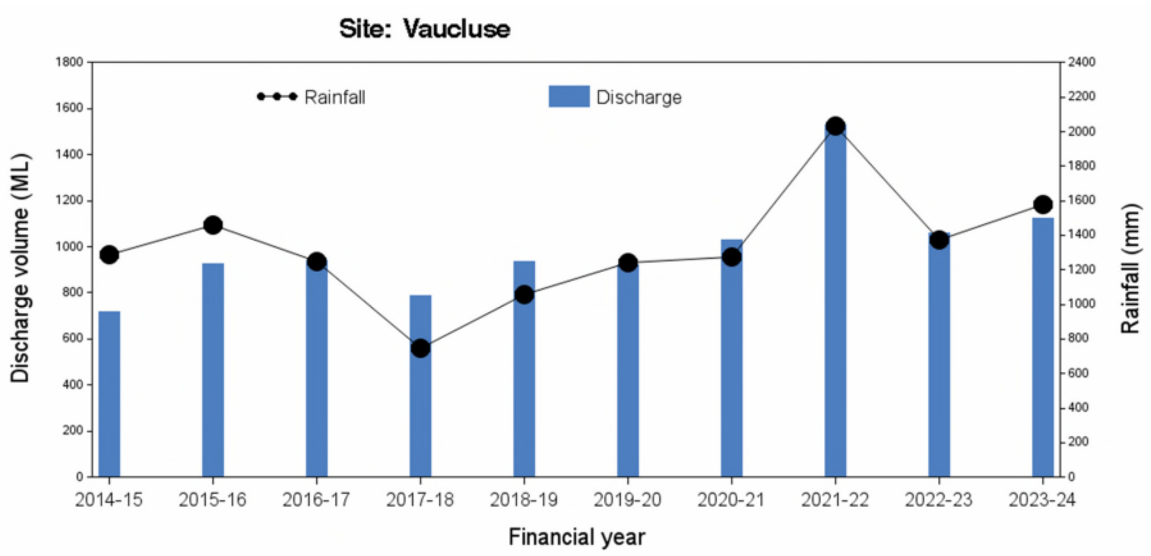


Figure 4-100 Warriewood WRRF inflow and discharge volume with catchment rainfall

4.4.2. Bondi WRRF (nearshore discharges, Vaucluse and Diamond Bay)

Pressure – Wastewater discharge

The majority of Sydney's wastewater (99%) is treated at water resource recovery facilities before being released to the environment. The exceptions are Vaucluse and Diamond Bay where untreated wastewater is discharged from cliff face outfalls. Sydney Water is in the process of redirecting wastewater during dry weather and small rain events (<10mm) from Vaucluse (Parsley Bay) and Diamond Bay discharges to the existing Bondi network for treatment at Bondi WRRF and subsequent offshore discharge via the deepwater ocean outfall.



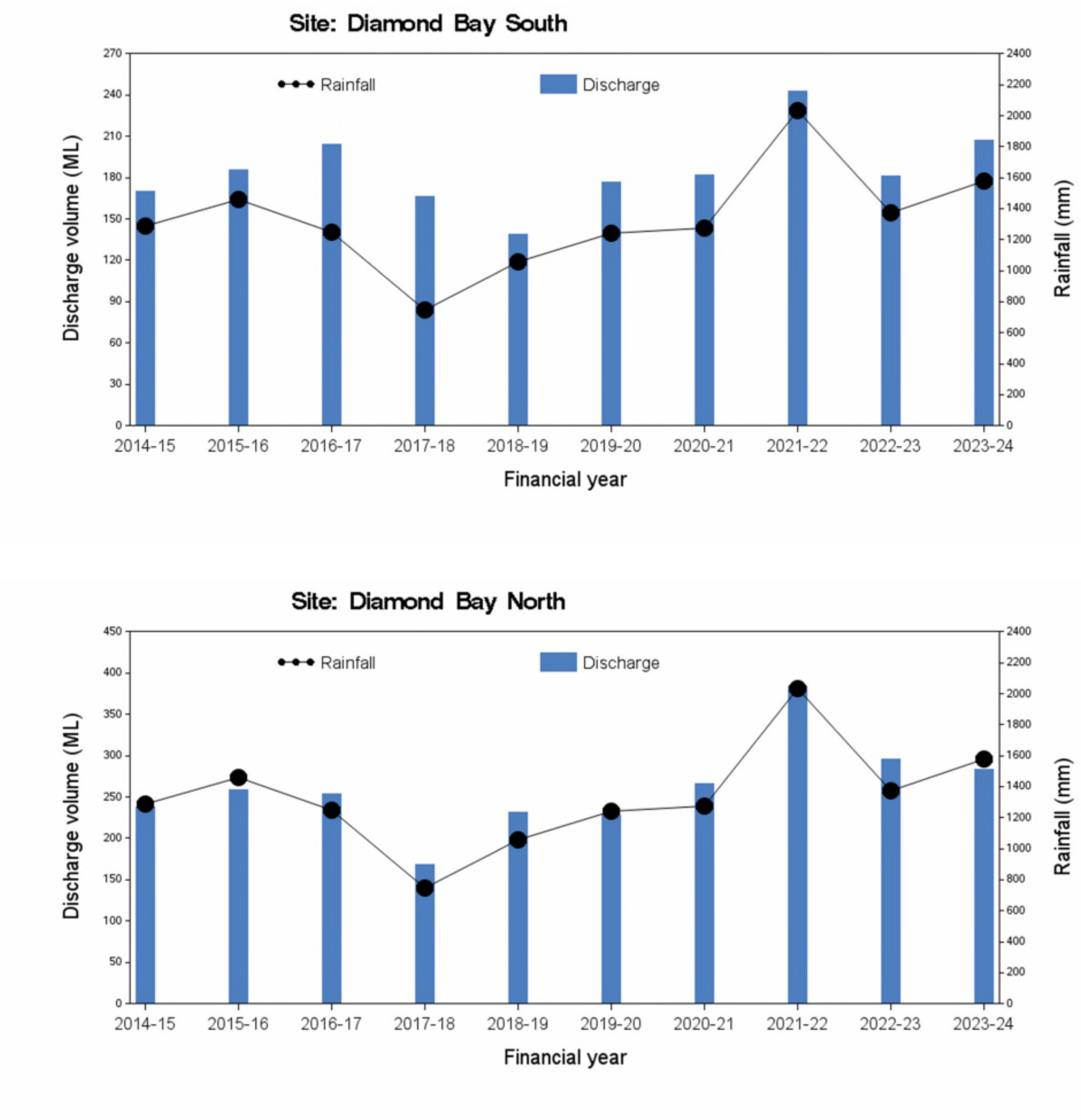


Figure 4-101 Bondi nearshore discharge volumes (Vaucluse and Diamond Bay) with catchment rainfall

4.4.3. Cronulla WRRF

- All parameters (concentrations and loads) in the discharge from Cronulla WRRF were within EPL limits in 2023-24. There were no significant trends observed in pollutant concentrations in the discharge compared to the previous nine years.

Pressure – Wastewater discharge

Table 4-76 Gate 1 Analysis outcome summary – Cronulla WRRF

Analytes / Cronulla WRRF	Nutrients			Conventional analytes				
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration	→			→	→	→	→	→
Load								

Analytes / Cronulla WRRF	Trace Metals								Other					
	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Chlorpyrifos	Cyanide	Diazinon	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Concentration	→			→				→	→	→	→	→	→	
Load														

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the Cronulla WRRF discharge were within the EPL limits during the 2023-24 reporting period.

Statistical analysis identified no significant trends in pollutant concentrations in 2023-24 compared to the previous nine years.

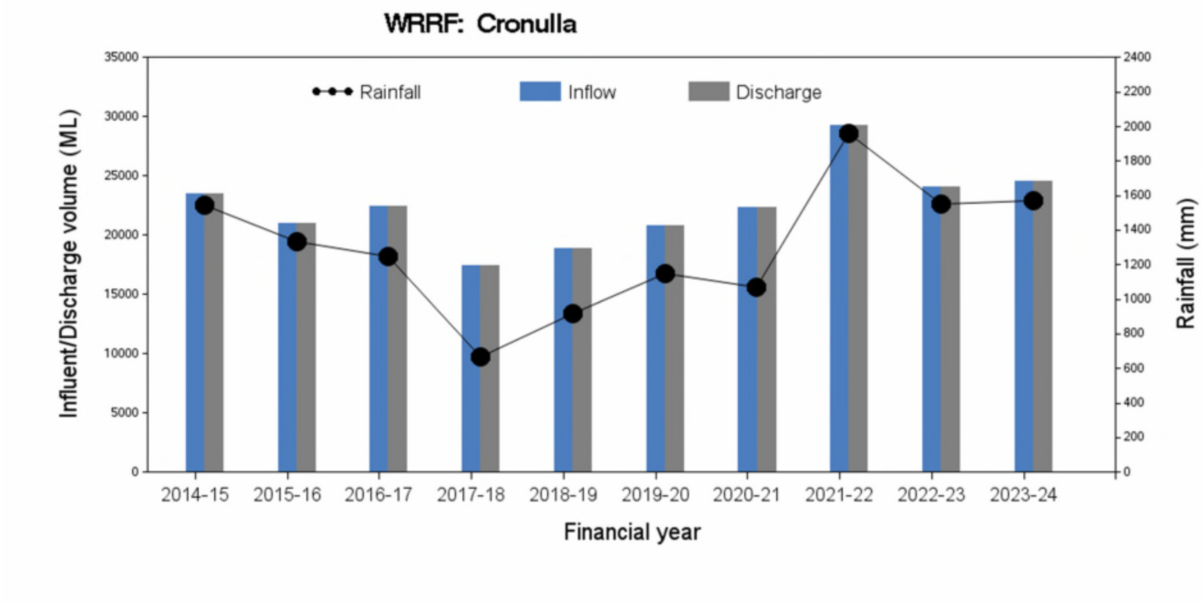


Figure 4-102 Cronulla WRRF inflow and discharge volume with catchment rainfall

4.4.4. Wollongong WRRF

- Biochemical oxygen demand and total suspended solid EPL load limits were exceeded in the discharge from Wollongong WRRF during 2023-24. All other parameters (concentrations and loads) were within EPL limits. There were increasing trends in biochemical oxygen demand and total suspended solids concentrations, and a decreasing trend in copper concentration in the discharge compared to previous years.

Pressure – Wastewater discharge

Table 4-77 Gate 1 Analysis outcome summary –Wollongong WRRF

Analytes / Wollongong WRRF	Nutrients		Conventional analytes			Trace Metals		Other	
	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Oil and grease	Total suspended solids	Aluminium	Copper	Diazinon	Hydrogen sulfide (un-ionised)
Concentration			↗		↗	→	↘	→	→
Load			EPL limit exceedance		EPL limit exceedance				

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
(orange)	EPL limit exceedance	(white)	Within EPL limit	(grey)	Analyte not required in EPL or no concentration limit

All concentrations in the discharge from Wollongong WRRF were within EPL limits during the 2023-24 reporting period. The biochemical oxygen demand and total suspended solids load limits were exceeded during the 2023-24 reporting period. All other load values were within EPL limits.

Statistical analysis identified a significantly increasing trend in biochemical oxygen demand concentration in 2023-24 compared to the previous three years. A significantly increasing trend in total suspended solids concentration and a significantly decreasing trend in copper concentration in 2023-24 was identified compared to the previous nine years.

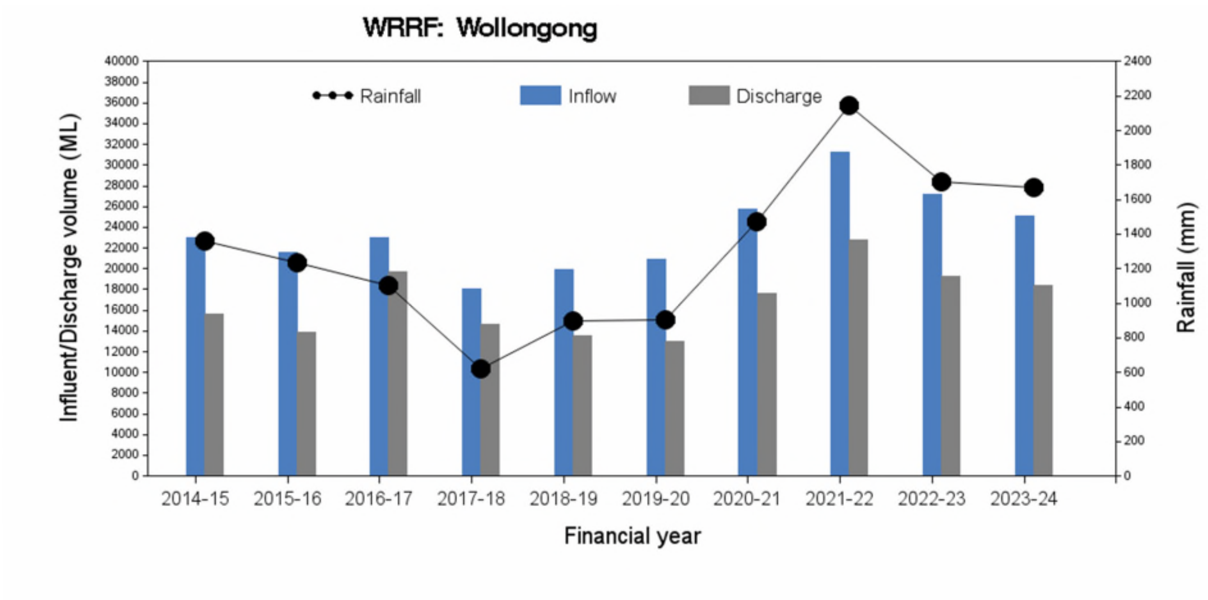
The increasing trends in biochemical oxygen demand concentration and total suspended solids can be attributed to catchment growth and a continuation of wet weather patterns within the reporting year, resulting in increased facility inflows. Currently Wollongong WRRF is undergoing renewal of tertiary filters and improvements to the Actiflo storm treatment plants to improve wet weather performance for biochemical oxygen demand and total suspended solids removal. As of July 2024, seven of ten tertiary filters have been renewed.

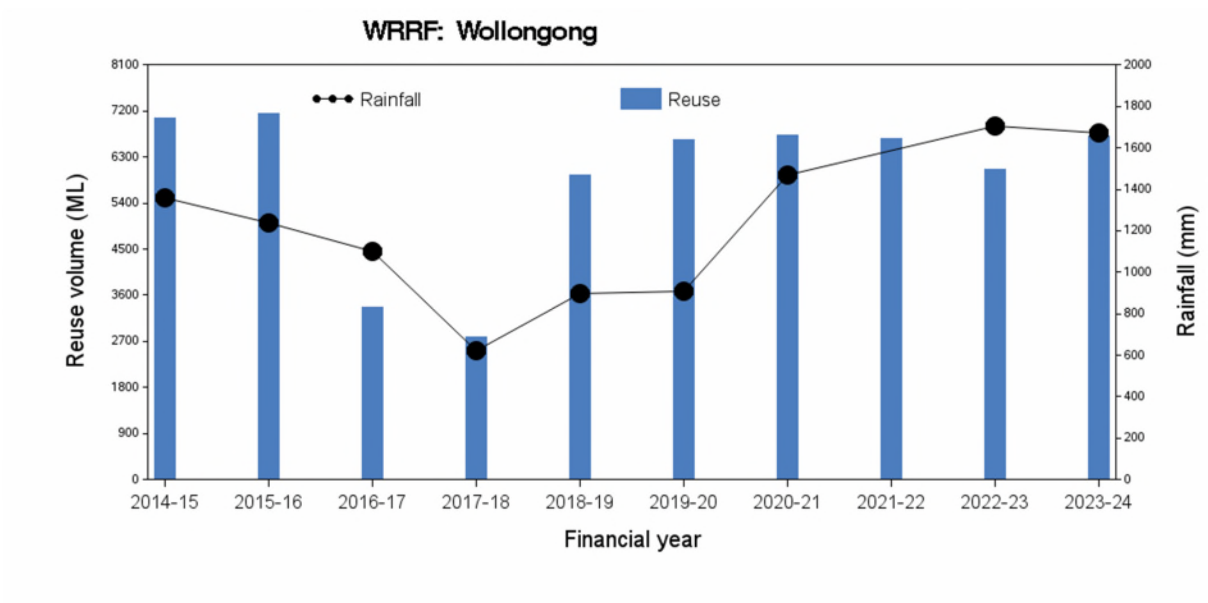
The exceeded annual load limits for biochemical oxygen demand and total suspended solids were largely due to the wet weather events experienced between 5-6 April, 3-14 May and 6-8 June 2024 within the Wollongong catchment, and the subsequent high wet weather flows received at the three treatment facilities under Wollongong EPL 218 (Wollongong WRRF, Bellambi and Port Kembla storm treatment facilities) during these periods.

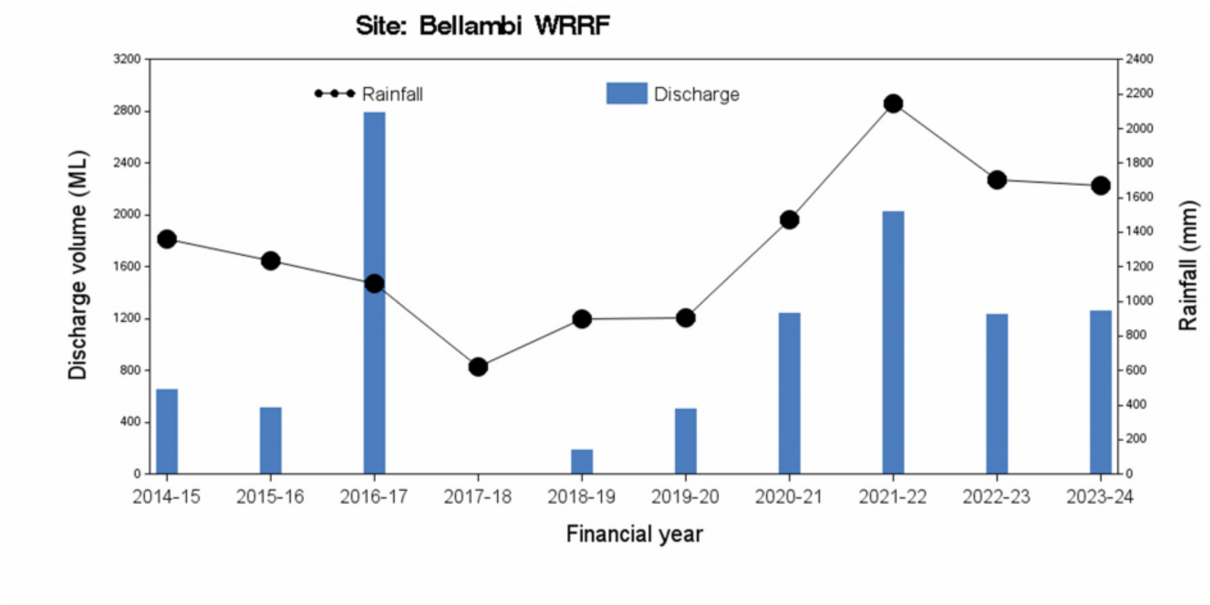
Wollongong EPL 218 accounts for emissions factors applied to unmonitored streams from Bellambi and Port Kembla storm treatment facilities which affect calculated loads under wet weather conditions. In 2023-24, 34% of the biochemical oxygen demand and 48% of the total suspended solids loads calculated as discharged from under the Wollongong EPL were generated by 12% of the overall discharge volume originating from Bellambi and Port Kembla.

No immediate actions could be undertaken as the facility was operating as designed under wet weather conditions during the periods of wet weather mentioned above. Performance against EPL percentile limits at Wollongong WRRF were good during dry weather conditions, with results well below 50th percentile limits.

Sydney Water has commenced discussions with the EPA on reviewing concentration and load limit exceedances associated with rainfall events, including the initiation of environmental assessments at five WRRFs (St Marys, Hornsby Heights, West Hornsby, Quakers Hill and Wollongong).







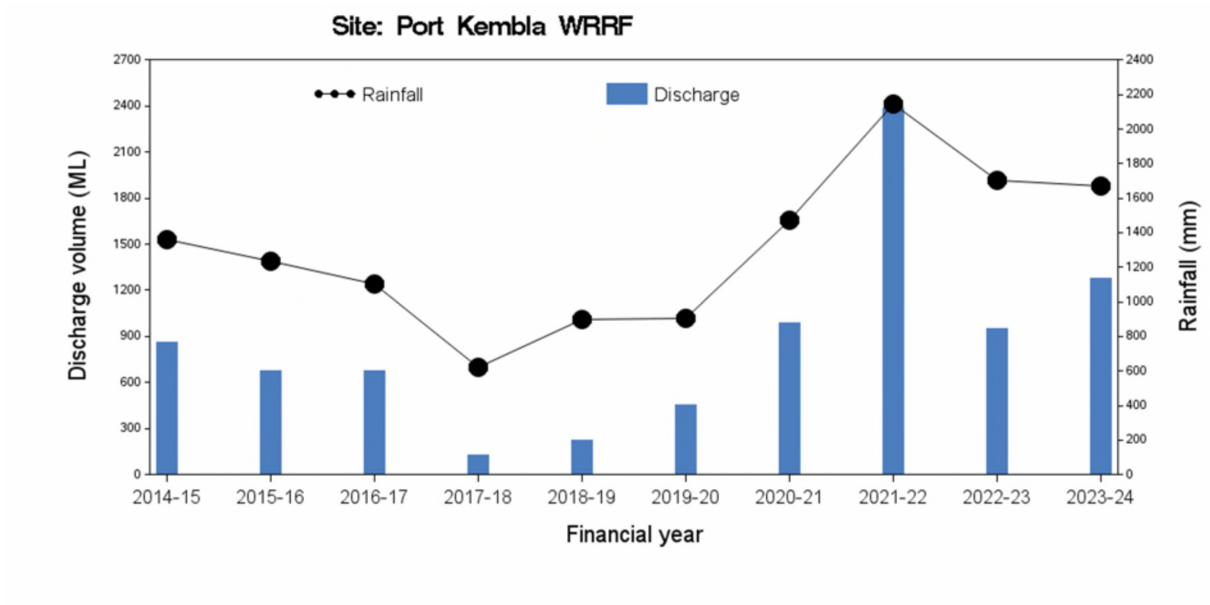
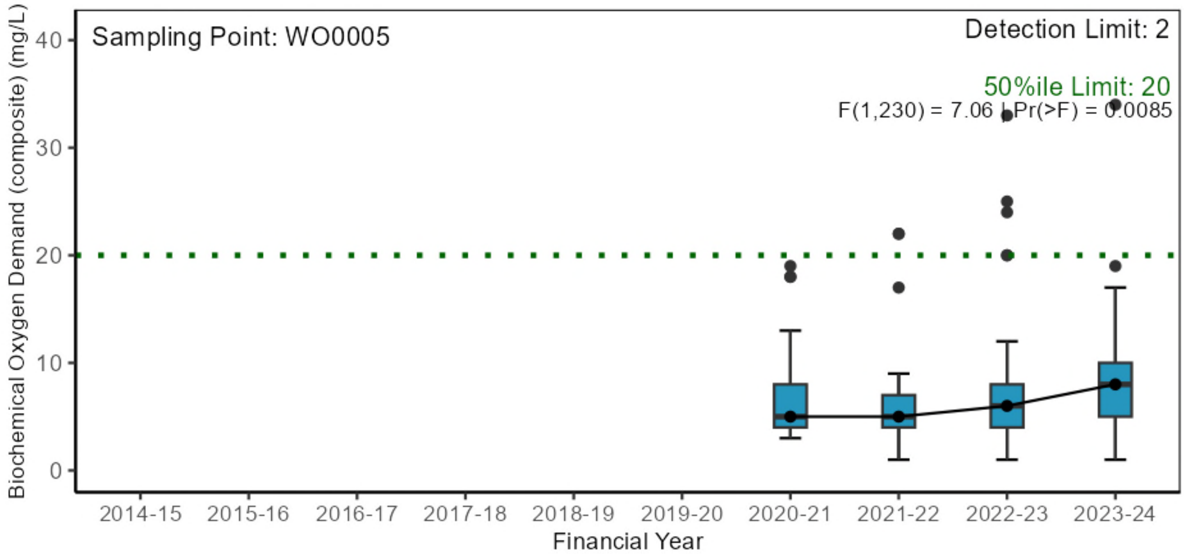
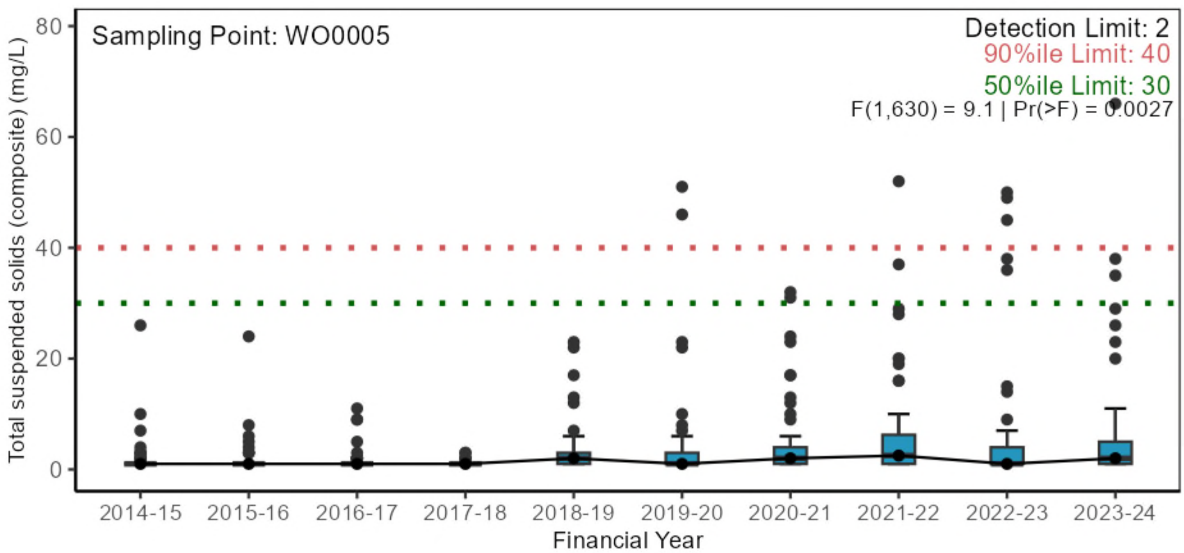


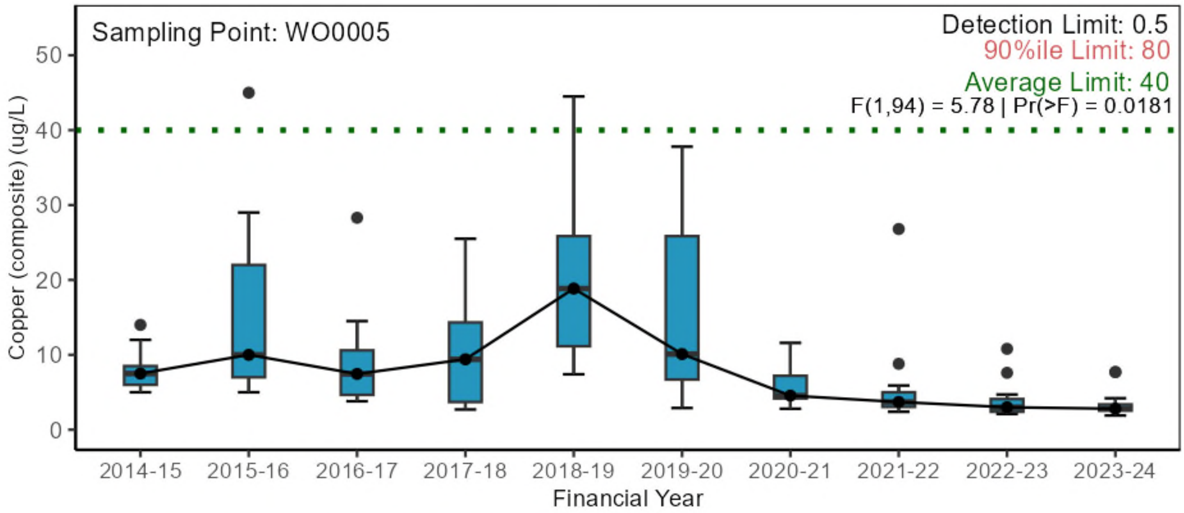
Figure 4-103 Wollongong STS inflow, discharge and reuse volume with catchment rainfall



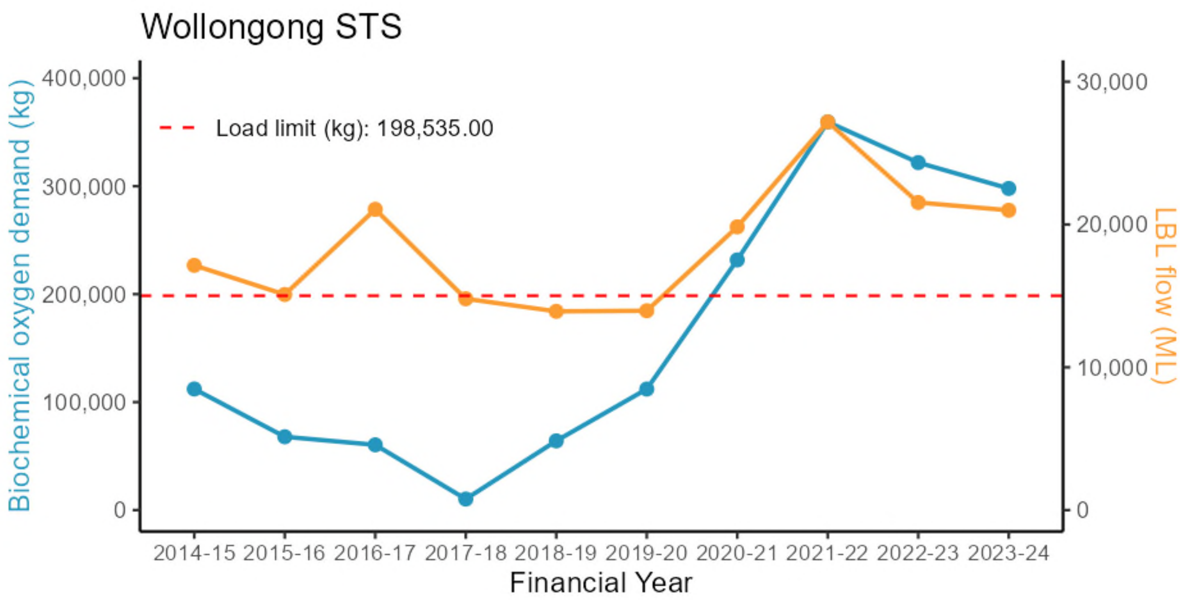
Sampling Point: WO0005
Detection Limit: 2
50%ile Limit: 20
F(1,230) = 7.06 | Pr(>F) = 0.0085
Biochemical Oxygen Demand (composite) (mg/L)
0
10
20
30
40
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Sampling Point: WO0005
Detection Limit: 2
90%ile Limit: 40
50%ile Limit: 30
F(1,630) = 9.1 | Pr(>F) = 0.0027
Total suspended solids (composite) (mg/L)
0
20
40
60
80
2014-15
2015-16
2016-17
2017-18
2018-19
2019-20
2020-21
2021-22
2022-23
2023-24
Financial Year



Statistical test excludes data prior to 2016-17 due to method detection limit change.



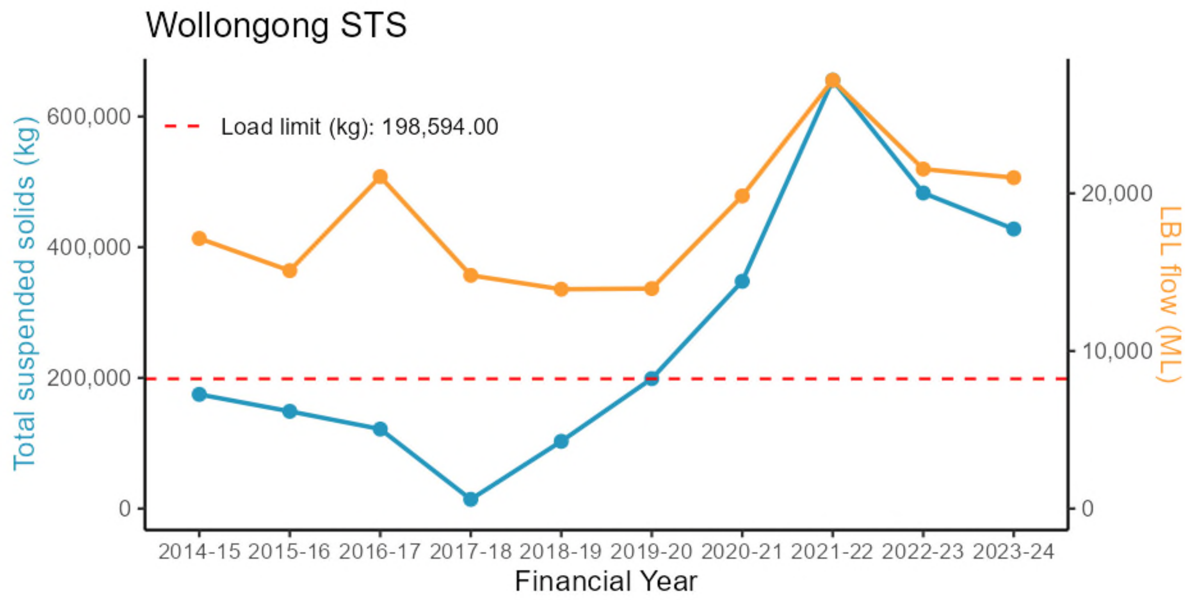


Figure 4-104 Wollongong STS discharge and reuse quality exception plots

4.4.5. Shellharbour WRRF

- The 90th percentile concentration limit for nonyl phenol ethoxylate was exceeded in the discharge from Shellharbour WRRF during 2023-24. All other parameters (concentration and load) were within EPL limits. There was a decreasing trend in biochemical oxygen demand concentration in the discharge compared to previous years

Pressure – Wastewater discharge

Table 4-78 Gate 1 Analysis outcome summary – Shellharbour WRRF

Analytes / Shellharbour WRRF	Nutrients			Conventional analytes					Trace Metals		Other		
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Diazinon	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate
Concentration	→			↘	→		→	→	→	→	→	→	→
Load													

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

The 90th percentile concentration limit for nonyl phenol ethoxylate in the discharge from Shellharbour WRRF was exceeded during the 2023-24 reporting period. All other concentration and load levels in the Shellharbour WRRF discharge were within the EPL limits.

Statistical analysis identified a significantly decreasing trend in biochemical oxygen demand concentrations during 2023-24 compared to the previous three years of testing.

The 90th percentile concentration limit for nonyl phenol ethoxylate (NPE) was exceeded during the 2023-24 reporting period. Of the 12 monthly data points for the reporting period, only two were above the 90th percentile EPL limit (10 µg/L). These two elevated results from 06/12/2023 and 05/01/2024 (13 and 11 µg/L) were not obvious to the facility until well after the events once samples were analysed in the laboratory. All other 10 monthly data points for the reporting period were below the average limit of 6 µg/L for NPE. All other concentration values in the Shellharbour WRRF discharge were within the EPL limits.

Shellharbour WRRF treatment processes are not currently optimised for NPE removal. The 90th percentile non-compliance is compounded further by stage one limit review where concentration limits were set on historical performance. Continuous process control, monitoring and optimisation is in progress however continued compliance remains a risk until stage two concentration limit review reassesses the environmental risk and sets new limits.

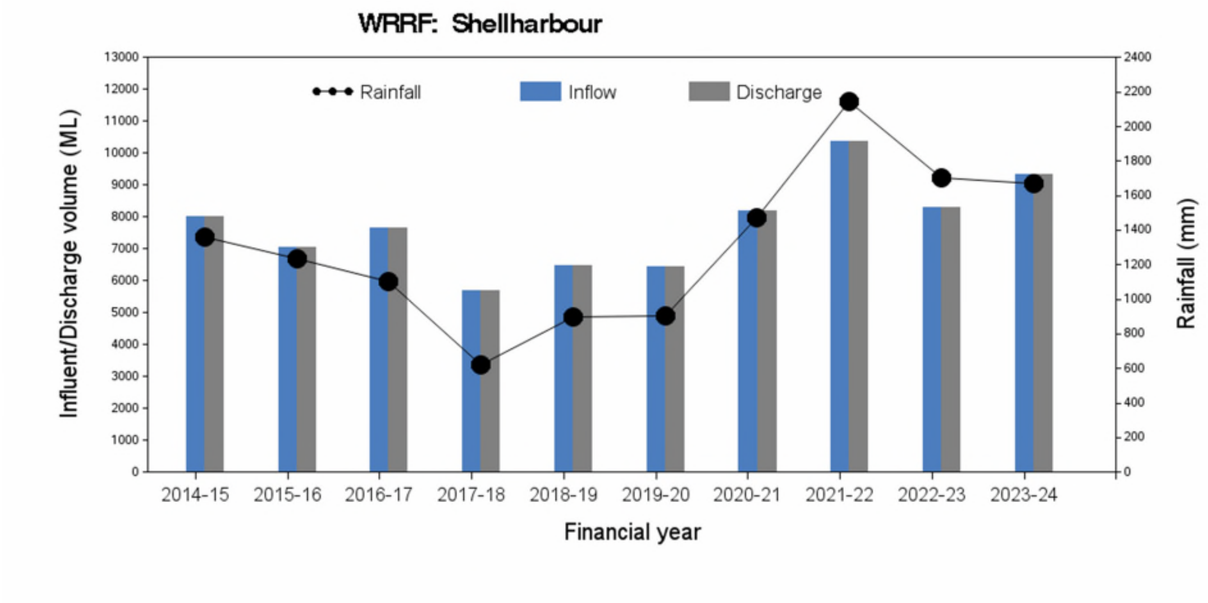
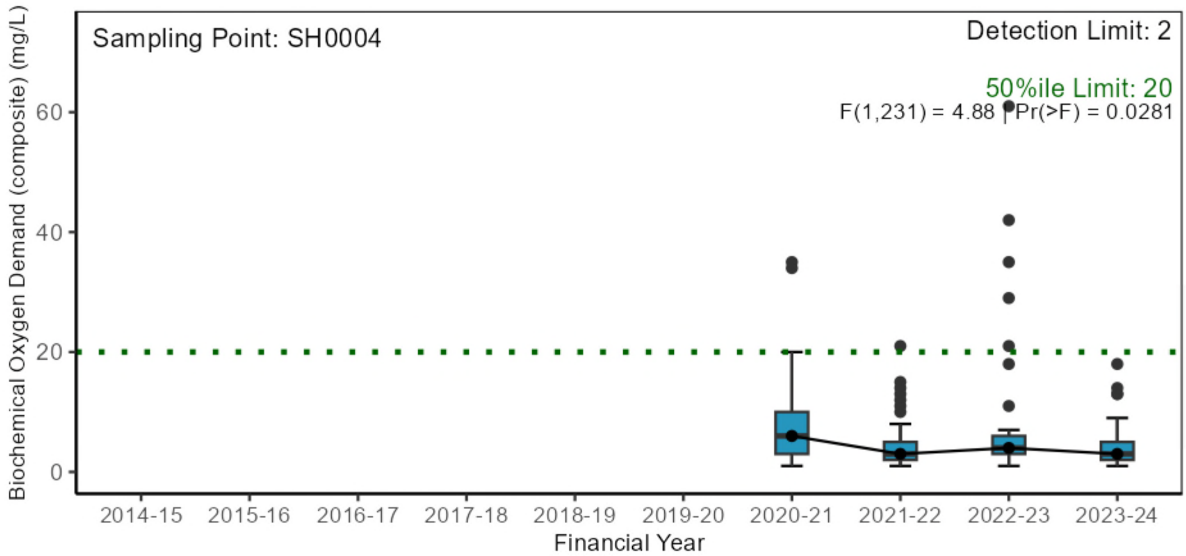


Figure 4-105 Shellharbour WRRF inflow and discharge volume with catchment rainfall



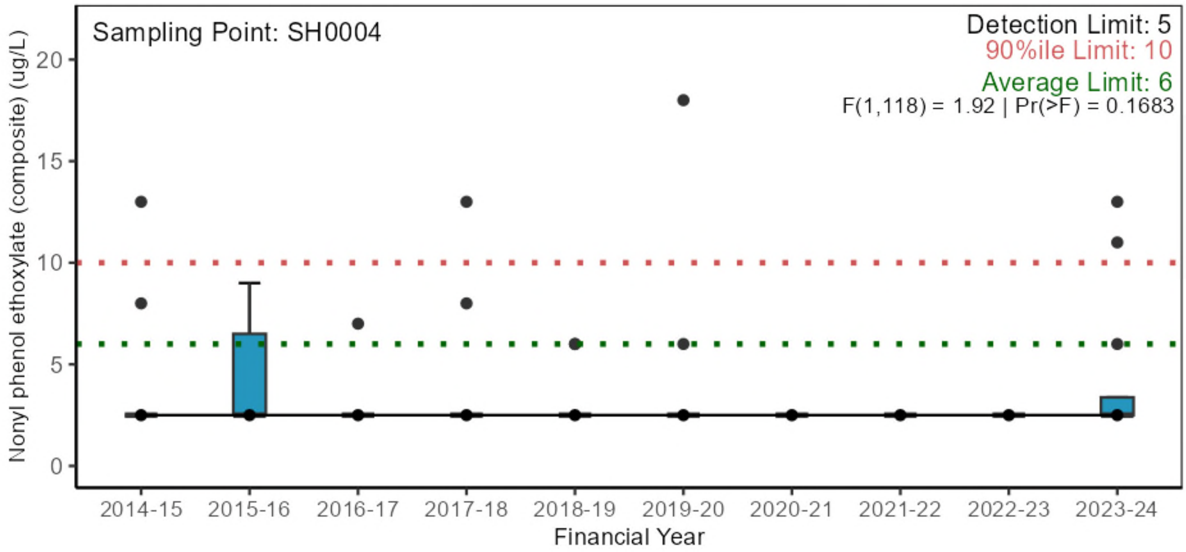


Figure 4-106 Shellharbour WRRF discharge quality exceptions plots

4.4.6. Bombo WRRF

- All parameters (concentrations and loads) in the discharge from Bombo WRRF were within EPL limits. There were decreasing trends in total suspended solids and aluminium concentrations identified in the discharge.

Pressure – Wastewater discharge

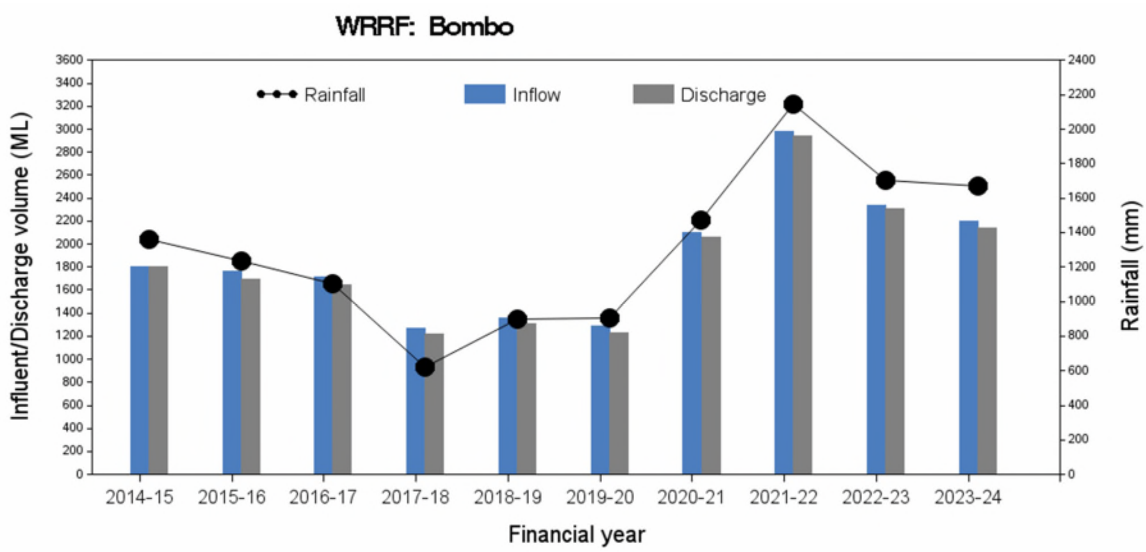
Table 4-79 Gate 1 Analysis outcome summary – Bombo WRRF

Analytes / Bombo WRRF	Nutrients			Conventional analytes					Trace Metals		Other		
	Ammonia nitrogen	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Faecal coliforms	Oil and grease	Total suspended solids	EC_{50} toxicity	Aluminium	Copper	Diazinon	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate
Concentration	→			→	→		→	→	→	→	→	→	→
Load													

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load levels in the Bombo WRRF discharge were within EPL limits during the 2023-24 reporting period.

Statistical analysis identified no significant trends in pollutant concentrations in 2023-24 compared to the previous nine years.



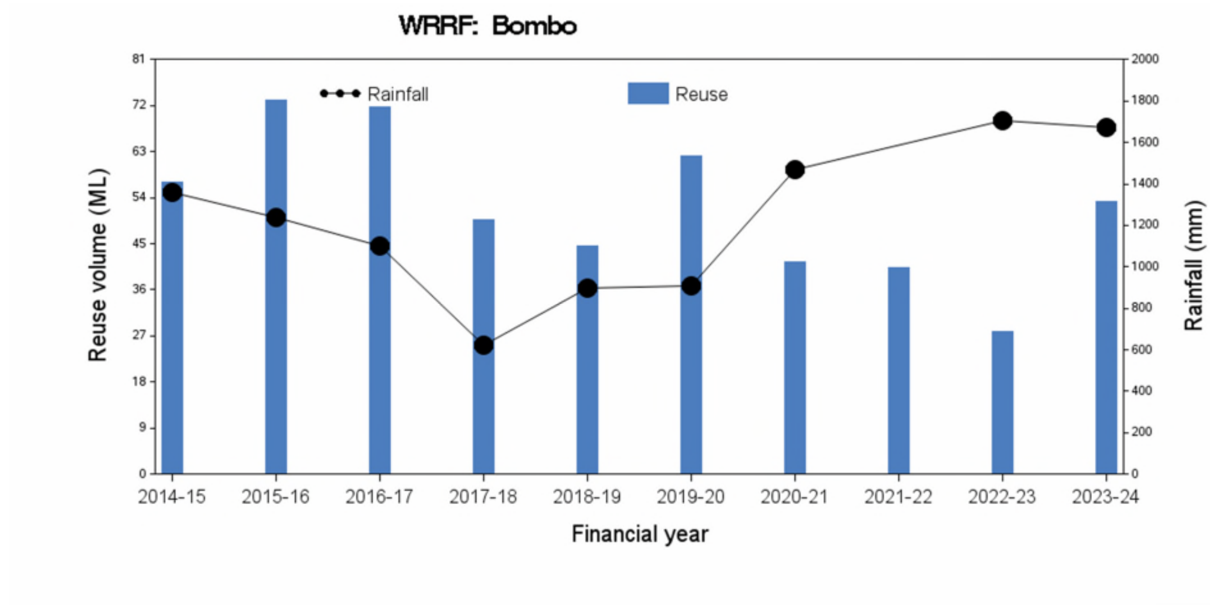


Figure 4-107 Bombo WRRF inflow, discharge and reuse volume with catchment rainfall

4.4.7. Nearshore marine environment

Stressor – Nearshore receiving water quality

Feasibility study required to inform an appropriate monitoring design and indicators (van Dam et al. 2023).

Ecosystem Receptor – Nearshore intertidal and subtidal macro-algae

Assessment of the 2008-09 to 2023-24 monitoring data from the Shellharbour WRRF and two control sites indicated a relatively stable equilibrium in the rocky-intertidal community structure (Volume 2 Appendix D-5.5). These results also suggest no measurable impact had developed in the intertidal rock platform community near the outfall at Barrack Point from wastewater discharges from the Shellharbour WRRF as the community assemblage at the outfall site was very similar to the control site 1 over the 2008-09 to 2023-24 period. The results from control site 2 represents natural variation in rocky-intertidal community structure that has been demonstrated to occur for closely spaced sites on the shoreline (Underwood and Chapman, 1995).

4.5. Offshore marine environment

The treated wastewater discharged from the offshore marine environment discharging WRRFs in 2023-24 and the population serviced by these WRRFs are shown in Table 4-80.

This section contains a summary of exceptions offshore marine environment discharging WRRFs.

Trend plots of discharge volume and catchment specific rainfall are presented first, and then reuse volume where applicable. This is followed by load limit plot where there was an exceedance of an annual EPL limit during the 2023-24 monitoring period.

Trend plots showing the concentration of analytes in the discharge are only presented where they exceeded the respective annual EPL limit for a WRRF during the 2023-24 monitoring period, or there was a significant increase/decrease in concentrations in 2023-24 in comparison to earlier years.

All trend plots showing the analyte concentration and load data for offshore marine WRRFs, including applicable EPL limits, can be found in Volume 2 Appendix E.

An electronic appendix file summarising the results for all offshore marine WRRFs by year has been provided to the EPA (December 2024).

Trend plots and multivariate statistical outcomes for the Ocean Reference Station and Ocean Sediment Program can be found in Volume 2 Appendix E-6. Summarised sediment chemistry data and invertebrate fauna data have been provided to the EPA in electronic appendix files (December 2024).

Table 4-80 Offshore marine environment WRRFs operated by Sydney Water

WRRFs	Treatment level	Discharge 2023-24 (ML/year)[a]	Projected population 2023-24[b]	Discharge location
North Head	Primary	145,527	1,386,933	North Head Deepwater ocean outfall, 3.7 km from shoreline, 65 m maximum water depth, 762 m diffuser zone
Bondi	Primary	45,644	314,598	Bondi Deepwater ocean outfall; 2.2 km from shoreline, 63 m maximum water depth, 512 m diffuser zone
Malabar	Primary	191,518	1,698,339	Malabar Deepwater ocean outfall, 3.6 km from shoreline, 82 m maximum water depth, 720 m diffuser zone

a Discharge volume excludes onsite and offsite reuse.
b Projected populations (at 30 June 2023) are based on forecasts by the Australian Bureau of Statistics and the DCCEEW

4.5.1. North Head WRRF

- Pressure: All parameters (concentrations and loads) measured in the discharge from North Head WRRF in 2023-24 were within EPL limits. There were no increasing or decreasing trends for any of the parameters in 2023-24 compared to the previous nine years.

Pressure – Wastewater discharge

Table 4-81 Gate 1 Analysis outcome summary – North Head WRRF

Analytes / North Head WRRF	Nutrients		Conventional analytes			
	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration				→	→	→
Load						

Analytes / North Head WRRF	Trace Metals								Other			
	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Chlorpyrifos	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Concentration	→			→					→	→	→	
Load												

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All parameters (load and concentration) measured in the discharge from North Head WRRF were within the EPL limits during the 2023-24 period. Statistical analysis did not identify any significant trends in the discharge during the 2023-24 reporting period compared to the previous nine years.

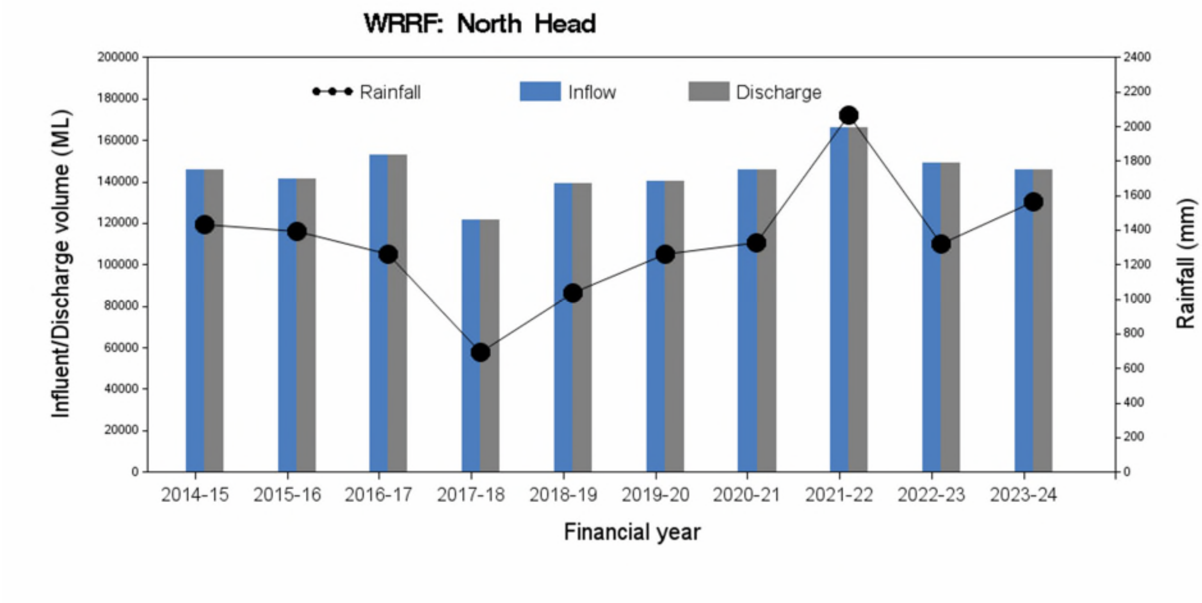


Figure 4-108 North Head WRRF inflow and discharge volume with catchment rainfall

4.5.2. Bondi WRRF

- Pressure: All parameters (concentrations and loads) measured in the discharge from Bondi WRRF in 2023-24 were within EPL limits. There were decreasing trends in total suspended solids and aluminium concentrations in the discharge compared to the previous nine years.

Pressure – Wastewater discharge

Table 4-82 Gate 1 Analysis outcome summary – Bondi WRRF

Analytes / Bondi WRRF	Nutrients		Conventional analytes			
	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration				→	↘	→
Load						

Analytes / Bondi WRRF	Trace Metals								Other		
	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Concentration	↘								→	→	
Load											

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All concentration and load limits for parameters measured in the final discharge from Bondi WRRF were within the EPL limits in 2023-24.

Statistical analysis identified significant decreasing trends in suspended solids and aluminium concentrations in 2023-24 compared to the past nine years.

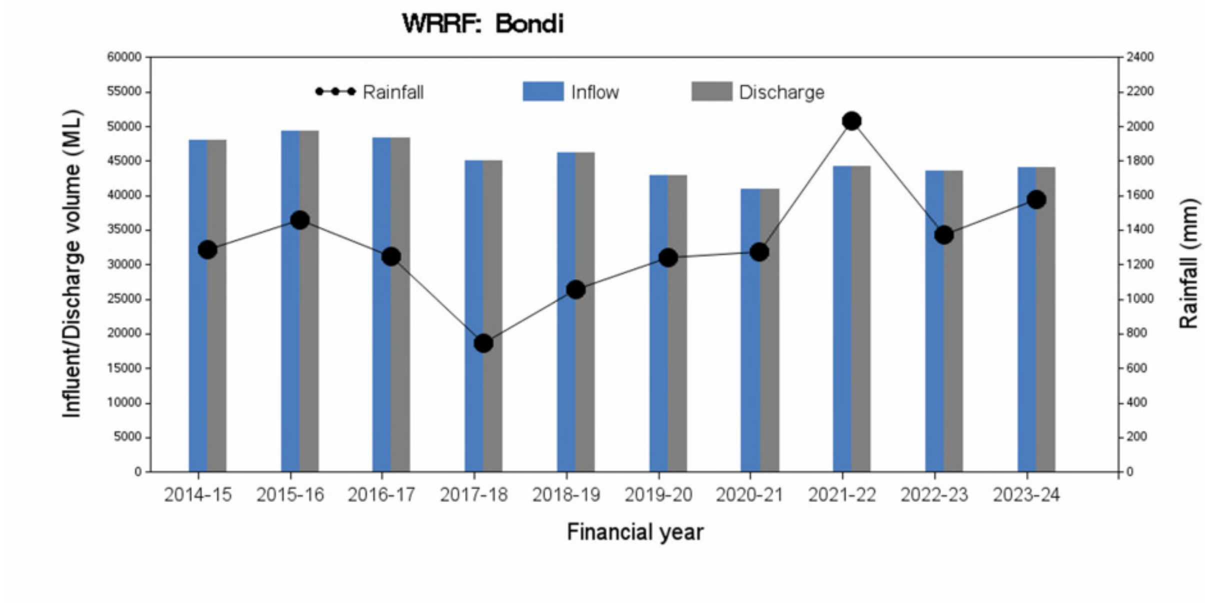
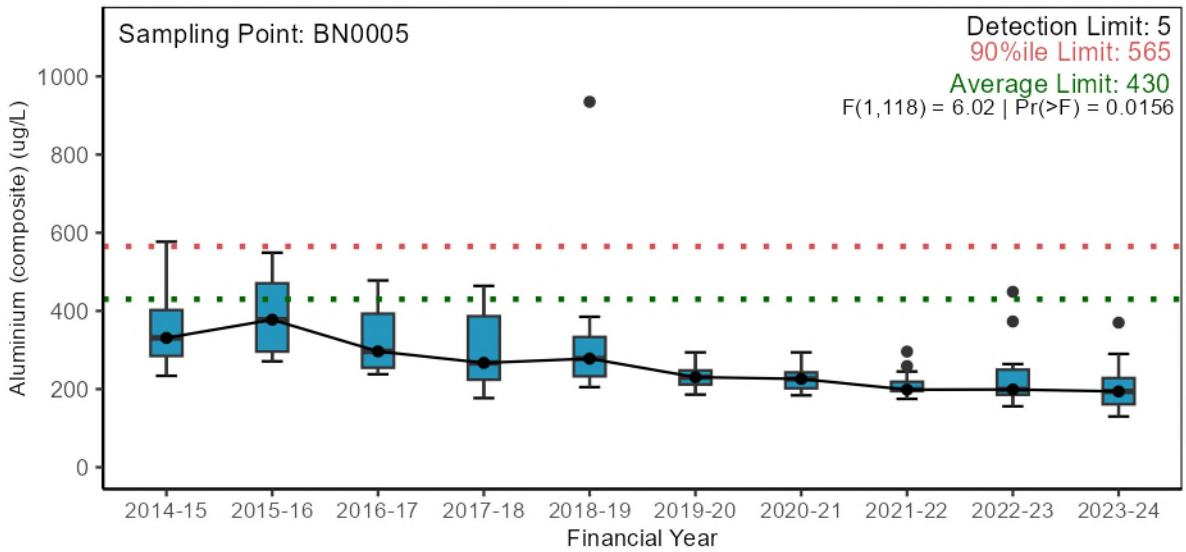


Figure 4-109 Bondi WRRF inflow and discharge volume with catchment rainfall



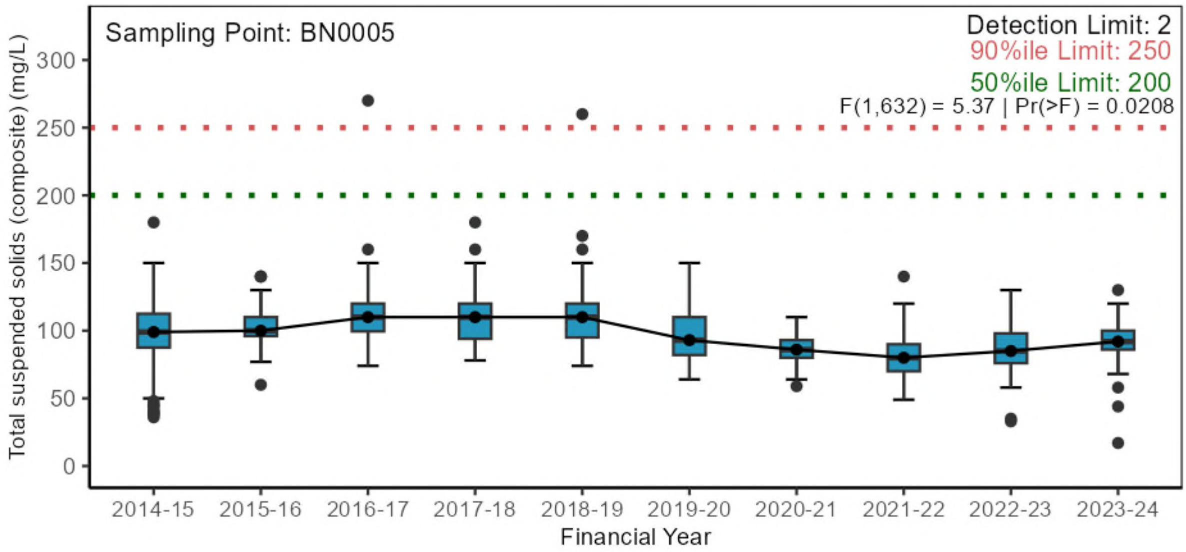


Figure 4-110 Bondi WRRF discharge quality exception plots

4.5.3. Malabar WRRF

- Pressure: All parameters (concentrations and loads) measured in the discharge from Malabar WRRF in 2023-24 were within EPL limits. There were increasing trends in oil and grease and total suspended solids in the discharge compared to the previous nine years.

Pressure – Wastewater discharge

Table 4-83 Gate 1 Analysis outcome summary –Malabar WRRF

Analytes / Malabar WRRF	Nutrients		Conventional analytes			
	Total nitrogen	Total phosphorus	Biochemical oxygen demand	Oil and grease	Total suspended solids	EC_{50} toxicity
Concentration				↗	↗	→
Load						

Analytes / Malabar WRRF	Trace Metals								Other		
	Aluminium	Cadmium	Chromium	Copper	Lead	Mercury	Selenium	Zinc	Hydrogen sulfide (un-ionised)	Nonyl phenol ethoxylate	Pesticides and PCBs
Concentration	→								→	→	
Load											

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	EPL limit exceedance		Within EPL limit		Analyte not required in EPL or no concentration limit

All parameters (concentrations and loads) measured in the final discharge from Malabar WRRF were within the EPL limits in 2023-24.

Statistical analysis identified a significant increasing trend in oil and grease and total suspended solids concentrations in 2023-24 compared to the past nine years.

The increasing trend in oil and grease concentration is linked to a combination of population growth in the catchment, and successful reduction of saltwater ingress into the wastewater network. Sydney Water is initiating projects to improve scum and sludge removal efficiency at Malabar WRRF.

The increasing suspended solids trend can be linked to reduced capability of the sedimentation and solids capture system. Sydney Water is addressing this issue by undertaking major periodic maintenance on primary sedimentation assets at Malabar WRRF.

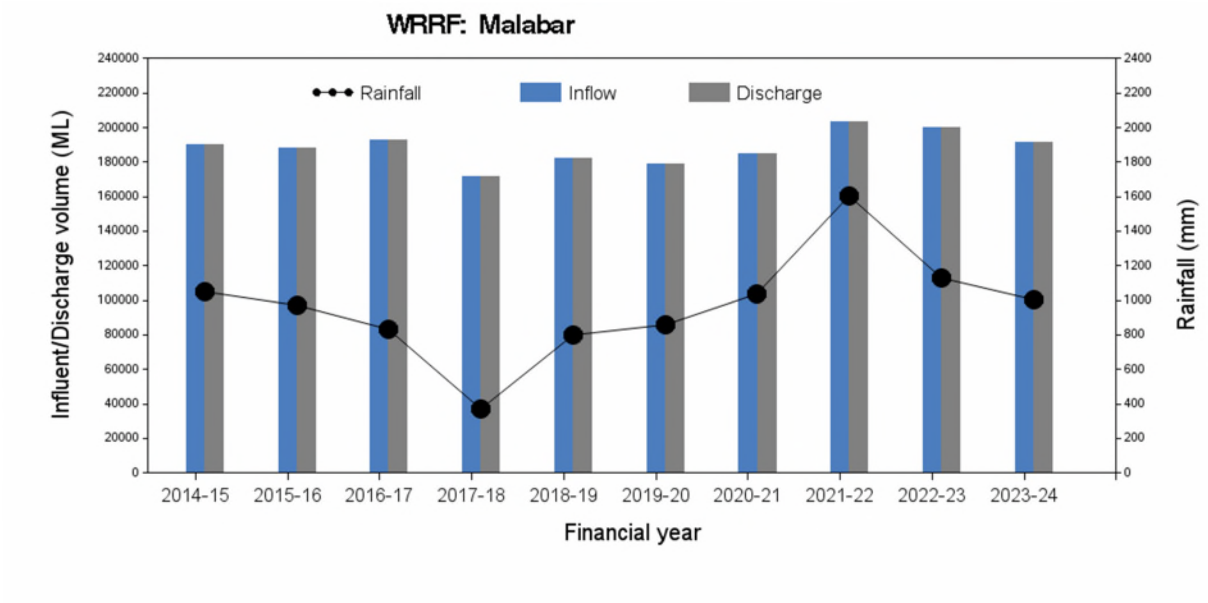
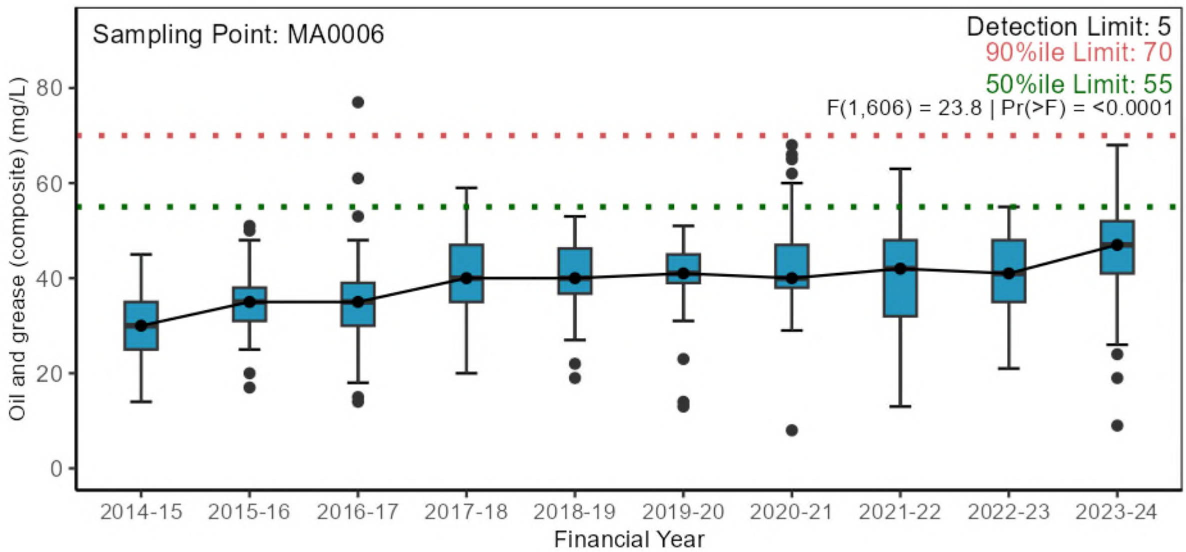


Figure 4-111 Malabar WRRF inflow and discharge volume with catchment rainfall



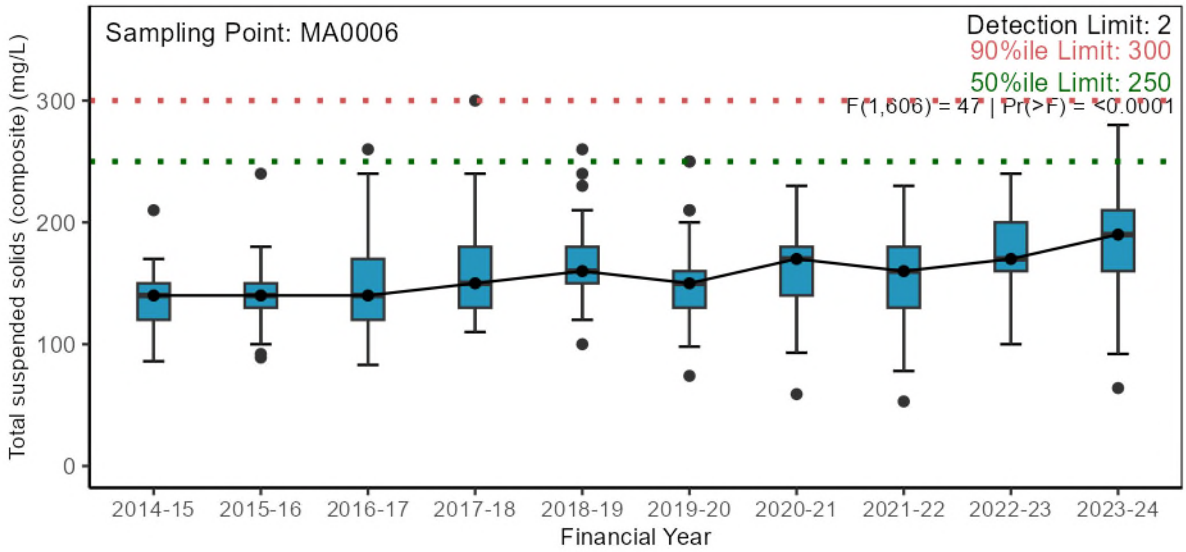


Figure 4-112 Malabar WRRF discharge quality exception plots

4.5.4. Offshore marine environment

Stressor – Ocean receiving water quality

Out of 11 chemicals assessed in 2023-24, modelled total nitrogen, total phosphorus, aluminium and copper concentrations in the receiving waters in the initial dilution zones of the deepwater ocean outfalls exceeded the ANZG (2018) guideline values for the protection of 95% of marine species. Modelled concentrations of total nitrogen and total phosphorus exceeded guideline values of 0.12 mg/L and 0.02 mg/L respectively, for the lower dilution scenario at all three deepwater ocean outfalls. Modelled concentrations of aluminium exceeded the guideline value of 0.5 µg/L at all three deepwater ocean outfalls for both modelled dilution scenarios except for the higher dilution scenario at Bondi. Modelled concentrations of copper exceeded the guideline value of 1.3 µg/L at North Head and Malabar deepwater ocean outfalls. A summary of results can be found in Volume 2 Appendix E-5.

A literature review of sources of critical contaminants in domestic wastewater from household studies in Australia indicated major inputs were from lead, zinc and copper (Tjadraatmadja and Diaper, 2006). Inputs of lead appear to originate from the laundry and bathroom, while zinc mainly originates from the bathroom, and the major sources of copper were from plumbing and water supply (Tjadraatmadja and Diaper, 2006).

Assessment year measurements of sedimentary copper concentrations collected under the Ocean Sediment Program of the SWAM were below the ANZG (2018) lower sediment quality guideline value for protection of marine species at all nine study locations (which included outfall and control locations).

Stressor – Offshore marine sediment quality

Outcomes from the current 2023-24 surveillance year data is contained in Volume 2 Appendix E-6. A summary of the results is given below.

In 2023-24, the total organic carbon (TOC) content for all ten samples collected from the Malabar 0 km location were less than the EPA specified 99th percentile trigger value of 1.2%. Although no specific trigger value has been set for either Bondi or North Head, TOC % content was less than 1.2% for all Bondi and North Head samples. The results from TOC laboratory analysis suggest elevated levels of anoxia were unlikely to have built-up in benthic sediment in 2023-24.

The average levels of fine sediments observed in 2023-24 were similar to those seen in past years, with no apparent build-up of fine particles (<0.063 mm). This suggests that sedimentary metal concentrations were unlikely to have increased in 2023-24 at the North Head, Bondi and Malabar 0 km deepwater outfall locations.

Ecosystem Receptor – Offshore marine sediment faunal communities

The current 2023-24 surveillance year data is contained in Volume 2 Appendix E-6. A summary of the results is given below.

The outcomes of abundance and richness measures in 2023-24 showed that the most common and abundant taxa were Crustaceans and Polychaete worms. The total number of individuals was lower than the previous year (2022-23) as fewer samples were collected in 2023-24, as recommended in the STSIMP Recommendations Report (van Dam et al 2023). Despite smaller sample numbers, there does not appear to be a sustained decline or increase in any of these four taxonomic groups over the 24 years of monitoring. Without any changes in sediment characteristics, the benthic community structure at the Malabar deepwater ocean outfall location was unlikely to have changed beyond the levels recorded in past assessment years.

5. Synthesis of Sydney Water's WRRF discharge impacts

5.1. Hawkesbury-Nepean River

5.1.1. Wastewater discharge

With the increasing pressure from a growing population and climate change, Sydney Water is challenged with:

- treating and discharging an increasing volume of wastewater
- aligning or managing treatment activities with more frequent and intense weather events.

Performance of WRRFs has been dominated by intense wet weather periods in the second half of the year between December 2023 and June 2024. The impact of wet weather, along with the reduced capacity of several Hawkesbury-Nepean facilities undergoing major capital upgrades has led to increasing trends in some analyte concentrations.

A total of six concentration EPL limit exceedances occurred from three Hawkesbury-Nepean WRRFs (90th percentile for ammonia nitrogen, average and 90th percentiles for copper at North Richmond; average and 90th percentile for copper at St Marys and average aluminium at Castle Hill) in 2023-24.

In addition, there were a total of three load EPL limit exceedances across four Hawkesbury-Nepean WRRFs (one total nitrogen, one total suspended solids and the combined total phosphorus bubble limit between Riverstone, Quakers Hill and St Marys WRRFs). This is a decrease from ten concentration exceedances from five facilities and four load exceedances recorded from the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Ammonia nitrogen concentrations showed an increasing trend in the discharge from two of the fifteen Hawkesbury-Nepean WRRFs (namely Picton and North Richmond). A decrease was observed in the discharge from Quakers Hill and St Marys WRRFs.
- Total nitrogen concentrations showed an increasing trend in the discharge from seven WRRFs (West Camden, Wallacia, Penrith, North Richmond, Richmond, St Marys and Castle Hill), but a decrease in six (Winmalee, Riverstone, Quakers Hill, Rouse Hill, West Hornsby and Hornsby Heights)
- Total phosphorus concentrations showed an increasing trend in the discharge from six WRRFs (Wallacia, Penrith, Winmalee, North Richmond, St Marys, and Quakers Hill), but a decrease in four (Picton, Richmond, Castle Hill and Brooklyn)
- All nutrient analytes along with suspended solids, aluminium and copper showed an increasing concentration trend in the discharge from North Richmond WRRF

- copper (from four WRRFs), aluminium (from three WRRFs) and nickel (from one WRRF) showed an increasing trend in the discharge from the Hawkesbury-Nepean WRRFs.

Sydney Water is committed to reducing pollutant concentrations being discharged into the Hawkesbury-Nepean River through key initiatives and programs, including:

- A major $220M amplification of West Camden WRRF, including the construction of a new membrane bioreactor (MBR) plant. This amplification will increase the treatment capacity to cater for population growth in the Camden district and reduce nutrient concentrations in the final discharge. Expected completion date is May 2024.
- Refurbishment works to the Stage 7 biological nutrient removal (BNR) process is in progress at Penrith WRRF to improve reliability and performance of nutrient removal. Completion of the upgrade is expected late 2025.
- Winmalee WRRF has undergone a $50M upgrade to fulfil the requirements of the Pollution Reduction Program (PRP) 800 under Environment Protection Licence (EPL) 1963. The upgrade includes the construction of a membrane bioreactor, increasing biological process capability and reducing the nutrient concentrations in the discharge.
- Sydney Water has committed to upgrading Richmond WRRF. Following upgrade completion, flows from the North Richmond catchment will be transferred to the Richmond WRRF through a newly constructed pipeline, subsequently initiating North Richmond WRRF decommissioning. This is expected to be completed by the end of 2026.
- The St Marys and Quakers Hill WRRFs have undergone treatment upgrades to improve reliability and service growth. Construction is complete and process optimisation has continued through 2024.
- Upgrades to improve the nutrient performance at Castle Hill is expected for completion by the end of 2025.
- Treatment upgrades and amplification of Riverstone WRRF in 2019 increased the treatment capacity and improved the performance of the facility as illustrated in the decreasing trends in total nitrogen and total phosphorus over the past few years.
- Further upgrades to Castle Hill, Rouse Hill and Riverstone WRRFs are being planned to service continued growth along the transit corridors and growth precincts in the northwest of Sydney.
- Construction has commenced on the Upper South Creek Advanced Water Recycling Centre (AWRC) which is a new treatment plant to service growth in the South Creek catchment. The AWRC will have advanced treatment for dry weather discharge. The AWRC has multiple stages of operational capability with commissioning of the first preliminary treatment phase late 2025.

5.1.2. Water quality, phytoplankton and macroinvertebrates

The receiving water quality and phytoplankton data for 40 upstream/downstream monitoring sites associated with 14 Hawkesbury-Nepean River WRRFs were assessed to:

- determine temporal trends (increasing, decreasing or steady) in the 2023-24 compared to previous two to nine years.

- compare the 2023-24 median results against national guidelines/trigger values where available.
- make statistical comparisons between upstream and downstream monitoring results (for the 2023-24 year) and identify possible links with upstream influences e.g. WRRF discharges.

The 2023-24 year was dominated by above average rainfall throughout the Hawkesbury-Nepean River catchment, with the most intensive events between December 2023 and June 2024. The total rainfall ranged from 746 mm (upper Nepean River catchment) to 1,291 mm (Berowra Creek catchment). The impact of wet weather, along with the increasing/ decreasing trends in the concentration of nutrient analytes in the discharge from some of Sydney Water's WRRFs might have influenced the nutrient concentrations at the downstream receiving water sites.

Temporal trends (2023-24 vs previous two to nine years) and guideline comparison (2023-24 median or 50th percentile value)

- The trends in nutrients and chlorophyll-a concentrations in 2023-24 compared to the previous two to nine years were mixed and highly variable by individual sites or site-pairs. The impact of increased or decreased nutrient concentrations in the WRRF discharge was not often reflected in the nutrient concentration trend at the downstream receiving water site. Nor was it reflected on the impact or benefit on downstream phytoplankton, as indicated by chlorophyll-a.
- Median total ammonia nitrogen concentrations were within the 95% species protection limit at nearly all upstream/downstream sites in 2023-24. Oxidised nitrogen and total nitrogen exceeded at nearly all upstream/downstream sites. Total phosphorus exceeded at the majority of these sites and chlorophyll-a at half of these sites.

A summary of data analysis outcomes comparing key nutrients concentrations in WRRF discharge with the respective concentration of these nutrients in receiving water and resulting impact on chlorophyll-a concentrations for the downstream receiving water sites is presented in Table 5-1.

- The total ammonia nitrogen concentration in the downstream receiving water (both tributary and river) remained steady in 2023-24 despite increasing trends in the discharge from Picton and North Richmond WRRFs, decreasing trends in the discharge from St Marys and Quakers Hill WRRFs.
- Total ammonia nitrogen concentrations increased significantly at the Boundary Creek upstream control site of Penrith WRRF in 2023-24, which was associated with two separate sewer overflow incidents.
- The increasing or decreasing trend in the total nitrogen concentration in WRRF discharge was not reflected at the majority of downstream receiving water sites (11 out of 13 cases):
  - downstream total nitrogen receiving water concentrations remained steady despite a significant increase in the total nitrogen concentration in the discharge from West Camden, Wallacia, Penrith, Richmond and St Marys WRRFs.

  - downstream total nitrogen receiving water concentrations remained steady despite a significant decrease in the total nitrogen concentration in the discharge from Winmalee, Riverstone, Quakers Hill, Rouse Hill, West Hornsby and Hornsby Heights WRRFs.

- The increasing or decreasing trend in total nitrogen concentration in the WRRF discharge was aligned with a corresponding increase or decrease in total nitrogen at the downstream receiving water site for two out of 13 cases:
  - downstream receiving water concentration in the Hawkesbury River site increased significantly in line with the increased total nitrogen concentration in the discharge from North Richmond WRRF. However, the trend in total nitrogen at the downstream tributary site was steady indicating the increase in the Hawkesbury River was not related to North Richmond WRRF.
  - downstream receiving water concentration increased significantly in line with the increased total nitrogen concentration in discharge from Castle Hill WRRF.
- Trends in total phosphorus concentration in the WRRF discharge had no observed effect on most downstream receiving water concentrations (eight of nine cases):
  - downstream receiving water concentrations remained steady despite an increase in the total phosphorus concentration in the discharge from Wallacia, Penrith, North Richmond, St Marys and Quakers Hill WRRFs
  - downstream receiving water concentrations remained steady despite a decrease in the total phosphorus concentration in the discharge from Picton, Richmond and Castle Hill WRRFs
- The downstream Nepean River site at Winmalee Lagoon was an exception where phosphorus concentration increased in line with the increased concentration in the discharge from Winmalee WRRF, although this was not validated for two downstream tributary sites because of insufficient data.
- Chlorophyll-a concentrations remained steady at 33 of the 36 upstream and downstream monitoring sites assessed. The exceptions were increased chlorophyll-a concentrations upstream of North Richmond WRRF, and decreased concentrations at the corresponding downstream tributary sites of Rouse Hill and Castle Hill WRRFs.
- Median total ammonia nitrogen concentrations were within the ANZG (2023) toxicant guideline for 95% level species protection at nearly all upstream/downstream receiving water sites in 2023-24. The only exception was the upstream tributary site of St Marys WRRF.
- Median oxidised nitrogen concentration exceeded the ANZG (2018) guideline at 39 of the 40 upstream or downstream monitoring sites. The only exception was the Matahil Creek site upstream of West Camden WRRF where oxidised nitrogen was within the guideline limit.
- Median total nitrogen concentrations exceeded the guideline at 38 of the 40 upstream or downstream monitoring sites. The exceptions were the tributary sites upstream of Picton and Hornsby Heights WRRFs where median concentrations were below the guideline.
- Median total phosphorus concentrations exceeded the guideline at 14 of the 20 downstream tributary/river sites in 2023-24. The guideline was exceeded at 13 of the 20 upstream monitoring sites.

- Median chlorophyll-a concentrations exceeded the ANZG (2018) guideline at approximately half of the upstream (11 of 20) or downstream (10 of 20) tributary/river sites in 2023-24.

Table 5-1 Summary of statistically significant trends in the Hawkesbury-Nepean River WRRF discharge, receiving water nutrients and chlorophyll-a concentrations and comparison with EPL and ANZG guidelines

WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Chlorophyll-a
Picton	WRRF discharge to waterway		↗		→		↘	
	Tributary	Upstream tributary (N911B)	→	→	→	→	→	→
		Downstream tributary (N911)	→	→	→	→	→	→
	River	Upstream river (N92)	→	→	→	→	→	→
		Downstream river (N91)	→	→	→	→	→	→
West Camden	WRRF discharge to waterway		→		↗		→	
	Tributary	Upstream tributary (N7824A)	→	→	→	→	→	→
		Downstream tributary (N7824)	→	→	→	↗	↗	→
	River	Upstream river (N78)	→	→	→	→	→	→
		Downstream river (N75)	→	→	→	→	→	→
Wallacia	WRRF discharge to waterway		→		↗		↗	
	River	Proxy upstream river (N67)	→	→	→	→	→	→
		Downstream river (N641)	→	→	→	→	→	→
Penrith	WRRF discharge to waterway		→		↗		↗	
	Tributary	Upstream tributary (N542)	↗	→	→	→	→	→
		Downstream tributary (N541)	→	→	→	→	→	→
	River	Upstream river (N57)	→	↗	↗	↘	→	→
		Downstream river (N53)	→	→	→	→	→	→
Winmalee	WRRF discharge to waterway		→		↘		↗	
	Tributary	Proxy upstream tributary (N462)	NA	NA	NA	NA	NA	NA
		Downstream tributary (N461)	NA	NA	NA	NA	NA	NA
	River	Upstream river (N48A)	→	↗	↗	→	→	→
		Downstream river (N464)	→	→	→	↗	↗	→
North Richmond	WRRF discharge to waterway		↗		↗		↗	
	Tributary	Upstream tributary (N412)	→	→	→	→	→	→
		Downstream tributary (N411)	→	→	→	→	→	→
	River	Upstream river (N42)	→	→	→	↗	↗	↗
		Downstream river (N39)	→	↗	↗	→	↗	→
Richmond	WRRF discharge to waterway		→		↗		↘	
	Tributary	Upstream tributary (N389)	→	→	→	→	→	→
		Downstream tributary (N388)	→	→	→	→	→	→

WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Chlorophyll-a
St Marys	WRRF discharge to waterway		↘		↗		↗	
	Tributary*	Upstream tributary (NS242)	NA	NA	NA	NA	NA	NA
		Downstream tributary (NS241)	NA	NA	NA	NA	NA	NA
	Tributary	Upstream river (NS26)	→	→	→	→	→	→
		Downstream river (NS23A)	→	→	→	→	→	→
Riverstone	WRRF discharge to waterway		→		↘		→	
	Tributary	Upstream tributary (NS082)	→	→	→	→	→	→
		Downstream tributary (NS081)	→	→	→	→	→	→
Quakers Hill	WRRF discharge to waterway		↘		↘		↗	
	Tributary	Upstream tributary (NS090)	→	→	→	→	→	→
		Downstream tributary (NS087)	→	→	→	→	→	→
Rouse Hill	WRRF discharge to waterway		→		↘		→	
	Tributary	Upstream tributary (NC53)	→	→	→	→	→	→
		Downstream tributary (NC516)	→	→	→	→	→	↘
Castle Hill	WRRF discharge to waterway		→		↗		↘	
	Tributary	Upstream tributary (NC8)	→	→	→	→	→	→
		Downstream tributary (NC75)	→	↗	↗	→	→	↘
West Hornsby	WRRF discharge to waterway		→		↘		→	
	Tributary	Upstream tributary (NB83)	→	→	→	→	→	→
		Downstream tributary (NB825)	→	→	→	→	→	→
Hornsby Heights	WRRF discharge to waterway		→		↘		→	
	Tributary	Upstream tributary (NB43)	→	→	→	→	→	→
		Downstream tributary (NB42)	→	→	→	→	→	→

Tributary: Unnamed tributary of South Creek*
NA: Statistical comparison not conducted due to only one financial year of data

↗	Upward trend (p<0.05)	↘	Downward trend (p<0.05)	→	No trend (p>0.05)
	Median value outside the guideline or EPL limit in 2023-24				

Upstream versus downstream comparison (2023-24)

- Statistical analysis confirmed that there was a localised impact from WRRF discharges at the majority of the downstream tributary sites in comparison to the upstream sites for key nutrients. Such impact was rarely evident at the downstream Hawkesbury-Nepean River sites into which these tributaries flow.
- Total ammonia nitrogen concentrations were significantly higher at the respective downstream receiving water sites in comparison to the upstream sites in 2023-24 for Picton, West Camden and North Richmond WRRFs, indicating a link with the elevated concentrations/loads in the discharge.
- Oxidised nitrogen and/or total nitrogen concentrations were significantly higher at the downstream sites for the majority of WRRFs (ten of 14 WRRFs assessed) compared to the upstream sites, confirming a link with the discharge from these facilities.
- Filterable and total phosphorus concentrations were significantly higher at the downstream receiving sites of six WRRFs compared to upstream, indicating a possible link with the corresponding phosphorus concentrations/loads in the discharge. For two WRRFs (Penrith and Rouse Hill), upstream phosphorus concentrations were higher than downstream indicating other upstream catchment influences such as sewer overflow, stormwater or urbanisation.
- Dissolved oxygen concentrations (and saturation) at the downstream sites were significantly higher than upstream at eight of 14 WRRFs indicating a benefit of the discharge. Similarly, turbidity at the upstream sites was significantly higher than downstream at six of 14 WRRFs indicating a benefit of discharges with low suspended particles.
- Chlorophyll-a concentrations at the upstream sites were significantly higher than downstream for two WRRFs (West Camden and Penrith) indicating localised conditions that favour phytoplankton growth (e.g. low flow, high nutrient availability).
- Stream health outcomes, as indicated by macroinvertebrates, showed localised ecosystem impacts in tributaries downstream of six of 14 WRRFs. These included Picton, West Camden, Winmalee, North Richmond, Castle Hill and Hornsby Heights. For Penrith, St Marys and Quakers Hill WRRFs, upstream ecosystem health was poorer compared to downstream health.
- Gate 1 analysis outcomes across all P-S-ER elements showed that waterways downstream of Picton, West Camden, Winmalee, North Richmond, Castle Hill and Hornsby Heights WRRFs were considered to have potential adverse ecological impacts resulting from treated discharges. Further investigation into water quality drivers will be undertaken in an upcoming interpretive report.

A summary of statistical analysis outcomes comparing the receiving water quality and ecosystem health indicators at each upstream and downstream pair for each Hawkesbury-Nepean River WRRF is presented in Table 5-1. Statistical analysis of 2023-24 data indicated that:

- Elevated total ammonia nitrogen concentrations at the corresponding downstream tributary or river receiving water sites are likely linked to the respective increased ammonia concentration in the discharge from three WRRFs (Picton, West Camden and North Richmond). The upstream Penrith WRRF site was impacted by two separate sewer overflow incidents which contained elevated ammonia.
  - Total ammonia nitrogen concentrations were significantly higher at both the respective downstream tributary and river sites compared to the corresponding upstream sites of Picton and West Camden WRRFs for 2023-24. This suggests that the impact of the elevated ammonia in these WRRF discharges is extending to the Nepean River.
  - Total ammonia nitrogen at the downstream tributary site was significantly higher than the corresponding upstream site of North Richmond WRRF for 2023-24. These increases did not extend to the Hawkesbury River to which this tributary flows.
  - Total ammonia nitrogen at the upstream tributary site was significantly higher than the downstream site of Penrith WRRF for 2023-24.
- Oxidised nitrogen and/or total nitrogen concentrations were significantly higher at the downstream sites for the majority of WRRFs (ten of 14 WRRFs) compared to the upstream sites, confirming a link with the discharge from these facilities.
  - Oxidised and total nitrogen concentrations were significantly higher at the respective downstream tributary sites in comparison to the upstream tributary for Picton, West Camden, Penrith, North Richmond, St Marys, Quakers Hill, Rouse Hill, Castle Hill, West Hornsby and Hornsby Heights WRRFs for 2023-24.
  - Oxidised nitrogen and/or total nitrogen concentrations at the downstream Nepean River site were also higher than upstream concentrations for West Camden WRRF indicating that this impact extended to the river, as also seen with total ammonia.
- Outcomes were mixed for filterable total phosphorus and total phosphorus concentrations when comparing the upstream and downstream site pairs for each WRRF. Both WRRF discharge concentration and upstream catchment factors were possibly associated with these outcomes.
  - Filterable total phosphorus and/or total phosphorus concentrations were significantly higher at the respective downstream tributary sites in comparison to the upstream tributary for West Camden, North Richmond, Castle Hill and Hornsby Heights WRRFs for 2023-24.
  - Filterable total phosphorus and/or total phosphorus concentrations at the downstream Nepean River sites were higher than the upstream Nepean River concentrations for Picton, West Camden and Winmalee WRRFs for 2023-24. This was not reflected in the immediate downstream tributary site for Picton WRRF.
  - Filterable total phosphorus and/or total phosphorus concentrations were significantly higher at the respective upstream tributary sites in comparison to the downstream tributary for Penrith and Rouse Hill WRRFs for 2023-24. These were linked with the upstream sewer overflow incidents and catchment run-off for the Penrith and Rouse Hill WRRFs, respectively.

- Outcomes for physico-chemical analytes was highly variable.
  - Conductivity was significantly higher at the respective downstream tributary site compared to the corresponding upstream site for North Richmond, Castle Hill, West Hornsby and Hornsby Heights WRRFs for 2023-24.
  - Conductivity was significantly higher at upstream sites compared to the corresponding downstream site for West Camden, Wallacia (proxy site) and Penrith WRRFs for 2023-24.
  - Dissolved oxygen concentration and/or saturation was significantly higher at the respective downstream tributary site compared to the corresponding upstream site for West Camden, Wallacia, Penrith, North Richmond, Richmond, Quakers Hill, Rouse Hill and Hornsby Heights WRRFs for 2023-24. This reflects a benefit of WRRF discharges to these tributaries.
  - pH was significantly higher at the respective downstream sites for Wallacia (proxy site) and Hornsby Heights WRRFs for 2023-24. Conversely, pH was significantly higher at the upstream site compared to the corresponding downstream site for West Camden and Castle Hill WRRFs.
  - Water temperature was significantly higher at the respective downstream tributary sites for West Camden, West Hornsby and Hornsby Heights WRRFs.
  - Turbidity was significantly higher at the upstream site compared to the corresponding downstream site for West Camden, Penrith, Quakers Hill, Castle Hill, West Hornsby and Hornsby Heights WRRFs. This reflects a benefit of discharges with low suspended particles.
- Chlorophyll-a concentrations in the upstream sites were significantly higher than downstream concentrations for two WRRFs (West Camden and Penrith) indicating localised conditions upstream that favour phytoplankton growth (e.g. low flow, high nutrient availability).
- Stream ecological health in the Hawkesbury-Nepean catchment was assessed statistically using the macroinvertebrate index, SIGNAL-SG (Sydney genus):
  - Results suggested localised ecosystem impacts in tributaries downstream of Picton, West Camden, Winmalee, Castle Hill, Hornby Heights, North Richmond and Hornsby Heights WRRFs in 2023-24. There was no evidence that these impacts had any effect on the Hawkesbury-Nepean River system to which these creeks flow.
  - Results suggested a decline in stream health at the site downstream of Wallacia WRRF. The upstream site could not be sampled due to persistent high flows. Using a proxy upstream site on the Nepean River (SoE site N67) returned a statistically significant outcome. A definitive impact from the wastewater discharges of Wallacia WRRF could not be determined as these sites are located in different waterways with different habitat types. The decline in stream health at the downstream site could be attributed to impacts from wet weather flows in 2023-24, which resulted in the macrophytes and habitat at the downstream site being scoured out.

Table 5-2 Statistical analysis outcomes – upstream and downstream site comparison for water quality, chlorophyll-a and macroinvertebrates

WRRF	Waterway	Monitoring site	Ammonia nitrogen	Oxidised nitrogen	Total nitrogen	Filterable total phosphorus	Total phosphorus	Conductivity	Dissolved oxygen	Dissolved oxygen saturation	pH	Temperature	Turbidity	Chlorophyll-a	Macroinvertebrates
Picton	Tributary	Upstream vs downstream (N911B vs N911)	D	D	D	-	-	-	-	-	-	-	-	-	D
	River	Upstream vs downstream (N92 vs N91)	D	-	-	D	D	-	-	-	-	-	-	-	-
West Camden	Tributary	Upstream vs downstream (N7824A vs N7824)	D	D	D	D	-	U	D	D	U	D	U	U	D
	River	Upstream vs downstream (N78 vs N75)	D	D	D	D	D	-	-	-	-	-	-	-	-
Wallacia	River	Proxy upstream vs downstream (N67 vs N641)	-	U	U	-	-	U	-	D	D	-	-	-	D
Penrith	Tributary	Upstream vs downstream (N542 vs N541)	U	D	-	U	U	U	D	-	-	-	U	U	U
	River	Upstream vs downstream (N57 vs N53)	D	-	-	-	-	-	-	-	-	-	-	-	-
Winmalee	Tributary	Proxy upstream vs downstream (N462 vs N461)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	D
	River	Upstream vs downstream (N48A vs N464)	-	-	-	D	D	-	-	-	-	-	-	-	-
North Richmond	Tributary	Upstream vs downstream (N412 vs N411)	D	D	D	D	D	D	-	D	-	-	-	-	D
	River	Upstream vs downstream (N42 vs N39)	-	-	-	-	-	-	-	-	-	-	-	-	-
Richmond	Tributary	Upstream vs downstream (N389 vs N388)	-	-	-	-	-	-	D	D	-	-	-	-	-
St Marys	Tributary*	Upstream vs downstream (NS242 vs NS241)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
	Tributary	Upstream vs downstream (NS26 vs NS23A)	-	D	D	-	-	-	-	-	-	-	-	-	U
Riverstone	Tributary	Upstream vs downstream (NS082 vs NS081)	-	-	-	-	-	-	-	-	-	-	-	-	-
Quakers Hill	Tributary	Upstream vs downstream (NS090 vs NS087)	-	D	D	-	-	-	D	D	-	-	U	-	U
Rouse Hill	Tributary	Upstream vs downstream (NC53 vs NC516)	D	D	D	U	U	-	D	D	-	-	-	-	-
Castle Hill	Tributary	Upstream vs downstream (NC8 vs NC75)	-	D	D	D	-	D	-	-	U	-	U	-	D
West Hornsby	Tributary	Upstream vs downstream (NB83 vs NB825)	-	D	D	-	-	D	-	D	-	D	U	-	-
Hornsby Heights	Tributary	Upstream vs downstream (NB43 vs NB42)	-	D	D	D	D	D	-	D	D	D	U	-	D

Tributary: Unnamed tributary of South Creek*
NA: Statistical comparison not conducted due to only one financial year of data

D	Downstream higher (p<0.05)	U	Upstream higher (p<0.05)	-	No difference (p>0.05)

5.2. Georges River

5.2.1. Wastewater discharge

Georges River discharges are primarily influenced by rainfall and have experienced increasing pressure from climate change.

During the 2023-24 monitoring period, there were no concentration EPL limit exceedances. There was also no change in trends for biochemical oxygen demand and total suspended solids from the previous 2022-23 monitoring period.

No load limits are applicable to enclosed waters under the Malabar EPL.

5.2.2. Receiving water quality and phytoplankton

The receiving water quality and phytoplankton data for three upstream and downstream monitoring sites for Glenfield WRRF were collected for the first time during the 2023-24 period. Statistical analysis will be included in SWAM reports from 2024-25 to further validate these trends.

The 2023-24 median total ammonia nitrogen concentration was within the 95% species protection limit at all sites. Oxidised nitrogen, total nitrogen and dissolved oxygen concentrations exceeded the respective guidelines at Bunbury Curran Creek and downstream Georges River sites. The total phosphorus concentration exceeded the ANZG (2018) guideline at the Bunbury Curran creek site. Turbidity was below the lower limit at both the upstream and downstream Georges River sites.

For the Fairfield and Liverpool WRRFs, a feasibility study is yet to be designed on appropriate monitoring sites and indicators.

5.2.3. Macroinvertebrates

Stream health, as indicated by macroinvertebrates, was not assessed because of insufficient data (monitoring commenced in 2023-24). Statistical analysis will be included in SWAM reports from 2024-25 alongside water quality outcomes.

5.3. Nearshore marine environment

5.3.1. Wastewater discharge

Similar to the Hawkesbury-Nepean River WRRF discharges, Sydney Water is challenged with increasing pressure from a growing population and climate change in WRRF discharges to the nearshore marine environment.

During the 2023-24 monitoring period, there was one concentration EPL limit exceedance (nonylphenol ethoxylate 90th percentile) from Bombo WRRF and two load EPL limit exceedances (one biochemical oxygen demand and one suspended solids) from Wollongong WRRF. This is an improvement from the single concentration exceedances and four load exceedances recorded in the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Biochemical oxygen demand and suspended solids concentrations increased in Wollongong WRRF discharge
- Biochemical oxygen demand concentration decreased in Shellharbour WRRF Discharge
- Copper concentrations decreased in Wollongong WRRF discharge.

Sydney Water is committed to reducing pollutant concentrations being discharged into the nearshore marine environment through key programs, including:

- Wastewater redirect from Vaucluse (Parsley Bay) and Diamond Bay discharges to the existing Bondi network for treatment and offshore discharge via the deepwater ocean outfalls. Expected completion late 2026.
- Dewatering upgrade at Shellharbour WRRF which will improve the reliability of the solids stream, reducing process pressure on liquid stream flows and help reduce high suspended solids in storm flows. Expected completion December 2024.

5.3.2. Nearshore intertidal and subtidal macroalgae

Assessment of the 2008-09 to 2023-24 monitoring data from the Shellharbour WRRF and two control sites indicated a relatively stable equilibrium in the rocky-intertidal community structure (Volume 2 Appendix D). These results also suggest no measurable impact had developed in the intertidal rock platform community near the outfall at Barrack Point from wastewater discharges from the Shellharbour WRRF as the community assemblage at the outfall site was very similar to the control site 1 over the 2008-09 to 2023-24 period. The results from control site 2 represent natural variation in rocky-intertidal community structure that has been demonstrated to occur for closely spaced sites on the shoreline (Underwood and Chapman, 1995).

5.4. Offshore marine environment

5.4.1. Wastewater discharges

There were no concentration or load EPL limit exceedances from the offshore WRRF discharges during the 2023-24 monitoring period, and no change from the previous 2022-23 monitoring period.

Based on statistical analysis comparing the 2023-24 monitoring period to the previous nine years, the following observations were made:

- Increasing oil and grease and suspended solids concentrations in the final effluent from Malabar WRRF
- Decreasing suspended solids and aluminium concentrations at Bondi WRRF

Sydney Water is committed to reducing pollutant concentrations being discharged into the offshore marine environment through key initiatives and programs, including:

- ongoing silt removal works in the Northern Suburbs Ocean Outfall Sewer (NSOOS) Northside storage tunnel and Southern and Western Suburbs Ocean Outfall Sewer (SWOOS) to reduce solid load entering the wastewater system.

5.4.2. Ocean receiving water and sediment

- Of the 11 chemicals assessed in 2023-24, modelled total nitrogen, total phosphorus, aluminium and copper concentrations in the receiving waters in the initial dilution zones of the deepwater ocean outfalls exceeded the ANZG (2018) guideline values for the protection of 95% of marine species. The total organic carbon content (%) of the sediment was less than 1.2% for all samples collected from Malabar, North Head and Bondi outfall locations, below the NSW EPA specified 99th percentile trigger value.
- Average levels of fine sediments in 2023-24 were comparable to those recorded in past years, with no apparent build-up of fine particles. This indicates that metal concentrations in the sediment were unlikely to have increased at the deepwater outfall locations.

5.4.3. Macroinvertebrates

- The benthic community structure was assessed at the Malabar deepwater outfall location in the 2023-24 surveillance year. Taxonomic compositions suggested that Polychaetes and Crustaceans continued to dominate the number of taxa collected at this site. While the total number of individuals was lower than the previous year, there has not been a sustained decline or increase in the main taxonomic groups over the 24 years of monitoring.

6. Results and discussion – wastewater overflows

6.1. Wet and dry weather overflows and leakage

6.1.1. Wet weather overflows

Wet weather overflow performance

A summary of wet weather overflow EPL conditions is presented in Table 6-1. All of the 23 wastewater treatment system models Sydney Water maintains were assessed as compliant with condition L7.1 during 2023-24. Of the 23 wastewater treatment system models, there were 17 models that were fully compliant (100% of gauges meeting the acceptance criteria) and 6 models that were partially compliant (75% or more gauges achieving the acceptance criteria). The 6 models (mostly larger systems) that achieved partial compliance were Cronulla, Malabar, North Head, St Marys, Winmalee and Wollongong. It was recommended that models transition to a more detailed breakdown into smaller subsystems to improve accuracy. Details of these upgrade recommendations are provided in the *Independent Criteria Review Committee report on Sewerage Trunk System Licence Models* (Urban Water Solutions, 2022). Eight models from eight systems were recalibrated in 2023-24 and 15 systems did not require calibration.

Ten systems complied with key EPL conditions (L7.2, O4.4 (c), O4.8(c), O4.9 and O4.10). The complying systems were Hornsby Heights, Quakers Hill, Richmond, Wallacia, Warriewood, West Hornsby, Cronulla, Bondi, North Head and Penrith.

One (1) sewage treatment system, Malabar, was non-compliant with O4.8(c) condition. One (1) sewage treatment system, Castle Hill, was non-compliant with O4.9 condition. One (1) sewage treatment system, Malabar (Fairfield), was non-compliant with O4.10 condition.

Two systems (Picton and Brooklyn-Dangar Island systems) don’t have conditions and hence were not assessed for EPL compliance conditions.

The frequency of wet weather overflows from the reticulation system of ten systems exceeded the L7.2 limits ie maximum number of overflows per 10 years (Table 6-1). These were Bombo, Castle Hill, North Richmond, Riverstone, Rouse Hill, Shellharbour, St Marys, West Camden, Winmalee and Wollongong.

The predicted wet weather overflow frequency for the Malabar system in 2023-24 was 294 overflow events in 10 years, exceeding the benchmark value of 238 overflow events in 10 years (Condition O4.8c).

The partial treatment capacity of the Fairfield stormwater plant in the Malabar system exceeded the benchmark limits of allowable discharges (maximum of 50 overflows in 10 years, Condition O4.10). There were 85 overflows from this stormwater plant in the last 10 years to 2023-24.

The non-compliances have been investigated and actions put in place to help identify and deliver works to bring systems back into compliance. Details of these mitigation measures and progress was reported via the *Annual Sewage Treatment System Performance Report – Wet Weather Overflow* (Sydney Water 2024b).

The key pollution reduction programs and pollution studies that were in place to reduce the volume and frequencies of wet weather overflows in 2023-24 were:

- Wet weather overflow abatement pollution reduction program to address non-compliance of the wet weather overflow limit in the North Richmond, Shellharbour, Wollongong and Rouse Hill systems.
  - Pipe relining
  - Modification of ERS
  - Repair of access chambers
  - Construction of additional storage
  - Gauging and model calibration
- Wet weather overflow pollution reduction program in the North Head, Malabar, Bondi and Cronulla systems.
  - Rectification and installation of backflow prevention valves
  - Repairing and installing rain stoppers to maintenance holes
  - Relining of mains
  - Investigate and repair defects at customer properties

Table 6-1 List of wet weather overflow non-compliances by EPL clause (2023-24)

Wastewater system EPL Clause	Non-compliant systems
L7.1 Ongoing use and development of a high-quality Hydraulic System Sewer model	Nil
L7.2 Wet weather overflow limits	Winmalee, North Richmond, Riverstone, Castle Hill, Rouse Hill, Bombo, Shellharbour, St Marys, West Camden, Wollongong
O4.9 Exceedance of design capacity of primary disinfection processes	Castle Hill
O4.8 (c) I Comparison of modelled wet weather overflows	Malabar
O4.10 Wet weather partial treatment discharges	Fairfield (Malabar)

Modelled occurrence and volume of wet weather overflows

Each year, the wastewater system's wet weather overflow performance (system performance) is compared against the benchmark year system performance or target system performance, to determine if any deterioration has occurred.

Sydney Water has developed hydraulic sewer models that are updated yearly due to growth, changes in the geometry and operation of the system. The model is then validated and if necessary recalibrated using rainfall and sewer flow and level data collected during the reporting year. The validated model is then used to simulate the performance for the base 10-year period, which is a fair representation of long-term climatic variation to predict long term average performance.

The modelled overflow volume from 14 inland wastewater systems was 1,097 ML in 2023-24 (Figure 6-1).The modelled wet weather overflows from eight ocean wastewater treatment systems were 26,216 ML in 2023-24 (Figure 6-2). Further details on recent year's wet weather overflow data including 2023-24, by each inland and ocean wastewater system are presented in Volume 2 Appendix F (Table F-1 and Table F-2).

The 2023-24 reporting year returned to more typical rainfall levels, following an extraordinary wet year in 2021-22 and less wet year in 2022-23. This resulted in a slight decrease in wet weather overflow volume by only 1 % in the ocean systems compared to the 2023-24 year. The volume of wet weather overflows from the inland systems decreased by 26 % compared to the 2022-23 year.

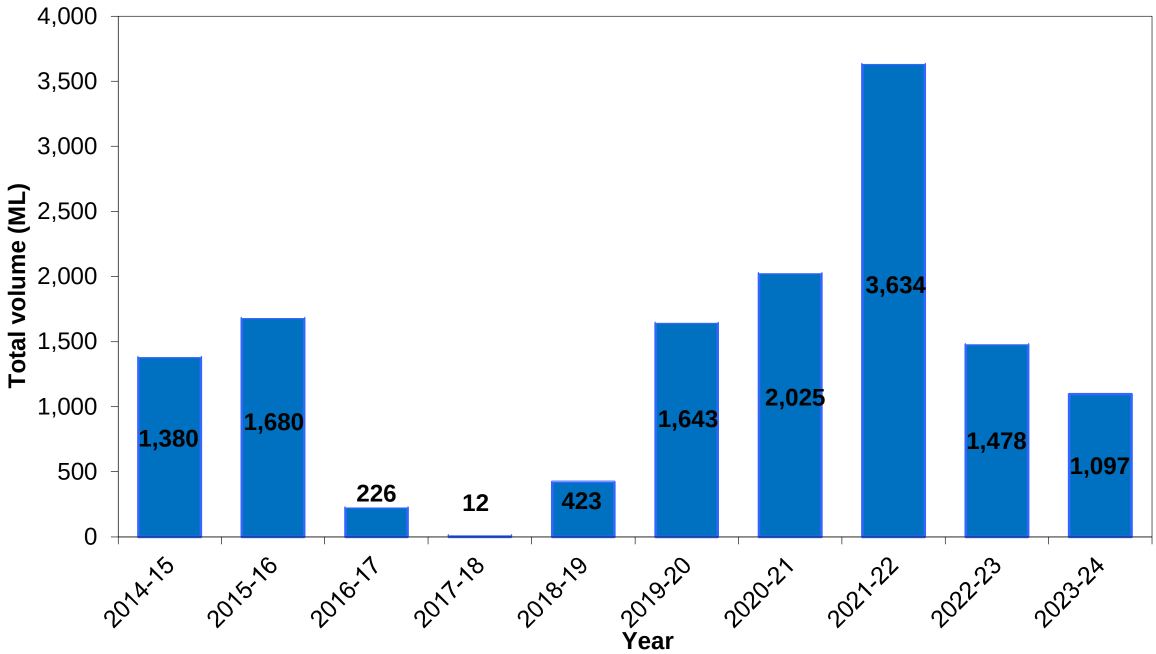


Figure 6-1 Previous 10 years of modelled wet weather overflow volumes by all inland wastewater systems

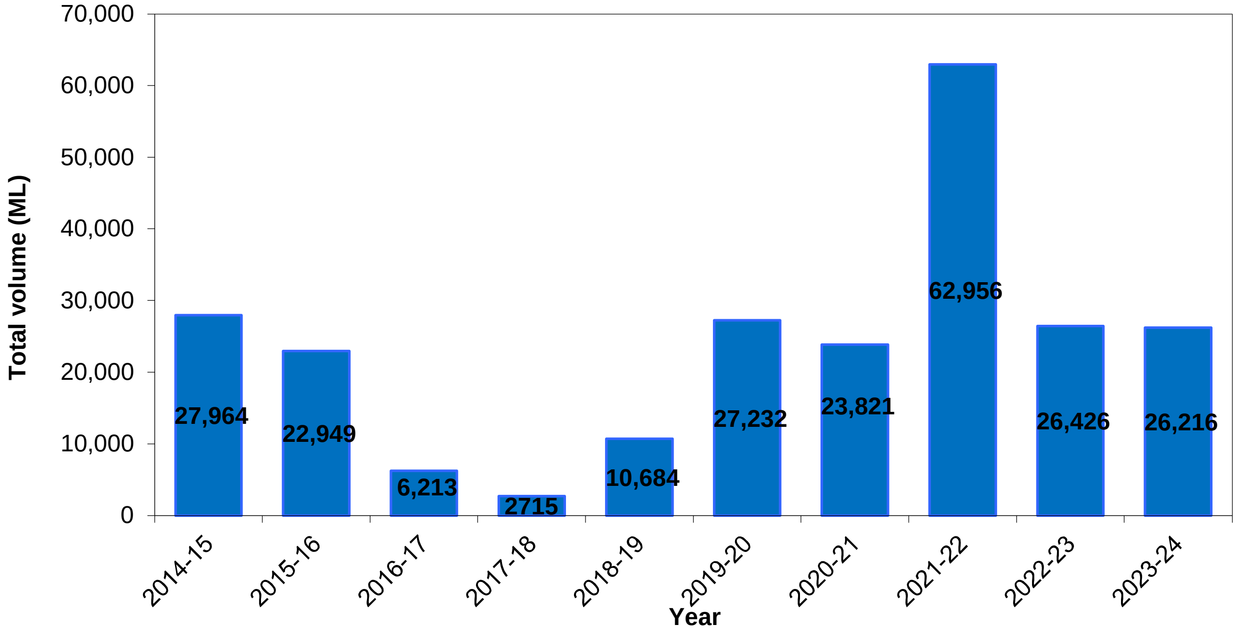


Figure 6-2 Previous 10 years of modelled wet weather overflow volumes by all ocean wastewater systems

6.1.2. Dry weather overflows

Dry weather overflow trends

Eleven large inland wastewater system networks were responsible for a total dry weather overflow volume of 2.2 ML in 2023-24 (Figure 6-3). There were no dry weather overflows recorded from the remaining four small wastewater system networks (Wallacia, Picton, North Richmond and Brooklyn). Further details on recent dry weather overflow data including 2023-24, by each inland wastewater system is presented in Volume 2 Appendix F (Table F-3).

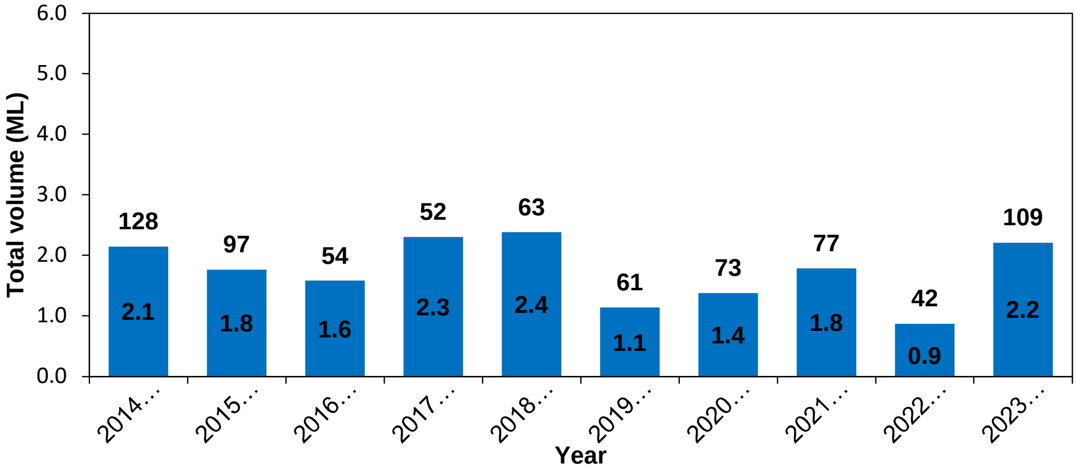
The total volume of dry weather overflows in 2023-24 from the inland catchments increased by 152% compared to 2022-23. Five inland wastewater systems contributed to 74.7 % of the total dry weather overflow volume (Penrith, St Marys, Castle Hill, Rouse Hill and West Hornsby).

From 2015-16 to 2022-23 the overflow frequency from the inland wastewater systems had been less than 100 incidents each year. There were 109 incidents in 2023-24, an increase of 67 incidents from 2022-23 to 2023-24.

Eight wastewater treatment systems draining to the ocean WRRFs were responsible for a total dry weather overflow volume of 21.2 ML in 2023-24 (Figure 6-3). Further details on recent year's dry weather overflow data including 2023-24, by each ocean wastewater system is presented in Volume 2 Appendix F (Table F-4).

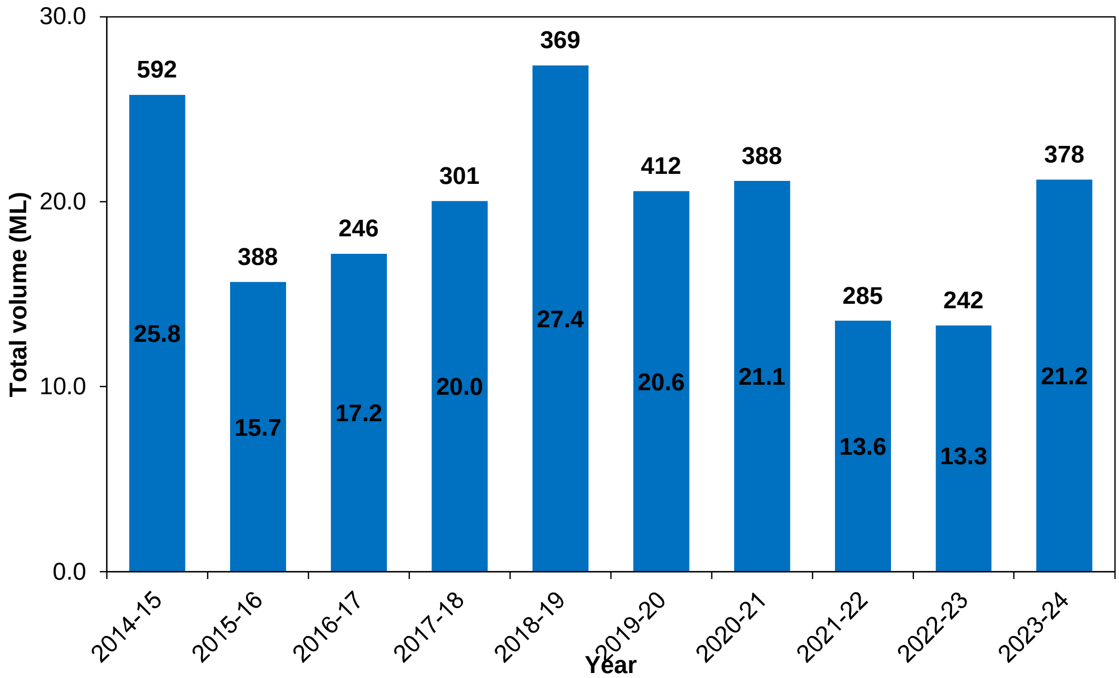
The total volume of dry weather overflows in 2023-24 from the ocean catchments increased by 59 % compared to 2022-23. The two largest systems of North Head and Malabar were responsible for 89 % of the total volume of dry weather overflows (North Head 25.8%, Malabar 63.3%).

The overflow frequency from the ocean catchments was 378 events in 2023-24 and was a 56% increase compared to last year (2022-23).



Note: number of overflows that reach waterways per year is shown at the top of each bar, volume (ML) at the middle of bar

Figure 6-3 Previous 10 years of dry weather overflow volumes that reach waterways in inland WRRF catchments



Note: number of overflows that reach waterways per year is shown at the top of each bar, volume (ML) at the middle of bar

Figure 6-4 Previous 10 years of dry weather overflow volumes that reach waterways in ocean WRRF catchments

Dry weather overflow performance (EPL)

Dry weather overflow volumes are calculated using the date and time when an incident is reported to Sydney Water, the leak/overflow cease date and time, the assumed flow rate and the number of properties upstream of the overflow. The total number of overflows and the overflow volume for each EPL and SCAMP is recorded, and the portion that reaches the receiving waters is reported via annual returns under EPL condition L7.4 for each EPL where applicable.

Twelve out of 23 wastewater systems have EPL specified limits on the number of dry weather overflow incidents reaching the waterways (Clause 7.4). Among these, three were under or equal to their limits in 2023-24 (Malabar, Winmalee and Wollongong) and nine systems exceeded their respective limits (Bondi, Cronulla, North Head, Penrith, Quakers Hill, Shellharbour, St Marys, Warriewood and West Camden).

Each SCAMP has an EPL target on the number of dry weather overflows reaching the waterways. Of the 216 SCAMPs with an EPL target (215 as Stanwell Park is combined with Engadine SCAMP), 136 (63%) were under or equal to their target. The remaining 79 (37%) areas exceeded their respective licence targets.

In 2023-24, Sydney Water experienced 11,220 chokes across all wastewater networks in relation to dry weather overflows (Sydney Water, 2024a). This was a 47% increase in network blockages compared to 2022-23. Sewer chokes are highly influenced by weather conditions. Dry conditions typically lead to an increase in chokes, whereas wet conditions lead to a decrease in chokes. The total number of wastewater overflows reaching waterways from these blockages was 487 (4.3% of total overflows). This was a 71 % increase when compared to 284 overflows reaching waterways in 2022-23.

Most of the blockages occurred in small diameter pipes resulting from a combination of factors. In 2023-24 most of the blockages (45.4%) were caused by tree roots entering through cracks, joints and private sewers. Other major causes of blockages were soft chokes due to residual solids, wet wipes, sanitary products (22.1%); debris from construction activity, broken pipes and non-flushable products (15.9%); and consolidation of fats on pipe walls from residential and commercial sources (9.2%). A more detailed analysis and performance of dry weather overflow volume and frequency by each of the SCAMPs and wastewater systems in relation to compliance limits is presented in a separate report (Sydney Water, 2022d).

The key initiatives or improvement strategies that were in place in 2023-24 to reduce the volume and frequencies of dry weather overflows reaching waterways were:

- reactive response to network blockages which involves establishing pollution controls, clearing of blockages (mainly using high-pressure water jetting equipment) and clean-up
- increased CCTV surveillance to inspect pipes after overflows reaching a waterway to identify maintenance, repair or renewal works to minimise repeat occurrence from the same asset
- early identification of blockages using online instruments to raise alarms when the level of wastewater in maintenance hole rises, and a crew can be sent to clear the sewers before the overflow occurs
- surveillance monitoring of abnormally low inflow rates at pumping stations to identify chokes and clear blockages before overflows occur

- continuous lining, where practical, of small diameter sewers that are most prone to tree root chokes caused by the high density of trees
- notification of property owners where CCTV finds tree roots entering Sydney Water's asset
- residential and business customer education campaigns which directly or indirectly helps to reduce dry weather overflows:
  - Wipes out of pipes: what should and shouldn't be flushed down the toilets
  - Other non-degradable items such as fats, oils & grease (FOG), bathroom products and sanitary wipes
  - Clean up not Down
  - It's Best to Bin It!
  - The Unflushables
  - FOG Source Control Project with business customers, initially in the Bondi WTS, which has been expanded to all food industry businesses
  - Construction industry campaign to prevent concrete from entering the sewer
- investigations, work and other activities are ongoing as a part of dry weather overflow abatement pollution reduction program (PRP) at Cronulla and North Head wastewater systems.

6.1.3. Dry weather leakage detection program

The Dry Weather Leakage Detection Program (DWLP) is a condition of Sydney Water's EPLs and has been conducted since 2006. The program is designed to identify leakage from the reticulated wastewater system and locate and repair any damaged assets. The program requires annual monitoring at 226 locations near the major stormwater outlets draining each SCAMP, and investigating the source of faecal coliforms where concentrations exceed the current EPL threshold (10,000 cfu/100mL). In 2022-23, there were 15 new SCAMPs added to the DWLP, which represent new residential areas and areas that have recently been connected to the sewer reticulation system.

SCAMP sites are visited annually, however when a site exceeds the EPL threshold for three consecutive routine sampling events, sampling frequency increases to quarterly. Conversely, if a SCAMP on a quarterly sampling regime is below the EPL threshold for three consecutive routine sampling events, it reverts to an annual sampling frequency.

In previous years, a desktop investigation was completed following every routine exceedance, to identify overflows or surcharges in the SCAMP that could cause the high faecal coliform result. It was deemed more effective to the DWLP to address an exceedance immediately, rather than delay until a desktop investigation was completed. Following EPA approval in July 2018 to improve the DWLP, desktop investigations were discontinued unless value can be added to rectifying the issue from the time involved to complete the investigation.

In 2023-24 there were 237 routine site visits for the DWLP across Sydney, Blue Mountains and the Illawarra. Of the 226 SCAMPs, 15 annually monitored sites were dry or ponded at the time of sampling indicating no dry weather leaks. 25 sites (11%) exceeded the >10,000 cfu/100 mL faecal coliform threshold at least once during the year, while 186 sites (82%) had faecal coliform results consistently below the threshold. Figure 6-5 shows the pattern of compliance for the last 10 years. All years have been compared against the EPL faecal coliform threshold (10,000 cfu/100 mL). Over the past 10 years, the percentage of sites exceeding the threshold has ranged from 5% (2022-23) to 21% (2018-19).

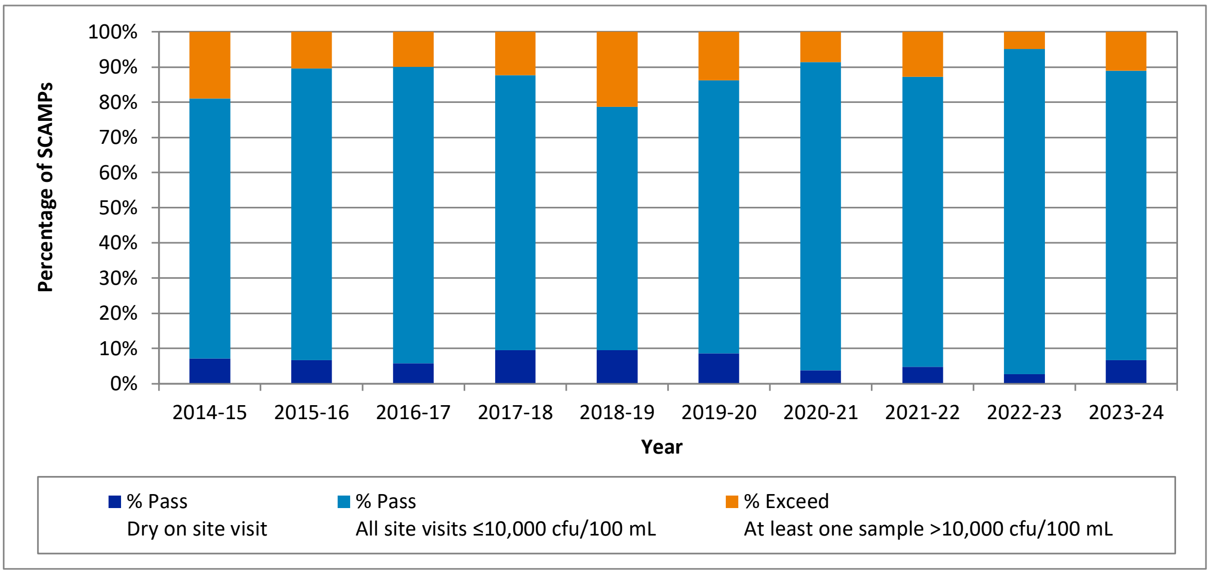


Figure 6-5 Percentage of SCAMP samples that were below (passed) or exceeded the faecal coliform threshold of 10,000 cfu/100 mL between 2014-15 and 2023- 4

Figure 6-6 displays a map of ranked SCAMP performances for the last 10 years of the program. SCAMP regions are colour-coded to represent the frequency that routine samples were observed to exceed the faecal coliform threshold of 10,000 cfu/100mL. The map shows that city and Inner West areas largely to the south of the harbour tend to have the highest percentage of faecal exceedances. Intrinsically higher wastewater leakage is associated with old and ageing wastewater infrastructure. The SCAMP that exceeded most often was Ashfield (78%), with other five other SCAMPs having increased exceedances ranked above 60% including Summer Hill (75%), Edgecliff (74%), Camperdown (70%), Woolooware (64%) and South Sydney (64%). These SCAMPs are identified by the dark orange regions. Eight SCAMPs exceeded 40-60% of the time (pale orange regions) Homebush (56%), Riverwood (50%), Liverpool (46%), Glenfield (45%), Bankstown (40%), Fairfield (40%) and South Wentworthville (40%). 38 SCAMPs exceeded 20-40% of the time (pale yellow regions), 58 sites exceeded 1- 20% of the time (pale green regions) and 116 SCAMPs were consistently below the threshold (dark green regions) and have never recorded an exceedance in this period. This includes fourteen of the new SCAMPs that were added to the DWLP in 2022-23. Investigations in the Woolooware SCAMP (on the southern side of Botany Bay) have found that elevated faecal coliform results are from a non-human source. This site has been relocated further upstream for 2024-25 following agreement with the EPA. These elevated faecal coliform results do not truly reflect the wastewater leakages within the SCAMP.

Figure 6-7 ranks the performance of SCAMPs over the most recent 3 years of the program. The key focus for the program has moved away from the Inner West region to include isolated SCAMPs in the south west and some heavily populated areas in the city where the most exceedances were recorded. The SCAMP that exceeded most often was Wollooware (86%), which is identified by the dark read areas. The reasons for the high exceedance rate are provided above and these results do not truly reflect the wastewater leakages within the SCAMP. SCAMPs with increased exceedances ranked above 60% include Edgecliff (73%), Bankstown (67%), Brighton (67%), Panania (67%), Riverwood (67%), Lidcombe (67%) and North Sydney (67%), identified as dark orange regions. Less significant exceedance levels were also evident at SCAMPs in the inner-west (pale yellow regions). The areas experiencing the greatest exceedances have trended away from the Inner West and areas with older wastewater infrastructure. This is due to successful leak investigations and repairs in these areas. In the last 3 years, 177 SCAMPs have recorded no exceedances at all, including fourteen of the new SCAMPs that were added to the DWLP in 2022-23. The SCAMPs that have increased exceedances in the last 3 years generally represent the catchments with current and ongoing source detection investigations.

Source detection work in 2023-24 identified approximately 44 individual leakage issues across 29 SCAMPs associated with Sydney Water assets and private faults. The significant findings from the SCAMPs where these faults were identified are detailed in Table 6-2Table . Additionally, special investigations completed outside of the DWLP routine monitoring program identified and rectified several faults. Investigations in the Camperdown, Edgecliff, Ashfield, Bankstown, Greenacre and Strathfield SCAMPs are ongoing. Potential sources of contamination have been identified, however subsequent sampling identified ongoing issues requiring further investigation and rectification.

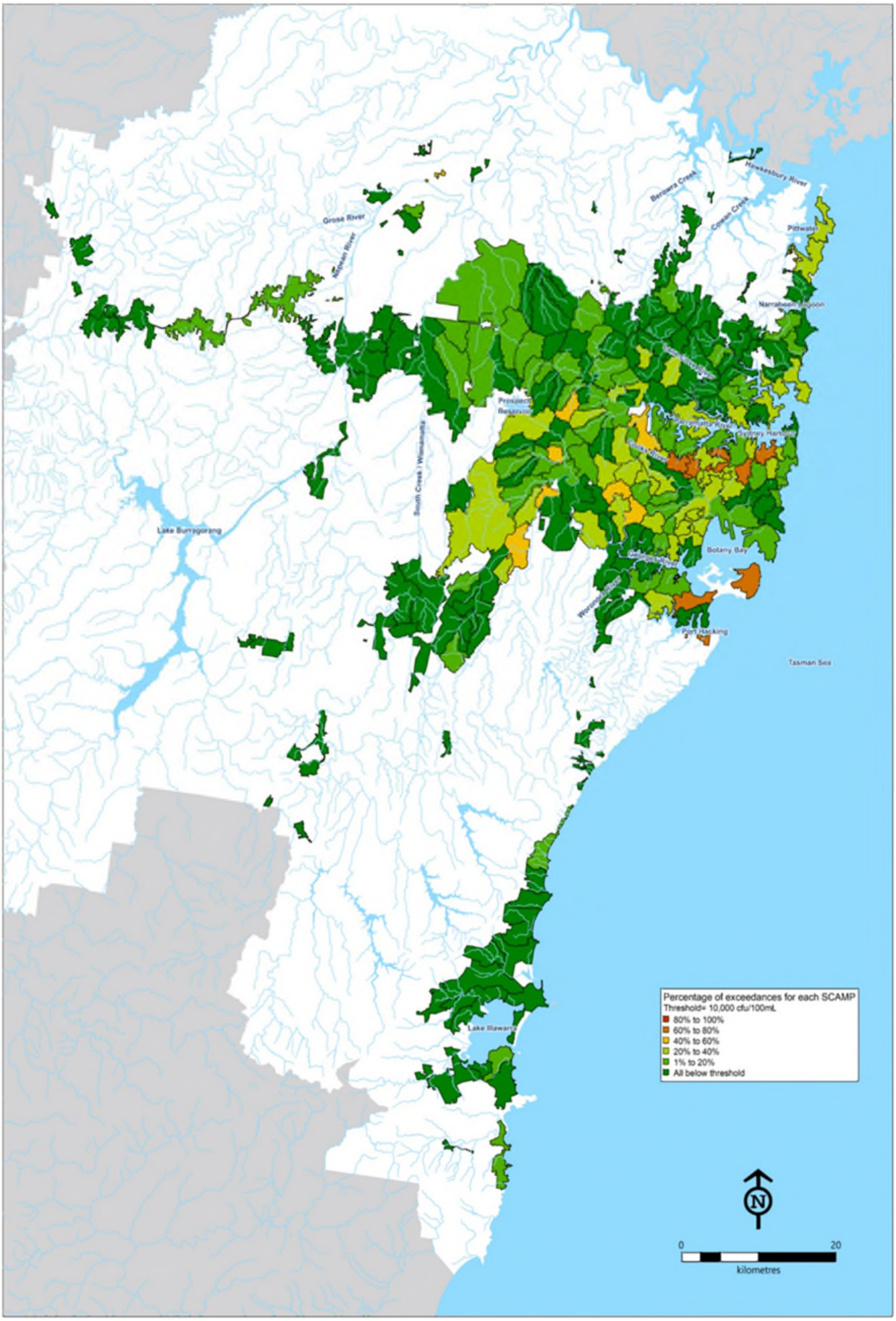


Figure 6-6 Percentage of exceedances for each SCAMP over the last 10 years of the DWLP, including 2023-24 data

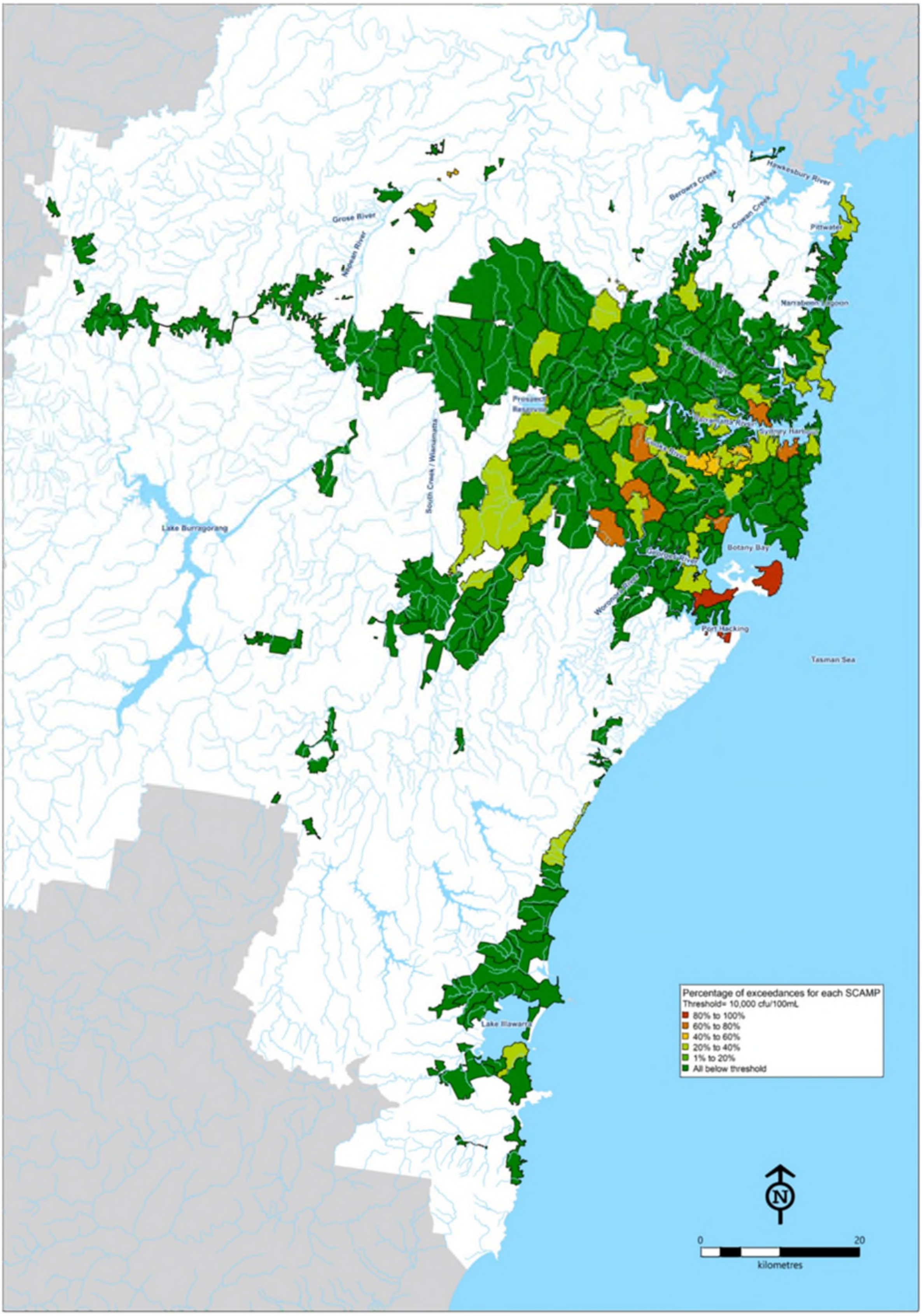


Figure 6-7 Percentage of exceedances for each SCAMP over last 3 years of the DWLP, including 2023-24 data

Table 6-2 SCAMP catchment investigation findings and status for the 2023-24 period

SCAMP	Outcome of investigations	Fault status
Camperdown	This catchment investigation has been ongoing since 2012. The routine quarterly samples for the 2023-24 fiscal period had no threshold exceedances. Private Leak Fowler and Tooth Lane A Networks investigation in July 2023 returned elevated bacteriological results from a stormwater outlet to the street on the corner of Tooth Lane and Fowler Lane. Networks called this into the Sydney Water emergency response line (WO 89229435). The crew attending deemed the fault private and reported it to the property owner to be rectified. Signage was installed indicating that there was sewage in the gutter occurring from a private source. In October 2023, Networks returned and found that the stormwater on the corner of Tooth Lane and Fowler Lane was still returning elevated bacteriological results. Networks conducted dye testing of several properties, with no dye observed in the stormwater. In December 2023, Networks investigated in coordination with Inner West Council and identified a private stormwater pit in 35-41 Mallett Street with elevated bacteriological results. Networks liaised with Inner West Council to have this private fault rectified. Networks reattended site and observed the outlet was dry confirming that the private fault was rectified. In March 2024, a stormwater pit in Fowler Lane just downstream of the private fault at 35-41 Mallett Street returned elevated bacteriological results during an FST investigation. In April and May 2024, dye testing of private and Sydney Water assets on Gibbins Street, Tooth Lane and Mallett Street returned no conclusive results. In June 2024, Networks booked in CCTV to investigation Sydney Water sewer assets. Roberts Lane An FST investigation in July 2023 indicated continued elevated bacteriological results at a site in Roberts Lane. Networks followed up with Sydney Water Network Repairs about the lining Work Order (WO) that was created and found that the full lining was not going to be installed for an extended period of time. Networks re-created the previous repair WOs to be installed on the sewer assets in Roberts Lane in the interim while awaiting the full liner to be installed. These WOs were completed in November 2023. In December 2023 an FST investigation at that the site in Roberts Lane was still elevated for bacteriological results. FST conducted dye testing of 7 and 9 Roberts	WO 89640148 - Manhole rehab - Asset 1117152 WO 89707586 - Manhole rehab - Asset 1399196 WO 89921462 – Manhole rehab - Asset 1401928 WO 90058956 - Patch liner - Asset 3048301 WO 90058952 - Patch liner - Asset 3048301 WO 90058948 - Patch liner - Asset 3048301 Private faults 5 Roberts Street, 7 Roberts Street and 9 Roberts Street, Newtown (ongoing). Private fault at 35-41 Mallett Street, Camperdown.

SCAMP	Outcome of investigations	Fault status
	Street, both returned a positive dye testing result in the stormwater. FST also conducted dye testing on the Sydney Water sewer assets, with no dye present in the stormwater. In February 2024, FST conducted dye testing from properties on Federation Street, no dye was present in the stormwater in Roberts Lane. In March 2024, Networks met with Inner West Council in Robert Lane and conducted dye testing of the Sydney Water sewer assets, no dye was present in the stormwater. On the same day Networks dye tested 5 ,7 and 9 Roberts Street separately with different colours, each of these colours was then present in the storm water in Roberts Lane. Inner West Council liaised with property owners to have the private sewer networks rectified. In late June 2024, the stormwater in Roberts Lane returned elevated bacteriological results, indicating ongoing leakage. This remains open for investigation. Mallett Street & Tooths Place In July 2023 an FST investigation at a site on Mallett Street indicated elevated bacteriological results. Networks investigated the site and found that the stormwater was blocked with debris and had no flow. Networks requested Inner West Council drain and clean the stormwater pits. FST sampling in October 2023 returned results under the threshold after networks had received communication that the stormwater had been drained and cleared. Gehrig Lane In September 2023, Networks conducted CCTV of the sewer assets in Gehrig Lane. Multiple areas of damage requiring rectification were observed and work orders were created for the repairs. In April 2024, all sites in Gehrig Lane returned results under the threshold.	
Edgecliff	This catchment investigation has been ongoing since 2013. The routine quarterly samples for the 2023-24 fiscal period had threshold exceedances in quarters one, three and four (12,000 cfu/100mL, 13,000 cfu/100mL and 21,000 cfu/100mL respectively). An FST investigation in July 2023 returned results slightly above the threshold at a site at Boundary Street and Comber Street. Subsequent visit in February 2024 returned results under the threshold at this site.	WO 89713476 - Full lining - Asset 2609046 (in progress) WO 89620450 - Manhole rehab - Asset 1043076 WO 89713637 - Manhole rehab - Asset 1045384 (in progress) WO 89712877 - MH cover replacement - Asset 1045384 WO 89713571 - Dig and repair - Asset 2750263

SCAMP	Outcome of investigations	Fault status
	Networks conducted a CCTV investigation in August and September of 2023 around Liverpool St, Boundary St and Leichhardt Street and found extensive damage, WOs were subsequently created to rectify the damage. An FST investigation in February and April 2024 returned slightly elevated results at a site on Boundary Street downstream of ongoing rectification WOs. In May 2024, precautionary sampling of Rushcutters Bay downstream of the routine site returned results under the ANZG guidelines for a secondary contact waterway.	
Sydney East (city)	The routine sample collected in April 2024 exceeded the faecal coliform threshold (65000 cfu/100ml). The resample had a faecal coliform concentration of 1800 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Sydney West (city)	The routine sample collected in May 2024 exceeded the faecal coliform threshold (34000 cfu/100ml). The resample had a faecal coliform concentration of 1500 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Miranda	The routine sample collected in December 2023 exceeded the faecal coliform threshold (11000 cfu/100ml). The resample had a faecal coliform concentration of 330 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Woolooware	The routine quarterly samples for the 2023-24 fiscal period had threshold exceedances in quarters two, three and four (600,000 cfu/100mL, 17,000 cfu/100mL and 28,000 cfu/100mL respectively). The resample in quarter 2 (December 2023) had a faecal concentration of 1300000 cfu/100mL, this was above the threshold and an investigation was commenced. In January 2024 investigations with Microbial Source Tracking (MST) analysis indicated that the elevated bacteriological counts were not from a human source. Consequently, the investigation was closed. The following quarterly routine samples had additional MST sampling done to confirm that the elevated bacteriological counts were not from a human source.	No rectification actions taken at this time.
Ashfield	This catchment investigation has been ongoing since 2012. The routine quarterly samples for the 2022-23 fiscal period had threshold exceedances in quarters one, three and four (11,000 cfu/100mL, 13000 cfu/100mL and 26000 cfu/100mL respectively). Alt Street	Private fault at 7 Wetherill Street, Croydon (ongoing) Private Fault at 64 Alt Street, Ashfield Private fault at 9 Albert Parade, Ashfield Private fault at 42 Alt St, Ashfield (ongoing)

SCAMP	Outcome of investigations	Fault status
	An FST investigation in August 2023 returned elevated bacteriological results at a site in Margaret Street. FST conducted dye testing and had a positive result from 64 Alt Street. In August 2023, Inner West council confirmed that damage had been rectified to the private line of 64 Alt Street. FST sampling in late August indicated ongoing sewer leakage, FST dye testing in September of 64 Alt Street indicated further damage to the private network. Sampling in November 2023 indicated that the private at 64 Alt Street had been rectified, however, sites in the adjacent stormwater branch in Alt Lane remained elevated. Further investigation by FST and Networks in December 2023 and March 2024 confirmed private faults at 9 Albert Parade and 42 Alt Street that were contributing to the elevated bacteriological results at the site in Margaret Street. Both private faults were reported to Inner West Council. In February 2024, Networks received confirmation of the completion of rectification works at 9 Albert Parade; subsequent FST sampling confirmed this. In March 2024, Networks met with council and repeated the positive dye test at 42 Alt Street. This private fault at 42 Alt Street is ongoing. <u>Church Street</u> FST sampling in August 2023 returned elevated results in the stormwater at Church St Burwood. Considering the extensive investigations and dye testing that occurred at this location in the previous financial year no further dye testing was conducted. In September 2023, Networks requested Burwood Council pump out and clean the affected pit; Networks did not receive confirmation from Council that this stormwater pit had been cleaned out. In October 2023, Networks conducted a CCTV investigation of the sewer assets in the vicinity of the affected site in Church Street, which identified damage to the sewer assets and subsequent rectification WOs were created. <u>Wetherill Street</u> In August 2023, an FST investigation found an outlet at the rear of Wetherill Street to have field indications of sewage (high ammonia indicator), however, the flow was too low to sample. Dye testing of the Sydney Water sewer main and 7 Wetherill Street did not return a positive result. In May 2024, an FST investigation returned elevated bacteriological results at the site at the rear of 7 Wetherill Street. FST conducted dye testing on the Sydney Water sewer assets and did not observe any dye in the stormwater. Several properties on Wetherill Street were dye tested; a positive dye test was recorded from 7 Wetherill Street. This private fault was reported to the Inner West Council.	WO 90094539 - Junction jetting - Asset 3804103 (in progress) WO 90098886 - Junction jetting - Asset 3804095 (in progress) WO 90099638 - Patch liner - Asset 3804095 WO 90094580 - Manhole rehab - Asset 1097773

SCAMP	Outcome of investigations	Fault status
	Etonville Parade and Heighway Avenue In June 2024, the routine monitoring site returned elevated bacteriological results. The Sydney Water SCENT (Sydney Canine Environmental Networks Team) leak detection dogs traversed Iron Cove Creek and identified 2 leakage points which were subsequently sampled by FST. Both sites returned bacteriological results above the threshold. Both sites are known faults at Etonville Parade and Heighway Avenue. Networks is liaising with Inner West council about these faults.	
Bexley	The routine sample collected in July 2023 exceeded the faecal coliform threshold (13000 cfu/100ml). The resample had a faecal coliform concentration of 1100 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Bankstown	This investigation has been ongoing since 2021. The routine sample collected in March 2024 exceeded the faecal coliform threshold (170,000 cfu/100ml). The resample had a faecal coliform concentration of 5900 cfu/100ml, below the threshold value. Brancourt Avenue In July 2023, Sydney Waters customer advocate team was working with the owner of 30 Brancourt Avenue to stop waste from their chicken coup from reaching the canal. They also contacted 3 Allum Street and asked that they stop throwing their dogs waste into the canal. FST investigations in October 2023 also located seepage from the canal wall adjacent to 31 Brancourt Avenue and confirmed a private fault from the property with dye testing. After confirmation of rectification had been received from the council, FST conducted follow up sampling in December and confirmed the fault had been rectified. Shenton Avenue In July 2023, FST investigations detected elevated bacteriological results near Shenton Avenue. In September 2023, further investigations with the SCENT dog leak detection team located wastewater seeping from a wall in the side of the stormwater canal adjacent to 45 Shenton Avenue, Bankstown. FST dye testing confirmed the seepage was a private fault from 45 Shenton Avenue and the local council was contacted. No confirmation of rectification has been received from the council and sampling sites downstream remain above the exceedance threshold. This branch of investigation is ongoing.	Private fault at 45 Shenton Avenue, Bankstown (ongoing) Private fault at 31 Brancourt Avenue, Bankstown

SCAMP	Outcome of investigations	Fault status
	Bankstown Sports Complex In March 2023, a sample collected from a stormwater pit within the Bankstown Sports Complex returned elevated bacteriological results. As there are no nearby Sydney Water assets the matter was forwarded to the council to have the stormwater pits cleaned to check for ongoing leakage. A sample collected and analysed using MST methods in May 2024 indicated the elevated bacteriological results were not from human sources. Warren Avenue Throughout September 2023 to March 2024, Networks and Business Customer teams conducted extensive investigations into the ongoing elevated bacteriological results at 29-31 Warren Avenue, Bankstown. Some issues were located within their trade waste system that were rectified; however, elevated bacteriological results persisted. MST sampling and analysis conducted in March 2024 confirmed the source of the pollution was not from human sources and the investigation was handed over to the Business Customer representatives for further investigation.	
Brighton	The routine sample collected in July 2023 exceeded the faecal coliform threshold (11000 cfu/100ml). The resample had a faecal coliform concentration of 4300 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Beverly Hills	This catchment investigation has been ongoing since 2020. The routine quarterly samples for the 2023-24 fiscal period had no threshold exceedances. In July 2023, Networks met council on site and repeated a positive dye test performed by FST at 2 Dennis Place, Beverly Hills, confirming a private fault. Council arranged with the owner to have the fault rectified and follow up sampling in August 2023 confirmed this fault had been rectified. In August 2023, FST traced sewage field indicators to 12 Gregory Crescent where sewage was observed flowing from a drainage line into the gutter. FST carried out dye testing but were unable to locate the source of the pollution. The fault was reported to Sydney Waters emergency hotline (WO 89398834) so that signage and containment could be installed. After a CCTV investigation, several rectification WOs were created. Follow up sampling in April 2024 indicated the fault had been rectified. In January 2024, FST sampled an outlet at 203 Penshurst St, Beverly Hills which returned elevated bacteriological results. Networks performed dye testing but were unable to locate the source of the leak. Despite several attempts to resample the	WO 89587186 – Patch liner – Asset 3337668 WO 89587193 – Patch liner – Asset 3337668 WO 8964137 – Full liner – Asset 3338520 (in progress)

SCAMP	Outcome of investigations	Fault status
	affected outlet, the flow from the outlet remained too low to collect a sample. This investigation was subsequently closed due to no risk of downstream impact.	
Drummoyne	The routine sample collected in August 2023 exceeded the faecal coliform threshold (67000 cfu/100ml). The resample had a faecal coliform concentration of 440 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Greenacre	This catchment investigation has been ongoing since 2018. The routine quarterly samples for the 2023-24 fiscal period had no threshold exceedances. In February 2024, FST reported evidence of a sewage overflow in the stormwater canal and reported the overflow to the Sydney Water emergency line (WO 91059188). Denman Avenue In July 2023, Networks and the SCENT detection dog team investigated elevated counts upstream of Hillcrest Street. The dogs indicated the presence of sewage at an outlet behind 9 Ferguson Avenue, Wiley Park. FST continued sampling and dye testing on Denman Street in August 2023 with no dye observed in the stormwater. Networks conducted a CCTV investigation of Sydney Water assets and located several points of damage that were subsequently rectified. Robinson Street FST sampled the previously affected stormwater pit in Robinson Street North in October 2023 which returned elevated bacteriological results. In December 2023, Networks met with local council and the homeowner of 5 Robinson Street to repeat previously confirmed dye test for a private fault. Dye testing of the private line and Sydney Waters assets confirmed ongoing private fault. Once the fault at number 5 was confirmed to be rectified, sampling in March 2024 found bacteriological counts remained elevated. Further dye testing was conducted in April 2024 with local council present. Dye testing from the Sydney Water sewer main did not result in any dye in the stormwater, however dye testing of 3 Robinson Street North returned a positive result of dye in the stormwater pit. Due to some damage to the junction where this property joins Sydney Water's asset, works to rectify this damage were booked in before the homeowner will be required to investigate their privately owned line should the elevated bacteriological results continue. Defoe Street	Private fault at 5 Robinson Street North, Wiley Park (ongoing) WO 90784289 – Dig and repair – Asset 3339142 WO 90784346 – Dig and repair – Asset 3339142 WO 90784404 – Junction jetting – Asset 3339138 WO 90784546 – Junction jetting – Asset 3339658 WO 90784581 – Junction jetting – Asset 3339658 WO 90809528 – Patch liner – Asset 3339658 (in progress) WO 90837684 – Dig and repair – Asset 3336402 (in progress) WO 90837907 – Full liner – Asset 3336402 (in progress) WO 90838234 – Junction jetting – Asset 3336402 WO 92242605 – Dig and repair – Asset 3626881 (in progress)

SCAMP	Outcome of investigations	Fault status
	In August 2023, Networks met with council to dye test from the granny flat of 57 Defoe Street, Wiley Park. No dye was observed in the stormwater canal. FST attended site in September 2023 and the flow was no longer present indicating a fault had been rectified. Ferguson Avenue In January & February 2024, Networks and FST investigated the elevated bacteriological counts at Ferguson Avenue with no conclusive dye testing. CCTV of Sydney Water assets was conducted in February 2024 and multiple rectification WOs were created and are waiting to be completed.	
Homebush	This catchment investigation has been ongoing since 2018. The routine quarterly samples for the 2023-24 fiscal period had no threshold exceedances. In July 2023, Networks and council investigated 167-173 Parramatta Road, Homebush and located a toilet that was leaking into a drainage line. Follow up sampling at this property later that month returned bacteriological results below the exceedance threshold. Between August to December 2023, Networks and plumbers investigated elevated counts coming from within Sydney Markets. MST samples collected at the routine monitoring site and the affected outlet into the canal just downstream of The Crescent indicated the majority of the bacteriological results were not from human sources. The matter was reported to Sydney Markets for them to investigate. This investigation was subsequently closed.	Private fault at 167-173 Parramatta Road, Homebush
Hoxton Park	The routine sample collected in January 2024 exceeded the faecal coliform threshold (46000 cfu/100ml). The resample had a faecal coliform concentration of 7900 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Leichhardt	The routine sample collected in August 2023 exceeded the faecal coliform threshold (33000 cfu/100ml). The resample had a faecal coliform concentration of 1500 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Panania	The routine sample collected in November 2023 exceeded the faecal coliform threshold (38,000 cfu/100ml). The resample had a faecal coliform concentration of 57,000 cfu/100mL, so an investigation was commenced. Initial investigations in December 2023, saw bacteriological results indicate the source of the leakage was on Benfield Parade. Follow up sampling in January 2024 returned	No rectification actions taken at this time.

SCAMP	Outcome of investigations	Fault status
	faecal coliform counts below the exceedance threshold at all previously elevated sites. This investigation was subsequently closed.	
Riverwood	The routine sample collected in March 2024 exceeded the faecal coliform threshold (19000 cfu/100ml). The resample had a faecal coliform concentration of 2000 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Strathfield	This catchment investigation has been ongoing since 2021. The routine quarterly samples for the 2023-24 fiscal period had no threshold exceedances. Station Street Resampling of sites above the exceedance threshold in the 22-23 FY collected in August 2023 remained elevated. Further sampling in September 2023 returned results now below the exceedance threshold. Carrington Avenue Follow up sampling conducted throughout the year to monitor these sites while rectification work was being conducted indicated evidence of ongoing leakage. Awaiting remaining rectification workorders to be completed. George Street In August and September 2023, FST traced elevated ammonia from an outlet in Powell's Creek to a private stormwater pit at 1/5 George Street, North Strathfield. Based on the lack of nearby Sydney Water assets and no dye observed in the affected pit when the sewer main was dye tested, the issue was deemed to be private and reported to council. After council had reported that the fault had been rectified, FST attended the site in February 2024 for follow up sampling. No sample was able to be collected due to the very low flow within the pit and no evidence of grey staining was observed. A sample collected at the outlet into the canal in November 2023 returned bacteriological results below the exceedance threshold meaning there was no downstream impact from this fault. Pilgrim Avenue In May 2024, FST located evidence of sewage in Powell's Creek from an outlet at the rear of 7 Pilgrim Avenue, Strathfield. FST investigated and located an overflowing boundary trap at the property. The overflow was reported to the Sydney Water emergency phone line (WO 91866360). Crews reported the fault as private and strata	Private fault at 1/5 George Street, North Strathfield

SCAMP	Outcome of investigations	Fault status
	was notified for rectification. Follow-up sampling in June 2024 found the overflow had ceased and the previously affected outlet had no flow.	
Summer Hill	The routine sample collected in August 2023 exceeded the faecal coliform threshold (19,000 cfu/100ml). The resample had a faecal coliform concentration of 15,000 cfu/100mL, so an investigation was commenced. Initial investigations in August and September 2023 led FST to Carrington Street, Summer Hill. Dye testing was conducted in the area with no dye being observed in the stormwater. Follow up sampling in December 2023 returned all previously affected sampling sites below the exceedance threshold. The investigation was subsequently closed.	No rectification actions taken at this time.
Balgowlah	The routine sample collected in July 2023 exceeded the faecal coliform threshold (20000 cfu/100ml). The resample had a faecal coliform concentration of 760 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Dundas Valley	The routine sample collected in February 2024 exceeded the faecal coliform threshold (12000 cfu/100ml). The resample had a faecal coliform concentration of 8200 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Holroyd	The routine sample collected in August 2023 exceeded the faecal coliform threshold (20000 cfu/100ml). The resample had a faecal coliform concentration of 23,000 cfu/100mL, so an investigation was commenced. An investigation in September 2023 returned all results under the threshold. This investigation was subsequently closed.	No rectification actions taken at this time.
Hornsby	The routine sample collected in December 2023 exceeded the faecal coliform threshold (14000 cfu/100ml). The resample had a faecal coliform concentration of 1000 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Lidcombe	The routine sample collected in August 2023 exceeded the faecal coliform threshold (15000 cfu/100ml). The resample had a faecal coliform concentration of 14,000 cfu/100mL, so an investigation was commenced. Investigations in September and December 2023 returned elevated bacteriological results at and just upstream of the routine monitoring site. In January 2024, an	No rectification actions taken at this time.

SCAMP	Outcome of investigations	Fault status
	investigation returned results below the threshold at all previously elevated sites. This investigation was subsequently closed.	
Manly	The routine sample collected in July 2023 exceeded the faecal coliform threshold (45000 cfu/100ml). The resample had a faecal coliform concentration of 6800 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Naremburn	The routine sample collected in July 2023 exceeded the faecal coliform threshold (12000000 cfu/100ml). The resample had a faecal coliform concentration of 2100 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
North Sydney	The routine sample collected in July 2023 exceeded the faecal coliform threshold (31000cfu /100ml). The resample had a faecal coliform concentration of 1900 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.
Blacktown	The routine sample collected in November 2023 exceeded the faecal coliform threshold (23000cfu /100ml). The resample had a faecal coliform concentration of 5500 cfu/100ml, below the threshold value. This investigation was subsequently closed.	No rectification actions taken at this time.

6.2. Recreational water quality – harbour and beaches

Altogether there were 936 observations when *Enterococci* levels were above the ANZG (2018) primary contact guideline for recreational waters (35 cfu/100mL) at 111 of the 115 Beachwatch and Harbourwatch sites during the 2023-24 reporting year. Avalon Beach and Whale Beach from Northern Sydney, and Fishermans Beach and Wollongong Beach from Wollongong were the only sites where *Enterococci* levels were below the primary contact guideline throughout the year. There were one or more *Enterococci* exceedances above the secondary contact guideline for recreational waters (230 cfu/100 mL) at 85 sites (74% of all sites, Table 6-3).

Based on the assessment of high conductivity (≥30,000 μS/cm) and dry weather criteria (72-hour rainfall of ≤2 mm), 317 of these individual primary contact exceedances were identified across 87 sites for further investigation to determine if they had been impacted by dry weather overflows (Volume 2, Appendix G, Table G-4).

These 317 dry weather Beachwatch exceedances were from 87 beaches (76% of all sites). The investigation focused on assessing the data collected at sites sampled under the Environmental Response (ER) and Dry Weather Leakage (DWL) programs. All sampling data for these projects was extracted and then filtered by sites that exceeded primary contact guidelines. This site list was rationalised to only include wastewater inflow points (the point at which a surcharge reaches any waterway) or any site sampled that is deemed to be a primary or secondary contact waterway. This sampling information was then mapped against the 317 Beachwatch exceedances. Any site sampled under the ER or DWL program that met the above criteria and occurred within seven days before and seven days after the Beachwatch exceedance was deemed to have a potential impact.

Using the above methodology for 2023-24 data, wastewater overflows from Sydney Water's networks may have contributed to elevated *Enterococci* at 17 of the 115 Beachwatch sites (15% of all sites) on 31 occasions. Eight of these sites had only one incident. There were two incidents at Bilarong Reserve, Narrabeen Lagoon (Birdwood Park), Boat Harbour, Kyeemagh Baths, Clontarf Pool, and Murray Rose Pool; three incidents at Como Baths and Oatley Bay Baths; and five incidents at Foreshores Beach during 2023-24, where Sydney Water's network may have contributed to these exceedances. All impacted events are listed in Table 6-4.

27 wastewater overflow impacted sites from the last two years and respective beach suitability grades as determined by the DCCEEW (DCCEEW 2023 and DCCEEW 2024) were compared in Table 6-3. The beach suitability grades had deteriorated at two of these sites and remained stable at the remaining sites compared to last year's (2022-23) results.

- Four of the sites were consistently impacted by wastewater overflows for the last two years. These were Carss Point Baths, Foreshore Beach, Kyeemagh Baths and Murray Rose Pool.
- Of the three sites where beach suitability grades deteriorated, they were impacted by wastewater overflows in 2023-24 (Boat Harbour, Bronte Beach and Murray Rose Pool). Out of these three, only Murray Rose Pool was impacted in 2022-23.

Table 6-3 Summary of the number of beach monitoring sites that exceeded the primary or secondary contact guidelines that may have been impacted by wastewater overflows during 2023-24

Catchment	Sub-catchment	Number of sites						Overflow incidents impacting waterways
		Total monitoring sites	One or more secondary contact exceedance	One or more primary contact exceedance	One or more dry weather exceedance (primary contact)	Sewage overflow impacted sites	Number of incidents	Name of the beach/ site
Sydney Coastal Beaches	Northern Sydney	22	14	20	12	2	4	Bilarong Reserve, Narrabeen Lagoon (Birdwood Park)
	Central Sydney	11	11	11	11	3	3	Bronte Beach, Malabar Beach, Maroubra Beach
	Southern Sydney	8	6	8	8	1	2	Boat Harbour
Sydney Harbour	Botany Bay and Georges River	15	15	15	15	5	14	Carss Point Baths, Como Baths, Foreshores Beach, Kyeemagh Baths, Oatley Bay Baths
	Port Hacking	5	3	5	5	2	2	Jibbon Beach, Lilli Pilli Baths
	Port Jackson	15	13	15	11	2	3	Murray Rose Pool, Woolwich Baths
	Middle Harbour	11	10	11	10	2	3	Chinamans Beach, Clontarf Pool
	Pittwater	10	4	10	7	0	0	None
Illawarra	Wollongong	11	3	9	6	0	0	None
	Shellharbour	3	2	3	1	0	0	None
	Bombo	4	4	4	1	0	0	None
Total number of sites		**115**	**85**	**111**	**87**	**17**	**31**	**-**
Percent of all sites (%)		**-**	**74%**	**97%**	**76%**	**15%**	**-**	**-**

Table 6-4 Short-listed beaches, harbour and estuarine monitoring sites with possible pollution from wastewater overflows during 2023-24

Site Name	Sampling Date	*Enterococci* (≥35 cfu/100mL)	Conductivity (≥30,000 µS/cm)	Incident Date	Comments
Sydney Coastal Beaches					
Bilarong Reserve	29/02/2024	360	31660	4/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at South Creek, 270m northwest of 14 James Wheeler Place exceeded the primary contact threshold.
Bilarong Reserve	6/03/2024	1600	34850	4/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at South Creek, 270m northwest of 14 James Wheeler Place exceeded the primary contact threshold.
Boat Harbour	4/04/2024	150	53500	6/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Boat Harbour, 110m southwest of Boat Harbour Aquatic Reserve exceeded the primary contact threshold.
Boat Harbour	12/04/2024	40	51900	6/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Boat Harbour, 110m southwest of Boat Harbour Aquatic Reserve exceeded the primary contact threshold.
Bronte Beach	18/04/2024	300	52100	12/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Bronte Beach, 50m south of 9 Bronte Marine Drive exceeded the primary contact threshold.
Malabar Beach	1/11/2023	42	53800	6/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Malabar Beach 130m northeast of 53 Bay Parade exceeded the primary contact threshold.
Maroubra Beach	13/11/2023	210	53400	13/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Samples collected at Unnamed creek 400m southeast of 15 Byrne Crescent, downstream of stormwater outlet exceeded the primary contact threshold.

Site Name	Sampling Date	*Enterococci* (≥35 cfu/100mL)	Conductivity (≥30,000 µS/cm)	Incident Date	Comments
Narrabeen Lagoon (Birdwood Park)	12/03/2024	130	40200	4/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Narrabeen Lagoon, from boat ramp, 110m north of 36 The Esplanade exceeded the primary contact threshold.
Sydney Coastal Beaches					
Narrabeen Lagoon (Birdwood Park)	12/03/2024	130	40200	4/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Narrabeen Lagoon, from boat ramp, 110m north of 36 The Esplanade exceeded the primary contact threshold.
Sydney Harbour and Estuaries					
Carss Point Baths	12/12/2023	140	48300	19/12/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River 100m south of Carss Cottage Museum exceeded the primary contact threshold.
Chinamans Beach	20/02/2024	750	44880	20/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Clontarf Beach, 40m west of 31 Monash Crescent exceeded the primary contact threshold.
Clontarf Pool	26/02/2024	52	47700	23/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Clontarf Sea Pool, 160m southwest of 1 Peronne Avenue. exceeded the primary contact threshold.
Clontarf Pool	16/04/2024	150	45000	9/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Clontarf Beach Sea Pool exceeded the primary contact threshold.
Como Baths	2/11/2023	39	52900	3/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River 10m north of Como tidal baths exceeded the primary contact threshold.

Site Name	Sampling Date	*Enterococci* (≥35 cfu/100mL)	Conductivity (≥30,000 µS/cm)	Incident Date	Comments
Como Baths	8/11/2023	60	49000	3/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River 10m north of Como tidal baths exceeded the primary contact threshold.
Como Baths	14/11/2023	340	54700	13/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River 10m north of Como tidal baths exceeded the primary contact threshold.
Sydney Harbour and Estuaries					
Foreshores Beach	14/11/2023	100	53200	13/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Foreshore Beach, 170m southeast of Mill Stream Lookout exceeded the primary contact threshold.
Foreshores Beach	13/03/2024	80	48700	18/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Foreshore Beach, 180m southeast of Mill Stream lookout exceeded the primary contact threshold.
Foreshores Beach	2/04/2024	76	52300	10/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Foreshore Beach at end of Mill Stream Lookout exceeded the primary contact threshold.
Foreshores Beach	9/04/2024	290	36000	10/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Foreshore Beach at end of Mill Stream Lookout exceeded the primary contact threshold.
Foreshores Beach	17/04/2024	200	35490	10/04/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Foreshore Beach at end of Mill Stream Lookout exceeded the primary contact threshold.
Jibbon Beach	19/12/2023	100	53800	24/12/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Port Hacking, 50m southeast of 4 Cowra Place exceeded the primary contact threshold.

Site Name	Sampling Date	*Enterococci* (≥35 cfu/100mL)	Conductivity (≥30,000 µS/cm)	Incident Date	Comments
Kyeemagh Baths	27/02/2024	60	48000	28/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Muddy Creek, 70m west of Bayside Community Recreation Club, 60m downstream of Bestic Street road bridge exceeded the primary contact threshold.
Kyeemagh Baths	13/03/2024	270	50400	12/03/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Muddy Creek, 70m west of Bayside Community Recreation Club, 60m downstream of Bestic Street road bridge exceeded the primary contact threshold.
Sydney Harbour and Estuaries					
Lilli Pilli Baths	1/03/2024	74	52100	29/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Unnamed creek, adjacent to 19 Tallong Place exceeded the primary contact threshold.
Murray Rose Pool	2/02/2024	110	52400	24/01/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Double Bay Beach, 15m northwest of Double Bay Marina exceeded the primary contact threshold.
Murray Rose Pool	14/02/2024	270	51200	12/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Double Bay Beach, 15m northwest of Double Bay Marina exceeded the primary contact threshold.
Oatley Bay Baths	8/11/2023	67	47800	12/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River, approximately 20m northwest of 141 Queens Road exceeded the primary contact threshold.
Oatley Bay Baths	14/11/2023	100	46100	12/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Georges River, approximately 20m

Site Name	Sampling Date	*Enterococci* (≥35 cfu/100mL)	Conductivity (≥30,000 µS/cm)	Incident Date	Comments
					northwest of 141 Queens Road exceeded the primary contact threshold.
Oatley Bay Baths	27/02/2024	69	40430	28/02/2024	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Connells Bay, 40m southwest of 13 Morshead Drive, at stormwater outlet exceeded the primary contact threshold.
Woolwich Baths	16/11/2023	110	51900	11/11/2023	Overflow incident had the potential to impact *Enterococci* levels. Sample collected at Woolwich Baths, Lane Cove River, 60m north of 78 Woolwich Road exceeded the primary contact threshold.

Table 6-5 Summary of the wastewater overflow impacted sites, beach suitability grades and comparison between 2022-23 and 2023-24

Region and site names	2022-23	2023-24	Trend (Last two FY)
Sydney beaches			
Bilarong Reserve		Yes	Stable
Boat Harbour		Yes	Deteriorated
Bronte Beach		Yes	Deteriorated
Malabar Beach		Yes	Stable
Maroubra Beach		Yes	Stable
Narrabeen Lagoon (Birdwood Park)		Yes	Stable
Sydney harbours and estuaries			
Bayview Baths	Yes		Stable
Carss Point Baths	Yes	Yes	Stable
Chinamans Beach		Yes	Stable
Clontarf Pool		Yes	Stable
Como Baths		Yes	Stable
Dolls Point Baths	Yes		Stable
Dawn Fraser Pool	Yes		Stable
Foreshores Beach	Yes	Yes	Stable
Gymea Bay Baths	Yes		Stable
Hayes St Beach	Yes		Stable
Horderns Beach	Yes		Stable
Jew Fish Bay Baths	Yes		Stable
Jibbon Beach		Yes	Stable
Kyeemagh Baths	Yes	Yes	Stable
Lilli Pilli Baths		Yes	Stable
Monterey Baths	Yes		Stable
Murray Rose Pool	Yes	Yes	Deteriorated
Oatley Bay Baths		Yes	Stable
Parsley Bay	Yes		Stable
Sandringham Baths	Yes		Stable
Woolwich Baths		Yes	Stable
Illawarra beaches			
No site impacted			
Total number of impacted sites	**14**	**17**	

Yes	Potential impact from wastewater overflows		DPE Beach suitability grade: Good or Very Good
	DPE Beach suitability grade: Fair		DPE Beach suitability grade: Poor or Very Poor

7. Glossaries and references

7.1. Glossaries

Acronyms/ Abbreviations	Full meanings
ADCP	Acoustic Doppler Current Profiler
AIC	Akaike information criterion
APHA	American Public Health Association
ANOSIM	Analysis of similarities
ANOVA	Analysis of variance
ANZECC	Australian and New Zealand Environment and Conservation Council
ANZG	Australian and New Zealand guidelines for fresh and marine water quality
AWI	Antecedent Wetness Index
AWRC	Advanced Water Recycling Centre (Upper South Creek)
AWTP	Advanced Water Treatment Plant
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
BOM	Bureau of Meteorology
BOOS	Bondi Ocean Outfall Sewer
CAP	Canonical Analysis of Principal coordinates
CBOD	Carbonaceous Biochemical Oxygen Demand
CCTV	Closed-Circuit Television
cfu/100mL	Colony forming units per 100 millilitres
Ck	Creek
CL	Confidence limit
COOS	Cronulla Ocean Outfall Sewer
CRM	Certified reference material
CTD	A CTD or Sonde is an oceanography instrument used to measure the conductivity, temperature, and pressure of seawater (the D stands for ‘depth’, which is closely related to pressure
D	Downstream impact
DB 1	Diamond Bay outfall 1
DB 2	Diamond Bay outfall 2
DO	Dissolved oxygen concentration
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DECCW	NSW Department of Environment, Climate Change and Water

Acronyms/ Abbreviations	Full meanings
DF	Degrees of freedom
DGV	Default guideline value
DISTLM	Distance-based linear models
DOMS	Deepwater Outfall Modelling System
DCCEEW	Department of Climate Change, Energy, the Environment and Water
ds or DS	Downstream
DWLP	Dry weather leakage program
EC_{50}	Effect Concentration for immobilization of 50% of exposed target biota
EMMEANS	Estimated marginal means
EPA	Environment Protection Authority
EPL	Environment Protection Licence
ER	Environmental Receptor
ERS	Emergency Relief Structure
FOG	Fats, Oils and Grease
FST	Field Sampling and Testing
FY	Financial year
HN	Hawkesbury-Nepean River
HNNMF	Hawkesbury-Nepean Nutrient Management Framework
HQ	Hazard Quotients
hr	Hours
IDAL	Intermittently Decanted Aerated Lagoons
IMOS	Integrated Marine Observing System
IPART	Independent Pricing and Regulatory Tribunal
IQR	Interquartile Range
KL	Kilolitre
km	Kilometre
LVA	Licence Variation Application
LSCTUP	Lower South Creek Treatment Upgrade Program
m	Metre
MBR	Membrane Biological Reactor
MDL	Method detection limit
MOF	Maximum overflow frequency
Mean	Mean value of a set of observations
Median	Median or 50^{th} percentile value

Acronyms/ Abbreviations	Full meanings
MERMQs	Mean effects range median quotients
mg/L	milligrams per litre
Min or Minimum	Minimum value of a set of observations
mL	Millilitre
ML	Megalitre
ML/d	Megalitre per day
mm	millimetre
mm^3/L	Phytoplankton biovolume millimetre cubed per litre
MOS	Marine Observing System
MST	Microbial Source Tracking
NA	Not applicable or Statistical comparison not conducted due to only one financial year of data
NATA	National Association of Testing Authorities
NHMRC	National Health and Medical Research Council
nMDS	Non-metric multidimensional scaling
NPE	Nonyl phenol ethoxylate
NSOOS	Northern Suburbs Ocean Outfall Sewer
NSW	New South Wales
NTU	Nephelometric Turbidity unit
ORS	Ocean Reference Station
OSP	Ocean Sediment Program
P	Pressure
P value	The value which determines the level of significance (<0.0001, <0.05 etc.)
p25	25^{th} percentile value of a set of observations
p50	50^{th} percentile value of a set of observations
p75	75^{th} percentile value of a set of observations
PAHs	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated Biphenyls
PCO	Principal Coordinates Analysis
PEC	Predicted Environmental Concentration
PERMANOVA	Permutational Analysis of Variance
PNEC	Predicted No Effect Concentration
POEO Act	Protection of the Environment Operations Act 1997
ppt	Parts per thousand

Acronyms/ Abbreviations	Full meanings
PQL	Practical quantitation limit (PQL)
PRP	Pollution Reduction Program
PSC	Professional Service Contract
P-S-ER	Pressure, Stressor and Ecosystem Receptor (P-S-ER)
QA/QC	Quality assurance/Quality control
R	River
R or R^2	A statistical measure of fit that indicates how much variation of a dependent variable is explained by the independent variable(s) in a regression model
RBA	Rapid Biological Assessment
RBG	Multiple Red-Green-Blue
ROV	Remotely operated vehicle
S	Stressor
SCAMP	Sewer Catchment Area Management Plan
SCENT	Sydney Canine Environmental Networks Team
SE	Standard Error
SIGNAL-SG	Stream Invertebrate Grade Number Average Level – Genus taxonomic level for the greater Sydney region. This is a biotic index based on freshwater macroinvertebrate diversity, abundance and tolerance to organic pollution
SIMPER	Similarity percentage
SoE	State of the Environment
SOV	System overflow volume
SRA	State Recreation Area
Std. Dev	Standard deviation of a set of observations
STP	Sewage Treatment Plant
STSIMP	Sewage Treatment System Impact Monitoring Program
SS	Sum of squares
SWAM	Sydney Water Aquatic Monitoring (program)
SWOOS	Southern and Western Suburbs Ocean Outfall Sewer
TBC	To be confirmed
THP	Thermal Hydrolysis Process
TOC	Total organic carbon
Total Obs	Total number of observations
U	Upstream Impact
UAS	Unmanned Aerial Systems
us or US	Upstream

Acronyms/ Abbreviations	Full meanings
USEPA	United States Environmental Protection Agency
WO	Work order
WoE	Weight of Evidence
WQMF	Water Quality Management Framework
WRP	Water Recycling Plants
WRRF	Water Resource Recovery Facility
WTS	Wastewater Treatment System
WWOAP	Wet Weather Overflow Abatement Program
WWOM	Wet Weather Overflow Monitoring
% sat	Percent saturation
µg/L	micrograms per litre
µS/cm	micro siemens per centimetre (unit of conductivity)

7.2. References

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