Sydney Water Aquatic Monitoring (SWAM) Program

Version 1

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1 Introduction

Sydney Water operates 23 distinct wastewater network systems (previously known as sewage treatment systems or STS's) across the Greater Sydney, Blue Mountains and Illawarra area. Each of these discrete systems consists of one or more water resource recovery facilities (WRRFs) (also variously referred to as sewage treatment plants, wastewater treatment plants or water recycling plants) and their associated reticulation systems. Altogether, the 23 wastewater network systems provide an integrated and effective wastewater treatment service to over 5 million people.

Each system is distinct in terms of its discharge characteristics, processes, and management objectives. They are also distinct in terms of receiving waters, as treated wastewater is discharged into marine, estuarine and freshwater (creeks and rivers) environments.

The principal statutory instrument for each wastewater network system 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 undertake environmental monitoring as detailed in the Sewage Treatment System Impact Monitoring Program (STSIMP) (Sydney Water 2010), or any replacement document approved in writing by the EPA. The 2010 STSIMP was developed with, and endorsed by, the EPA. The STSIMP document outlined Sydney Water's routine monitoring of receiving waterways including oceans, estuaries, lagoons, rivers, and creeks. The aim of the STSIMP was to monitor the environment within Sydney Water's area of operations to determine general trends in water quality over time, monitor our performance and determine where our contribution to water quality may pose a risk to environmental ecosystems and human health. The indicators selected were based on current knowledge of the relationship between pollutants and ecological or human health impacts. The overall approach was consistent with the ANZECC/ARMCANZ (2000) *Guidelines for Fresh and Marine Water Quality*. The STSIMP was implemented in the 2008-2009 financial year with a minor variation to one of its sub-programs from July 2010.

The STSIMP was the successor to Sydney Water's previous waterways monitoring plan, the Environmental Indicators Monitoring Program (EIMP; Sydney Water 1995) which was a requirement of the Water Board (Corporatisation) Act 1994 (Sydney Water 1995). The aim of this program was to provide information on long-term environmental quality and the effects of Sydney Water's discharge operations on the environment. The EIMP was developed in 1995 after extensive consultation, with a final suite of ecosystem health indicators gazetted in December 1995. The EIMP was in place from 1995 to 2008.

In 2021-22 Sydney Water, in collaboration with the EPA, instigated a review of the STSIMP to ensure the program adequately targets the impact of Sydney Water's operations on the environment, and provides value to its customers and the community. A key focus of the review 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. The review looked at the design of the monitoring program, as well as the statistical analysis and annual reporting structure.

The review was undertaken by four independent specialists with complementary expertise across marine science, freshwater science, biostatistics, and relevant state/national water quality policies/guidelines, with the findings and recommendations detailed in van Dam et al. (2023).

The overarching aim of the revised program, renamed the 'Sydney Water Aquatic Monitoring' (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 SWAM program was approved by the EPA in early 2023 and gradually implemented from July 2023. The current version of the SWAM program described herein incorporates monitoring sub-programs for (i) WRRF effluent quantity, quality and toxicity, (ii) receiving water impacts of WRRF discharges, and (iii) some recreational water quality monitoring (i.e. Beachwatch). However, additional sub-programs for monitoring the impacts of wet weather overflows and dry weather overflows and leakage still need to be incorporated into the SWAM program following the completion of a series of ongoing and proposed research and development studies.

2 Drivers for Sydney Water's Aquatic Monitoring Program

The ***Sydney Water Act 1994*** sets out Sydney Water's objectives under Part 6, Sections 21 and 22. Section 21 of the Act establishes three principal objectives, each of which is equal in importance:

- To be a successful business
- **To protect the environment by conducting its operations in compliance with the principles of ecologically sustainable development**
- To protect public health by supplying safe drinking water to its customers

In implementing the principal objectives set out in Section 21, the Corporation has the following special objectives in Section 22:

- to reduce risks to human health
- to prevent the degradation of the environment

Since the establishment of the Sydney Water Act 1994, there have been several other regulatory drivers which have contributed to the development of the current monitoring program. These include but are not limited to: Sydney Water's Operating Licence (first issued in 1995) and the POEO Act.

Both the Sydney Water Act 1994 and the 1995 Operating Licence required Sydney Water to report on its achievements in meeting its statutory objectives on a variety of environmental issues as well as a suite of environmental indicators.

Each of the 23 wastewater network system's EPLs issued by the EPA includes condition M5 'Environmental Monitoring' which requires Sydney Water to undertake the monitoring programs detailed in the STSIMP or any replacement document approved in writing by the EPA.

In addition to our regulatory drivers, Sydney Water's 2020-2030 strategy sets our vision of 'creating a better life with world-class water services'. The strategy has identified the outcomes we want to deliver for waterways:

- our water and waterways are world-class and support thriving, liveable and sustainable cities
- our cities' waterways are clean, healthy and safe for swimming and recreation
- our environmental performance is world-class.

To achieve these outcomes requires an understanding of the impact of Sydney Water's operations on our ocean, estuaries, rivers and creeks. This can only be achieved by a well designed and comprehensive aquatic monitoring program.

3 Major Changes to the Monitoring Program

As noted in Section 1, the SWAM program is the successor to the 2010 STSIMP (Sydney Water 2010). The major changes to the SWAM program compared with the 2010 STSIMP are presented below.

3.1 Alignment with the ANZG (2018) Guidelines

3.1.1 The water quality management framework (WQMF)

The ANZG (2018) water quality management framework (WQMF) represents 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* (PSER) causal pathway elements. Van Dam et al. (2023) demonstrated that Sydney Water's aquatic impact assessment program was generally consistent with the WQMF, including both the PSER and WoE components; however, there was no explicit recognition of this. Therefore, the PSER approach has been explicitly embedded in the SWAM program (Section 3.1.2), meaning that the SWAM program is now formally and clearly aligned with the nationally-agreed approach for managing water quality.

3.1.2 The pressure-stressor-ecosystem receptor (PSER) approach

The SWAM program has been structured to be consistent with the ANZG (2018) PSER causal conceptual model approach. All analytes and indicators that are monitored fit within either the pressure, stressor or ecosystem receptor causal pathway elements, and are clearly identified as such. 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 PSER lines of evidence are used to determine whether WRRF discharges are impacting the aquatic environment.

3.2 Unified analysis workflow

Given the number of sub-programs within the SWAM program and the significant associated reporting requirements, the SWAM program would benefit from a structured and consistent approach to analysis and reporting across all its sub-programs. Consequently, a formal gated analysis workflow has been implemented that allows Sydney Water to clearly, efficiently 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. The workflow also complements the use of the PSER and WoE approaches for assessing impacts (circa ANZG 2018).

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

- Gate 1 – Undertake routine annual analyses of monitoring data.
- Gate 2 – Assessment of results of 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.

The outcomes from this workflow are captured in a consistent and transparent reporting process that is summarised in Sections 3.6 and 7.

3.3 Hierarchy of aims, objectives, analyses and outputs

The SWAM program is underpinned by a hierarchy of aims and objectives that includes an overarching aim (see Section 1) and specific aims and objectives for each of the sub-programs. The sub-program aims provide high level goals over a long timeframe, with specific objectives for each aim providing the details of what is to be achieved. The objectives make it clear what outcomes are being measured (eg water quality, ecosystem health, etc.), where they are being measured (eg upstream/downstream or impact/control sites), and what questions are being asked (eg comparison of sites for the current year or over the relevant historical record). The questions being asked by the objectives dictate the statistical estimates (eg medians, means ± 95% confidence intervals) and tests (eg t tests, analysis of variance, multivariate analyses) that are required, which in turn guides the reporting outputs that are needed to demonstrate the results.

3.4 Key design and methodological changes

Key design and methodological changes associated with the transition from the STSIMP to the SWAM program include (see van Dam et al. 2023 for details):

- *Cessation of some sub-programs deemed to be not fit for purpose.* Sub-programs that were aiming to assess impacts of overflows and leakage did not have the ability to distinguish Sydney Water impacts from other impacts (eg associated with urban or agricultural runoff) and, thus, could not achieve their aim. Such sub-programs did not address the overarching aim of the SWAM program (see Section 1) and, hence, were not fit-for-purpose and needed to be ceased and/or re-designed. However, sub-programs aimed at assessing impacts of overflows and leakage cannot be re-designed until Sydney Water's Wet Weather Overflow Abatement Program (WWOAP) has been completed.
- *Re-focus on upstream-downstream comparisons for inland WRRF discharges (Hawkesbury-Nepean and Georges river systems).* The STSIMP water quality and phytoplankton monitoring diverged from a targeted upstream/downstream design for inland WRRFs, which made it more difficult to attribute impacts to Sydney Water's operations. Consequently, the SWAM sub-programs for the WRRF discharges in the Hawkesbury-

Nepean and Georges river systems have been re-designed with a greater focus on directly assessing impacts from WRRF discharges.

- *Re-design of nearshore marine WRRF shoreline outfall sub-programs.* For various reasons, not all of Sydney Water's shoreline, cliff face and nearshore outfalls are monitored. Sub-programs assessing these types of outfalls need to be re-designed to properly monitor impacts.

In some cases, the adoption of new or re-design of existing sub-programs will require pilot studies to identify appropriate designs and methodologies (see Section 3.7), with the results informing future iterations of the SWAM program.

3.5 Statistical data analysis and presentation changes

Key statistical data analysis and presentation changes associated with the transition from the STSIMP to the SWAM program include (see van Dam et al. 2023 for further details):

- Additional graphics to assist in exploring and understanding trends for the current reporting year.
- Fitting more extensive analysis models to the discharge and receiving water quality data and the ocean sediment quality data from the relevant timeframe with pre-specified comparisons to provide informed answers to the specified objectives, as mentioned in Section 3.3.
- Taking a WoE approach to analysis and interpretation of results by (i) encouraging ranges of p-values to be used to assess the strength of evidence for an impact, rather than simply rejecting/accepting if there is an impact using $p=0.05$ as a binary cut-off, and (ii) increasing the use of estimated effects with corresponding 95% confidence intervals. This better aligns with the ANZG (2018) WoE approach (Section 3.1.1).
- Providing the results of the statistical model and model checking activities for completeness and transparency. Results are to be provided in a separate appendix so as not to detract from the main results.
- Ensuring that comparisons with previous monitoring data are based on the most relevant historical timeframes (eg if substantive environmental or operational changes have occurred then benchmarks and comparisons should consider this).
- All multivariate community analyses are accompanied by graphical exploratory data analysis to ensure other numerical summaries and models are appropriate and not missing important patterns (eg macroinvertebrate SIGNAL analysis should be accompanied with a nMDS).
- All analysis outcomes are to be reported and framed in the appropriate Gate (as per Section 3.2).

3.6 Key reporting changes

Key changes to the structure and content of the Annual Data Report associated with the transition from the STSIMP to the SWAM program include (see van Dam et al. 2023 for details):

- Ordering of the sub-program results based on pressure (ie WRRF discharges, overflows/leakage), followed by region/zone (ie “catchment to coast” approach).
- For each sub-program related to WRRF discharges, presenting the results for each WRRF discharge one by one, apart from the offshore marine sub-programs where all WRRF discharges are compared to all reference locations (where available).
- For each WRRF discharge, ordering the results according to the pressure, stressor and ecosystem receptor data (consistent with the ANZG (2018) PSER approach), and presenting the interpretation of the results according to the gated analysis workflow using a WoE approach.
- Main body of the report to include brief summary statement of the outcome of each objective, as well as succinct discussion of key results (eg where impacts are evident), including relevant tables and figures. Tables and figures of all results to be reported in hard copy and electronic appendices.
- A synthesis chapter summarising what the combined monitoring results reveal about the impact of Sydney Water’s operations on each of the zones/regions (eg Hawkesbury-Nepean River, shoreline outfalls, deep ocean outfalls).

3.7 Additional studies

The STSIMP Recommendations Report (van Dam et al. 2023) recommended additional studies to further inform the details of the SWAM program. The current (2023) SWAM program does not yet reflect the results of these studies and will need to be updated in the future when these studies are completed. A list of the recommended additional studies is provided in

Table 3-1, with the major items summarised below:

- Comprehensive sampling studies for treated wastewater and receiving water quality to inform future analyte suites
- Pilot studies to investigate the feasibility of eDNA and community DNA approaches for ecosystem receptor monitoring
- Feasibility studies to determine appropriate experimental design, indicators and sampling methods for the estuarine and nearshore marine WRRF discharges.

Also, Sydney Water’s Wet Weather Overflow Abatement Program (WWOAP) will need to be completed before a complete set of appropriate sub-programs for monitoring overflows and leakage can be designed and added to the SWAM program.

Table 3-1 Additional studies recommended in the STSIMP Recommendations Report (van Dam et al. 2023) to inform the SWAM program

Relevant monitoring sub-program	Study
All	Comprehensive sampling studies for treated wastewater and receiving water quality, with associated screening-level risk assessments, to inform future decisions on relevant stressor (analyte) suites
Hawkesbury-Nepean River water quality and aquatic ecosystem health Georges River water quality and aquatic ecosystem health Offshore sediment quality and ecosystem health	Pilot studies to assess potential application of molecular approaches for freshwater biomonitoring (including community DNA or eDNA), to inform future decisions on monitoring techniques for ecosystem receptors
Hawkesbury-Nepean River water quality and aquatic ecosystem health	Additional checks to ensure that the proposed water quality sites are aligned with, or close enough to be considered representative of, the macroinvertebrate sites
Georges River water quality and aquatic ecosystem health	Feasibility studies to determine the most appropriate design, indicators (stressor and ecosystem receptor) and sampling and processing methods for assessing the impacts of discharges from Liverpool and Fairfield WRRFs
Nearshore marine water quality and ecosystem health	Identification of additional intertidal reference sites for Shellharbour, Warriewood and Bombo Feasibility studies to determine the suitability of drone technology for sampling the intertidal ecology at Shellharbour and new reference sites Feasibility studies to determine the suitability of underwater remotely operated vehicles for sampling the subtidal ecology at Cronulla, Vaucluse and Diamond Bay

4 Monitoring Sub-Programs Overview

The SWAM program consists of 15 sub-programs to assess the impact of WRRF discharges, and wet and dry weather overflows and leakage on receiving waterways, as listed in Table 4-1. Currently, the SWAM program does not include a full set of sub-programs for monitoring overflows and leakage because these cannot be finalised until after the completion of the WWOAP.

For each type of Sydney Water pressure (i.e. WRRF discharges, wet and dry weather overflows and leakage), the sub-programs are listed by catchment/zone, and ordered from inland to ocean. For each catchment/zone, sub-programs are included that monitor the relevant pressure (P), stressor (S) and ecosystem receptor (ER) indicators, as indicated in Table 4-1. The only exception to this is the “Other freshwater” zone, which does not include any pressure indicator monitoring because this category captures reference sites at which there are no Sydney Water pressures present.

Table 4-1 Summary of the Sydney Water Aquatic Monitoring (SWAM) program

Pressure	Catchment / Zone	Sub-program	P-S-ER [a]	Overview
WRRF discharges	Hawkesbury-Nepean River and tributaries	Hawkesbury-Nepean River WRRF effluent quantity, quality and toxicity	P	*Section 5.1.1.* Treated wastewater quantity, quality and toxicity for 15 WRRFs as per specific EPL requirements.
		Hawkesbury-Nepean River water quality and ecosystem health	S, ER	*Section 5.1.2.* (i) Water quality and chlorophyll-a (3-weekly) and macroinvertebrates (biannually) at 42 sites, upstream and downstream of WRRF discharges; (ii) Water quality, chlorophyll-a and phytoplankton at 18 (long-term) sites known to be prone to high algal growth.
	Georges River and tributaries	Georges River WRRF effluent quantity, quality and toxicity	P	*Section 5.2.1.* Treated wastewater quantity, quality and toxicity for three WRRFs as per specific EPL requirements.
		Georges River water quality and ecosystem health [b]	S, ER	*Section 5.2.2.* Water quality and chlorophyll-a (3-weekly) and macroinvertebrates (biannually) at four 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.
	Other freshwater	Reference sites water quality and ecosystem health	S, ER	*Section 5.3.1.* Water quality (3-weekly) and macroinvertebrates (biannually) at seven reference sites without urban or rural influences on water quality. Used to re-calibrate macroinvertebrate SIGNAL-SG scores.
	Nearshore marine	Nearshore marine WRRF effluent quantity, quality and toxicity	P	*Section 5.4.1.* Treated wastewater quantity, quality and toxicity for eight WRRFs as per specific EPL requirements.
		Nearshore marine water quality and ecosystem health	S, ER	*Section 5.4.2.* (i) Water quality and intertidal macroalgae and

Pressure	Catchment / Zone	Sub-program	P-S-ER [a]	Overview
				macroinvertebrates (annually) at nine sites as groups of one outfall and two reference sites for three WRRFs; (ii) 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.
	Offshore marine	Offshore marine WRRF effluent quantity, quality and toxicity	P	*Section 5.5.1*. Treated wastewater quantity, quality and toxicity for three WRRFs as per specific EPL requirements.
		Offshore receiving water quality	S	*Section 5.5.2*. Water quality based on measured effluent concentrations and modelled dispersion of the effluent plume using ocean reference station data.
		Offshore sediment quality and ecosystem health	S, ER	*Section 5.5.3*. 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 IPART cycle) at 18 sites, at outfall and control locations.
Wet and dry weather overflows and leakage [c]	Estuaries, lagoons and beaches	Dry weather overflows – volume, frequency and trends	P	*Section 6.1.1*. 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
		Dry weather leakage detection	P	*Section 6.1.2*. Assessment of 223 sewer catchments for sewer leakage at least once per year

Pressure	Catchment / Zone	Sub-program	P-S-ER [a]	Overview
		Wet weather overflows – modelled volume, frequency and trends	P	*Section 6.1.3*. Annual model runs to determine overflow frequency and volume information
		Water quality and ecosystem health	S, ER	*Section 6.1.4*. To be determined following completion of WWOAP.
		Recreational water quality	S	*Section 6.1.5*. To be determined following completion of WWOAP.

[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] A complete set of sub-programs for assessing wet and dry weather overflows and dry weather leakage will be developed following completion of the WWOAP. This might include separate sub-programs for wet weather overflows and dry weather overflows and leakage, and is also likely to capture inland (i.e. freshwater) systems.

5 Monitoring of WRRF Discharges

5.1 Hawkesbury-Nepean River and tributaries

5.1.1 Hawkesbury-Nepean River WRRF effluent quantity, quality and toxicity

Rationale

Currently, there are 15 WRRFs operating in the greater Hawkesbury-Nepean River catchment (Figure 5-1). 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 of the WRRFs except Brooklyn discharge to freshwater environments, with Brooklyn discharging to an estuarine environment.

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 3.1.2).

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.These requirements vary between WRRFs and can also be varied for each WRRF from time to time. This could include changes to the analyte suite for assessing discharge quality as a result of comprehensive sampling studies recommended by van Dam et al. (2023).

Aims and objectives

The aim and specific objectives for the sub-program are presented in Table 5-2.

Table 5-1 Aim and objective for the Hawkesbury-Nepean River WRRF effluent quantity, quality and toxicity sub-program [a]

Aim	Objectives
To characterise and assess the quantity, quality and toxicity of the Hawkesbury-Nepean River 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.

[a] The aim and objectives are considered interim at this stage and will be assessed in a subsequent review of the SWAM program.

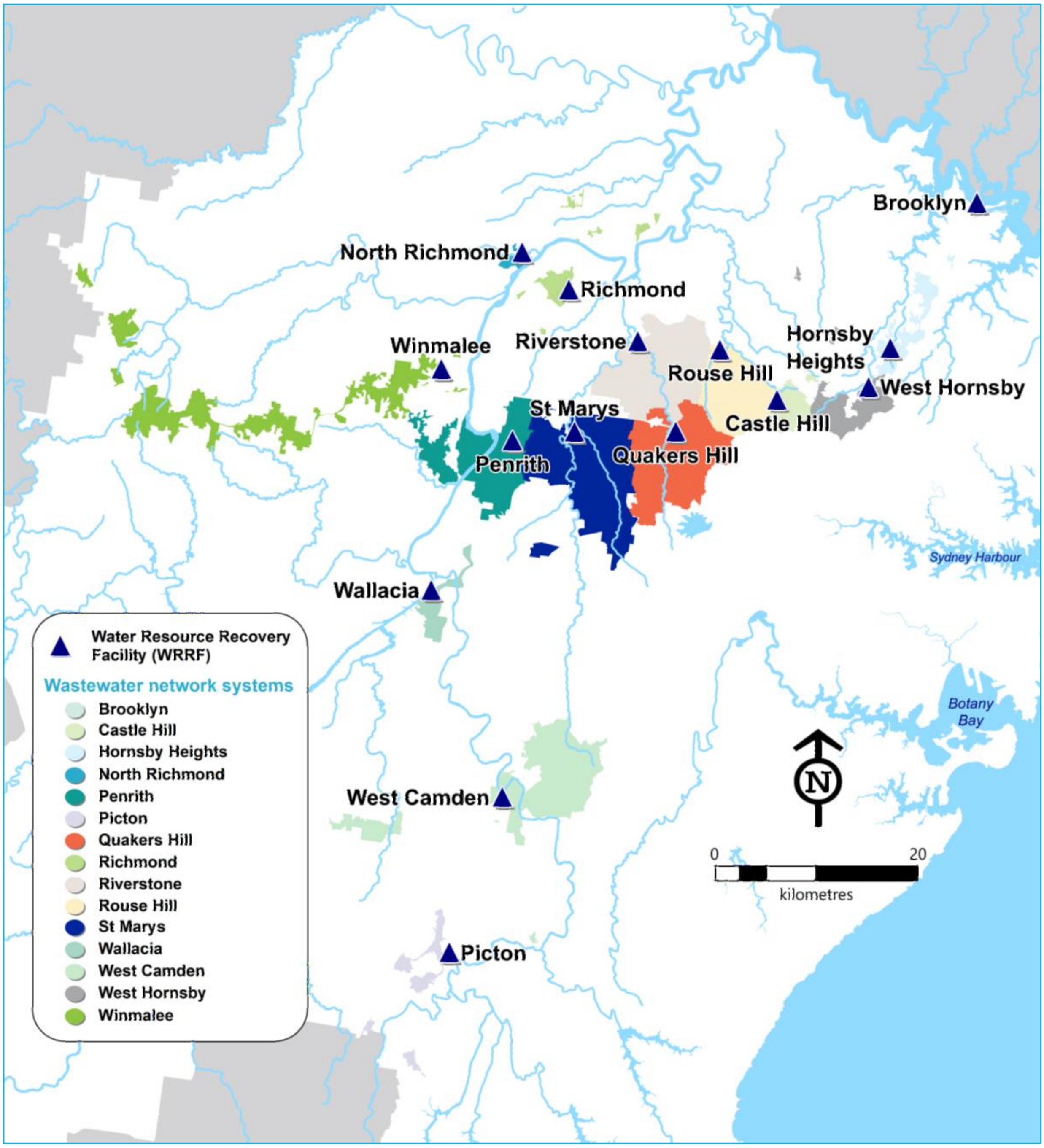


Figure 5-1 Location of WRRFs in the Hawkesbury-Nepean River catchment

Monitoring approach

Design and sites

The discharge monitoring sites for each WRRF are specified in the relevant EPL.

Analytes, indicators and sampling

Relevant quantity, quality and toxicity indicators and associated parameters and details (eg 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, which is reviewed and updated annually.

5.1.2 Hawkesbury-Nepean River water quality and ecosystem health

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 STPs, stormwater and agricultural runoff.

Distinguishing 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 previous Hawkesbury-Nepean River water quality, algae and stream health sub-programs. The sub-program is designed to monitor (i) the direct aquatic environmental impacts of SydneyWater's WRRF discharges, and (ii) 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.

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). Further details about this monitoring sub-program are in Sydney Water's 'SWAM – Inland to Nearshore Marine Waters monitoring plan'. The plan will be reviewed from time to time to include additional details or modification based on the outcomes from pilot studies and approved negotiation between Sydney Water and EPA.

Aims and objectives

The aims of this sub-program are to:

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.
2. 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 (ie the physico-chemical water quality analytes) and the ecosystem receptors (ie phytoplankton metrics including chlorophyll-a, and macroinvertebrates), are presented in Table 5-2.

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

Aim	Objective
(i) 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 (eg 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.

Aim	Objective
	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 (eg by comparing with water quality data).
(ii) Characterise water quality and phytoplankton community structure at selected sites in the H-N River susceptible to higher algal abundances.	*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. 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 biovolume, toxic blue-green algal counts) over the relevant historical record.

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 Winmalee WRRF, there exists no suitable upstream tributary site and, instead, two downstream sites at 0.3 km and 3 km distance from the discharge location are employed.
- For two WRRFs (Richmond, St Marys), the suitability of monitoring the unnamed creeks into which the WRRFs discharge needs to be investigated. However, paired sites are included in the creeks into which the discharge creeks flow (Rickabys Creek and South Creek, respectively).
- For five WRRFs (Picton, West Camden, Penrith, Winmalee and North Richmond), paired sites are located both on the tributary into which the discharge point is located, as well as on the Hawkesbury-Nepean River at the confluence of the tributary.
- 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 captured in the Nearshore marine water quality and ecosystem health sub-program (Section 5.4).

In total, there are 42 monitoring sites that address Aim 1 (Table 5-3, Figure 5-2). Where possible, water quality, chlorophyll-a and macroinvertebrates are all monitored at the same location. Where this cannot occur, sites are located as close together as logistically possible. As a result, water quality, chlorophyll-a and macroinvertebrates are monitored at 40, 38 and 39 sites, respectively, as listed in Table 5-3. 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, while in other cases, water quality data from one location are sufficiently representative of both locations.

Aim 2 – assessment of sites susceptible to high phytoplankton growth

The design focuses on assessment of stressors and ecosystem receptors (phytoplankton only) at 18 long-term sites located throughout the Hawkesbury-Nepean River system that are known to be susceptible to high phytoplankton growth (Table 5-3, Figure 5-2). These sites include seven sites that also act as one of a site pair for directly assessing WRRF discharges under Aim 1, above, and 11 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.

Water quality and full phytoplankton analysis are monitored at 10 sites, while an additional eight sites are monitored for water quality and chlorophyll-a, as listed in Table 5-3.

Table 5-3 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		Latitude	Longitude
			WQ [a]	Chl-a	Macroinver-tebrates	WQ [a] & Chl-a	Full algal [b]		
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
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 at Penrith Rowing Club ramp, downstream of Penrith Weir and upstream of Penrith WRRF	✓		✓			-33.74039	150.68533

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		Latitude	Longitude
			WQ [a]	Chl-a	Macroinvertebrates	WQ [a] & Chl-a	Full algal [b]		
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	N48A	Nepean River at Smith Road, Princes farm, upstream of Winmalee WRRF	✓	✓	✓	✓	✓	-33.666858	150.66703
19	N462	Unnamed Creek, 0.3 km downstream of Winmalee WRRF	✓	✓	✓			-33.67684	150.62926
20	N461	Unnamed Creek 3 km downstream of Winmalee WRRF	✓	✓	✓			-33.66856	150.65736
21	N464	Nepean River (Winmalee Lagoon) at Springwood Road, downstream of Winmalee WRRF, before Shaws Creek	✓	✓	✓			-33.6633	150.663
22	N44	Nepean River at Yarramundi Bridge, downstream of Winmalee WRRF			✓ [d]	✓		-33.6146	150.698
23	N42	Hawkesbury River upstream of North Richmond WRRF, downstream of Grose River	✓	✓	✓	✓	✓	-33.5868	150.723
24	N412	Redbank Creek, upstream of North Richmond WRRF	✓	✓	✓			-33.57592	150.7133
25	N411	Redbank Creek, downstream of North Richmond WRRF	✓	✓	✓			-33.5756	150.71892
26	N39	Hawkesbury River at Freemans reach, downstream of North Richmond WRRF, upstream of South Creek	✓	✓		✓		-33.57	150.747
27	N40	Hawkesbury River, downstream of North Richmond WRRF			✓			-33.56852	150.74857
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

No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		Latitude	Longitude
			WQ [a]	Chl-a	Macroinvertebrates	WQ [a] & Chl-a	Full algal [b]		
31	NS23	South Creek, downstream of St Marys WRRF	✓	✓	✓			-33.7333	150.766
32	NS082	Eastern Creek, upstream of Riverstone WRRF	✓	✓	✓			-33.6695	150.851
33	NS081	Eastern Creek, downstream of Riverstone WRRF	✓	✓	✓			-33.668	150.846
34	NS090	Breakfast Creek, upstream of Quakers Hill WRRF	✓	✓	✓			-33.7450	150.884
35	NS087	Breakfast Creek, downstream of Quakers Hill WRRF	✓	✓	✓			-33.7361	150.872
36	NS04A	Lower South Creek at Fitzroy pedestrian bridge, Windsor				✓	✓	-33.6088	150.824
37	N35	Hawkesbury River at Wilberforce, Butterfly farm, downstream of South Creek				✓	✓	-33.5730	150.838
38	NC53	Second Ponds Creek upstream of Rouse Hill WRRF at Withers Road	✓	✓	✓			-33.6716	150.9174
39	NC515	Second Pond Creek, downstream of Rouse Hill WRRF			✓			-33.6648	150.9248
40	NC516	Second Pond Creek, downstream of Rouse Hill wetland and bypass from Rouse Hill WRRF	✓	✓				-33.6649	150.92472
41	NC8	Cattai Creek, upstream of Castle Hill WRRF	✓	✓	✓			-33.7143	150.982
42	NC75	Cattai Creek, downstream of Castle Hill WRRF	✓	✓	✓			-33.7084	150.982
43	NC11A	Lower Cattai Creek at Cattai Road Bridge, 100m downstream of bridge				✓	✓	-33.5591	150.907
44	N3001	Hawkesbury River Off Cattai State Recreation Area (SRA), downstream of Cattai Creek				✓		-33.5583	150.889
45	N26	Hawkesbury River at Sackville Ferry, downstream of Cattai Creek				✓	✓	-33.5007	150.876
46	N2202	Lower Colo River at Putty Road Bridge, Reference site				✓		-33.4325	150.829
47	N18	Hawkesbury River at Leets Vale, opposite Leets Vale Caravan Park, downstream of Colo River				✓		-33.428	150.948
48	NB83	Waitara Creek, upstream of West Hornsby WRRF	✓	✓	✓			-33.7045	151.079

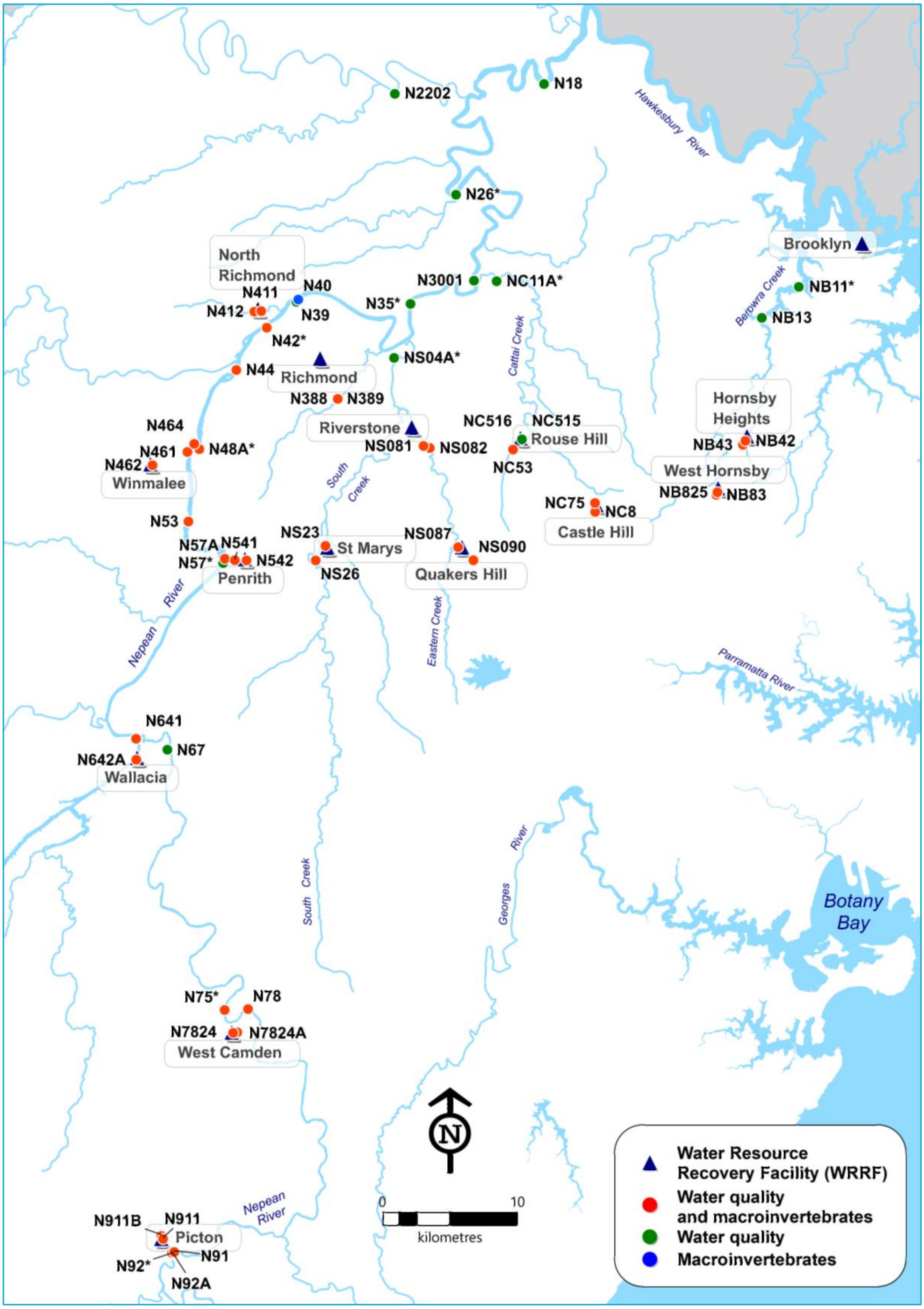
No.	Site code	Site description	Aim 1 – Upstream/downstream WRRF discharge			Aim 2 – SoE-type site		Latitude	Longitude
			WQ [a]	Chl-a	Macroinver-tebrates	WQ [a] & Chl-a	Full algal [b]		
49	NB825	Waitara Creek, downstream of West Hornsby WRRF	✓	✓	✓			-33.7028	151.08
50	NB43	Calna Creek, upstream of Hornsby Heights WRRF	✓	✓	✓			-33.6714	151.101
51	NB42	Calna Creek, downstream of Hornsby Heights WRRF	✓	✓	✓			-33.6688	151.103
52	NB13	Berowra Creek at Calabash Bay (Cunio Point)				✓		-33.5869	151.118
53	NB11	Berowra Creek, Off Square Bay (Oaky Point)				✓	✓	-33.5667	151.148

[a] Refer to Table 5-4 for specific water quality analytes/parameters to be measured.

[b] Refer to Table 5-4 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.



* phytoplankton cell counting site

Figure 5-2 Site locations for Hawkesbury-Nepean River water quality and ecosystem health sub-program

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-4.

Table 5-4 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the Hawkesbury-Nepean River water quality and ecosystem health sub-program [a]

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General water quality	Temperature, DO (% saturation), pH, conductivity, turbidity
	Chemical [b]	Nutrients	ammonia nitrogen, oxidised nitrogen, total nitrogen, total phosphorus, soluble reactive phosphorus
	Chemical [b]	Metals	General suite including (but not necessarily limited to) aluminium, cobalt, copper, nickel, zinc
Ecosystem receptor	Biodiversity	Phytoplankton communities	Chlorophyll-a, algal biovolume and cell count to genus level [c]
		Macroinvertebrate communities	SIGNAL-SG, Community structure

[a] Refer to Table 5-3 for details of sites at which analytes/indicators should be measured.

[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.

[c] 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.

Aim 1 – assessment of direct impacts of WRRF discharges

Water quality, chlorophyll-a and macroinvertebrates are monitored, depending on the site, as listed in Table 5-3. 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. 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 and chlorophyll-a, field measurements and samples are collected at an interval of three weekly ± four days. At each site, two samples are collected, where possible, at a depth of 0.5 m below the surface, 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 5-4). 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.

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. Samples are sorted in the field using a specific rapid biological assessment (RBA) method developed by Chessman (1995) and subsequently refined by others (eg 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, 8 "replicates" for each site (4 habitats x 2 sampling occasions) from one financial year (spring and autumn) are pooled.

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 5-3. Full phytoplankton parameters are chlorophyll-a, planktonic algal biovolume and cell count to genus level, with blue-green biovolume, toxic 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.

5.2 Georges River and tributaries

5.2.1 Georges River WRRF effluent quantity, quality and toxicity

Rationale

Currently, there are three WRRFs operating in the Georges River catchments (Figure 5-3). 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 the Liverpool Weir. Liverpool WRRF is located just below the Liverpool Weir, which marks the upper tidal/estuarine limit of the Georges River. 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 they only discharge partially-treated wastewater during wet weather.

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 3.1.2).

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. These requirements vary between WRRFs and can also be varied for each WRRF from time to time. This could include changes to the analyte suite for assessing discharge quality as a result of comprehensive sampling studies recommended by van Dam et al. (2023).

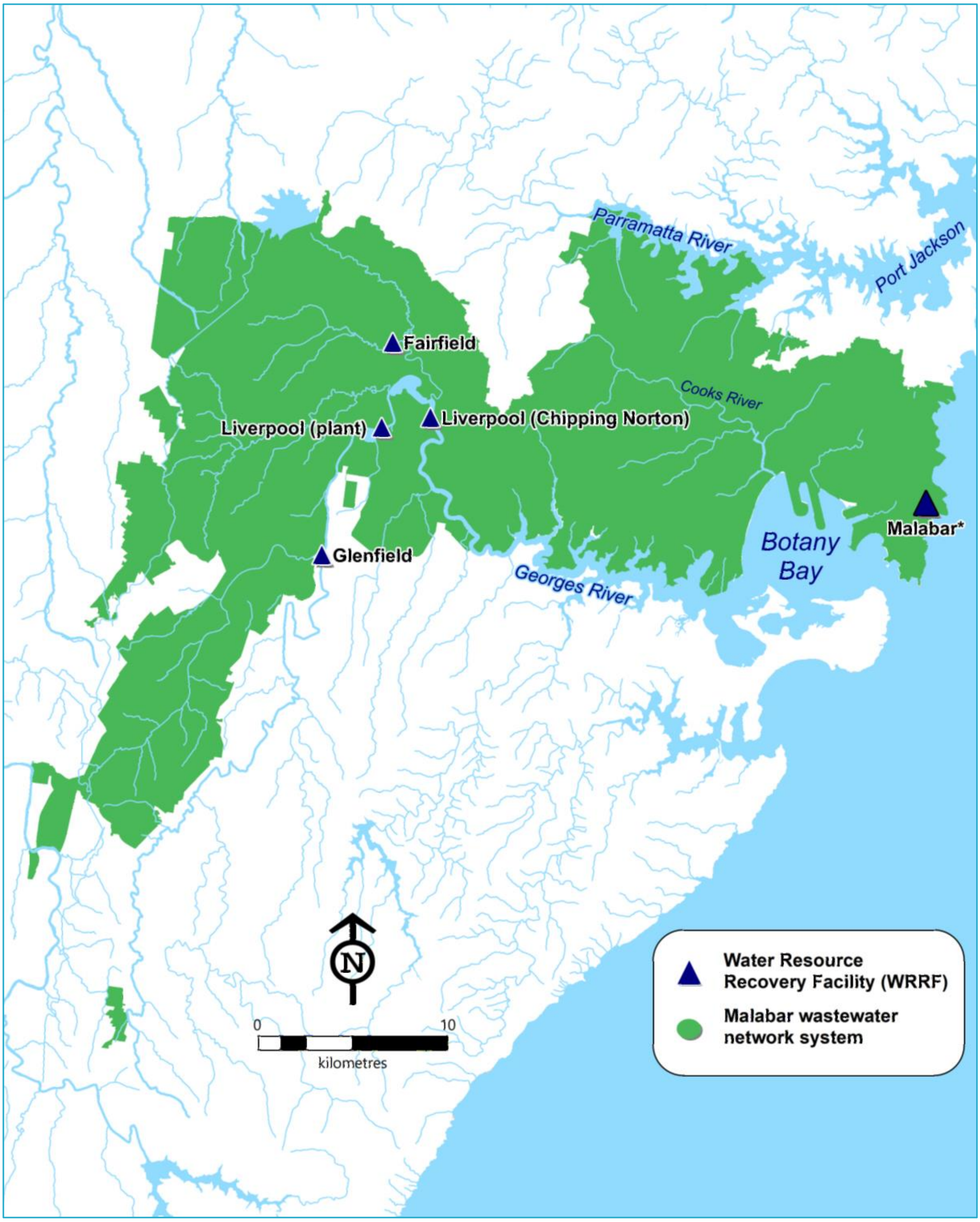
Aims and objectives

The aim and specific objectives for the sub-program are presented in Table 5-5.

Table 5-5 Aim and objective for the Georges River WRRF effluent quantity, quality and toxicity sub-program [a]

Aim	Objectives
To characterise and assess the quantity, quality and toxicity of the Georges River 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.

[a] The aim and objectives are considered interim at this stage and will be assessed in a subsequent review of the SWAM program.



* 96% of wastewater from Malabar system discharged to ocean via deep ocean outfall, the remaining 4% (2012-22 average) discharged to Georges River in wet weather

Figure 5-3 Location of WRRFs in the Georges River catchment

Monitoring approach

Design and sites

The discharge monitoring sites for each WRRF are specified in the relevant EPL.

Analytes, indicators and sampling

Relevant quantity, quality and toxicity indicators and associated parameters and details (eg 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, which is reviewed and updated annually.

5.2.2 Georges River water quality and ecosystem health

Rationale

The Georges River drains a catchment of ~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. Impact monitoring for the Liverpool and Fairfield WRRF discharges need to 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.

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). Further details about this monitoring sub-program are to be included in Sydney Water's 'SWAM – Inland to Nearshore Marine Waters monitoring plan'. The plan will be reviewed periodically to include additional details or modification based on the outcomes from pilot studies, and approved consultation between Sydney Water and the EPA.

Aims and objectives

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

- 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.

Specific objectives for the above aim, focusing on the relevant stressors and the ecosystem receptors, are presented in Table 5-6. The aim and associated objectives will be updated when monitoring for the Liverpool and Fairfield WRRF discharges is added.

Table 5-6 Aims and objectives for the Georges River water quality and ecosystem health sub-program

Aim	Objective
(i) 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 (eg 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.

Aim	Objective
	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 (eg by comparing with water quality data).

Monitoring approach

Design and sites

The design focuses on comparisons of stressors and ecosystem receptors from paired sites in Bunbury Curran Creek upstream and downstream of the Glenfield WRRF discharge, and the Georges River upstream and downstream of Bunbury Curran Creek, to directly assess the impacts of the discharge (Table 5-7 and Figure 5-4).

Table 5-7 Receiving water monitoring sites for the Georges River water quality and ecosystem health sub-program (Glenfield WRRF only)

Site code	Site description	Latitude	Longitude
TBC [a]	Bunbury Curran Creek, upstream of WRRF discharge	TBC	TBC
TBC	Bunbury Curran Creek, downstream of WRRF discharge	TBC	TBC
TBC	Georges River upstream of confluence with Bunbury Curran Creek [b]	TBC	TBC
GR23	Georges River, Cambridge Causeway, downstream of confluence with Bunbury Curran Creek	-33.97004	150.9122

[a] TBC: to be confirmed.

[b] Site could potentially be GR24 (Georges River at Ingleburn Reserve Weir, upstream of Glenfield WRRF, reference site) but, preferably, a new site closer to the confluence with Bunbury Curran Creek (eg at Simmo's Beach).

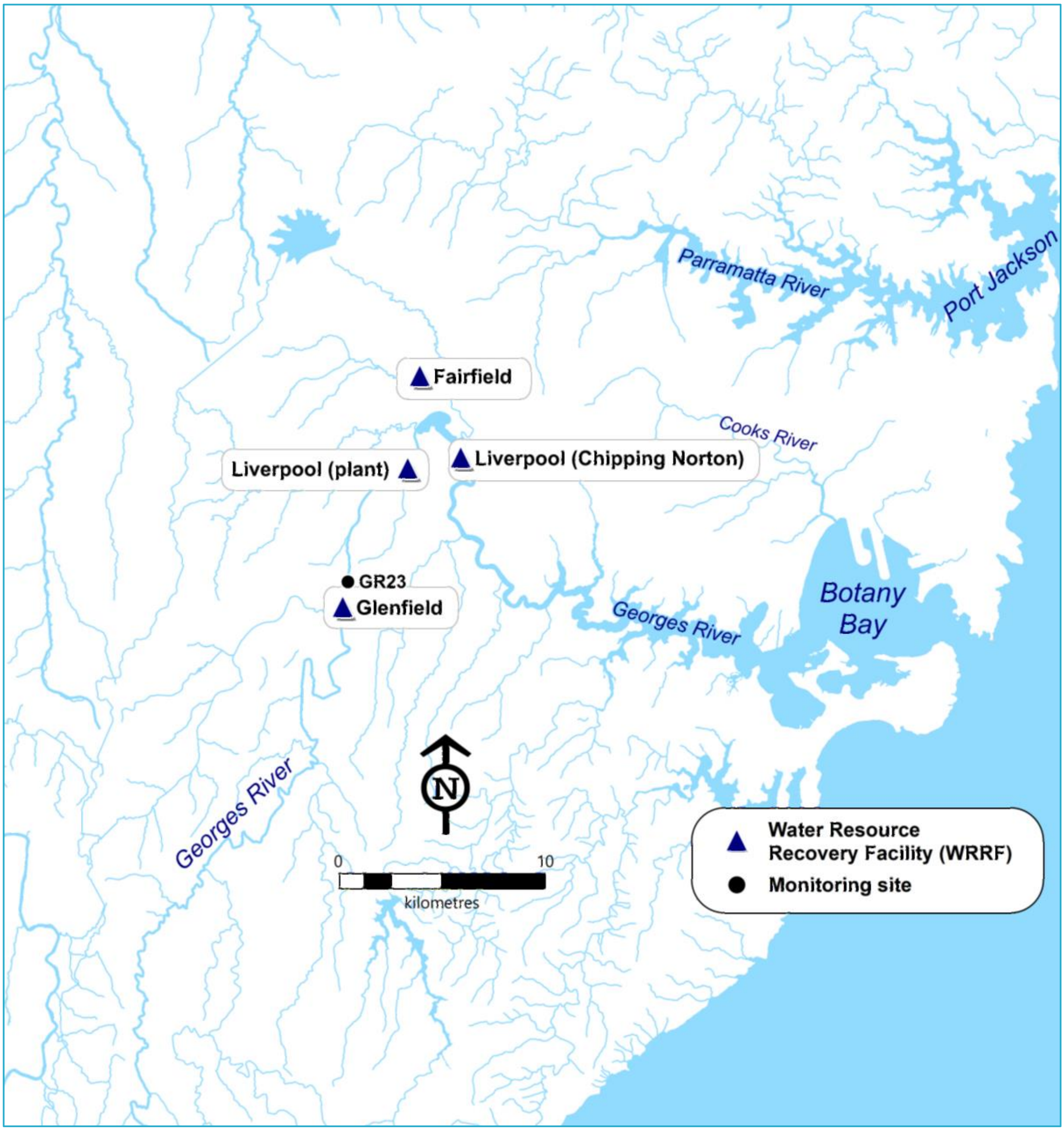


Figure 5-4 Site locations for Georges River water quality and ecosystem health sub-program (Glenfield WRRF only)

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-8.

Table 5-8 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the Georges River water quality and ecosystem health sub-program (Glenfield WRRF only)

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General water quality	Temperature, DO (% saturation), pH, conductivity, turbidity
	Chemical [a]	Nutrients	ammonia nitrogen, oxidised nitrogen, total nitrogen, total phosphorus, soluble reactive phosphorus
	Chemical [a]	Metals	General suite including (but not necessarily limited to) aluminium, cobalt, copper, nickel, zinc
Ecosystem receptor	Biodiversity	Phytoplankton communities	Chlorophyll-a
		Macroinvertebrate communities	SIGNAL-SG, Community structure

[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.

Water quality, chlorophyll-a and macroinvertebrates are monitored at all sites. The rationale for the selected analytes and indicators is the same as for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 5.1.2). Sampling details are also the same as described for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 5.1.2).

5.3 Other freshwater environments

5.3.1 Freshwater reference sites water quality and ecosystem health

Rationale

Sydney Water maintains a series of reference sites to help understand how the water quality and ecosystem health of freshwater sites potentially impacted by Sydney Water WRRF discharges in the Hawkesbury-Nepean River and Georges River systems compare with sites in streams of 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), while additional details of the monitoring sub-program methods are provided in Sydney Water's Annual Reporting preparation work instruction and a separate monitoring plan.

Aims and objectives

The aim and specific objective for the sub-program are presented in Table 5-9.

Table 5-9 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.

Monitoring approach

Design and sites

This sub-program consists of seven reference sites as listed in Table 5-10 and shown in Figure 5-5. Two sites are located in each of 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.

Table 5-10 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	-34.09440	150.83502
GR24	Georges River at Ingleburn Reserve Weir	-34.00675	150.88837
PH22	Hacking River at McKell Avenue	-34.10890	151.04800
LC2421	Unnamed tributary of Devlin's Creek, Lane Cove River	-33.75087	151.08427
NP001	McCarrs Creek	-33.66297	151.24966
N628	Bedford Creek	-33.77212	150.49906
N451	Lynchs Creek	-33.65118	150.66492

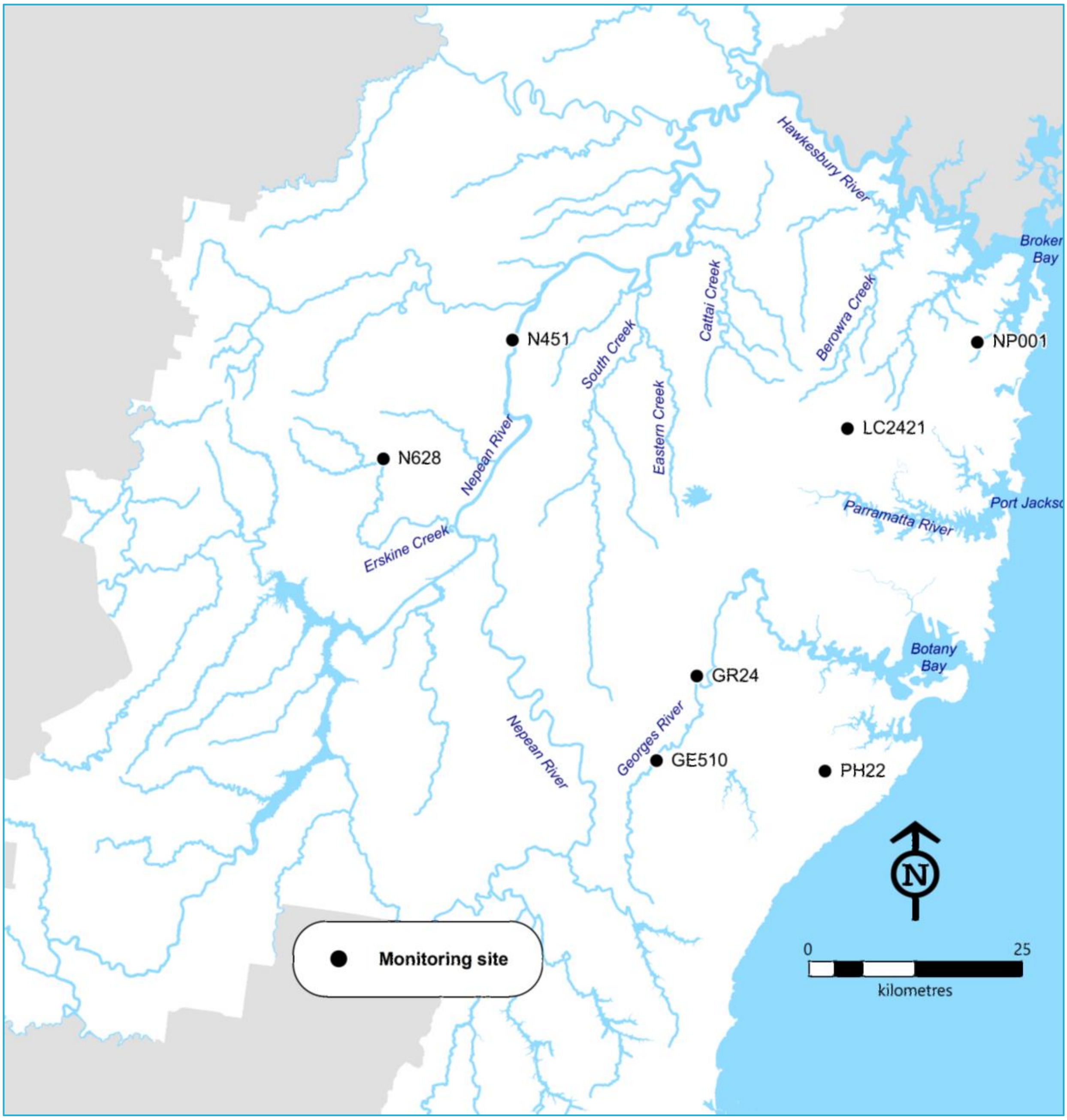


Figure 5-5 Site locations for the reference sites water quality and ecosystem health sub-program

The Hacking River site, PH22, was potentially compromised in 2022 as a result of a pollution event not related to Sydney Water's operations (Colin Besley, pers comm, Sydney Water, February 2023). This site has been retained for now but will be assessed for its ongoing suitability as a reference site, and a decision made on its future, accordingly.

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-11.

Table 5-11 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the reference sites water quality and ecosystem health sub-program

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General water quality	Temperature, DO (% saturation), pH, conductivity, turbidity
	Chemical [a]	Nutrients	ammonia nitrogen, oxidised nitrogen, total nitrogen, total phosphorus, soluble reactive phosphorus
	Chemical [a]	Metals	General suite including (but not necessarily limited to) aluminium, cobalt, copper, nickel, zinc
Ecosystem receptor	Biodiversity	Macroinvertebrate communities	SIGNAL-SG, Community structure

[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.

Water quality and macroinvertebrates are monitored at all sites. The rationale for the selected analytes and indicators is the same as for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 5.1.2). Sampling details are also the same as described for the Hawkesbury-Nepean River water quality and ecosystem health sub-program (see Section 5.1.2).

5.4 Nearshore marine

5.4.1 Nearshore marine WRRF effluent quantity, quality and toxicity

Rationale

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 (discussed further in Section 5.5), nearshore outfalls, cliff face outfalls and shoreline outfalls. The locations of the nearshore, cliff face and shoreline WRRFs are shown in Figure 5-6. Sydney Water's license permits an impact 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 nearshore WRRF discharges are shown in Table 5-12.

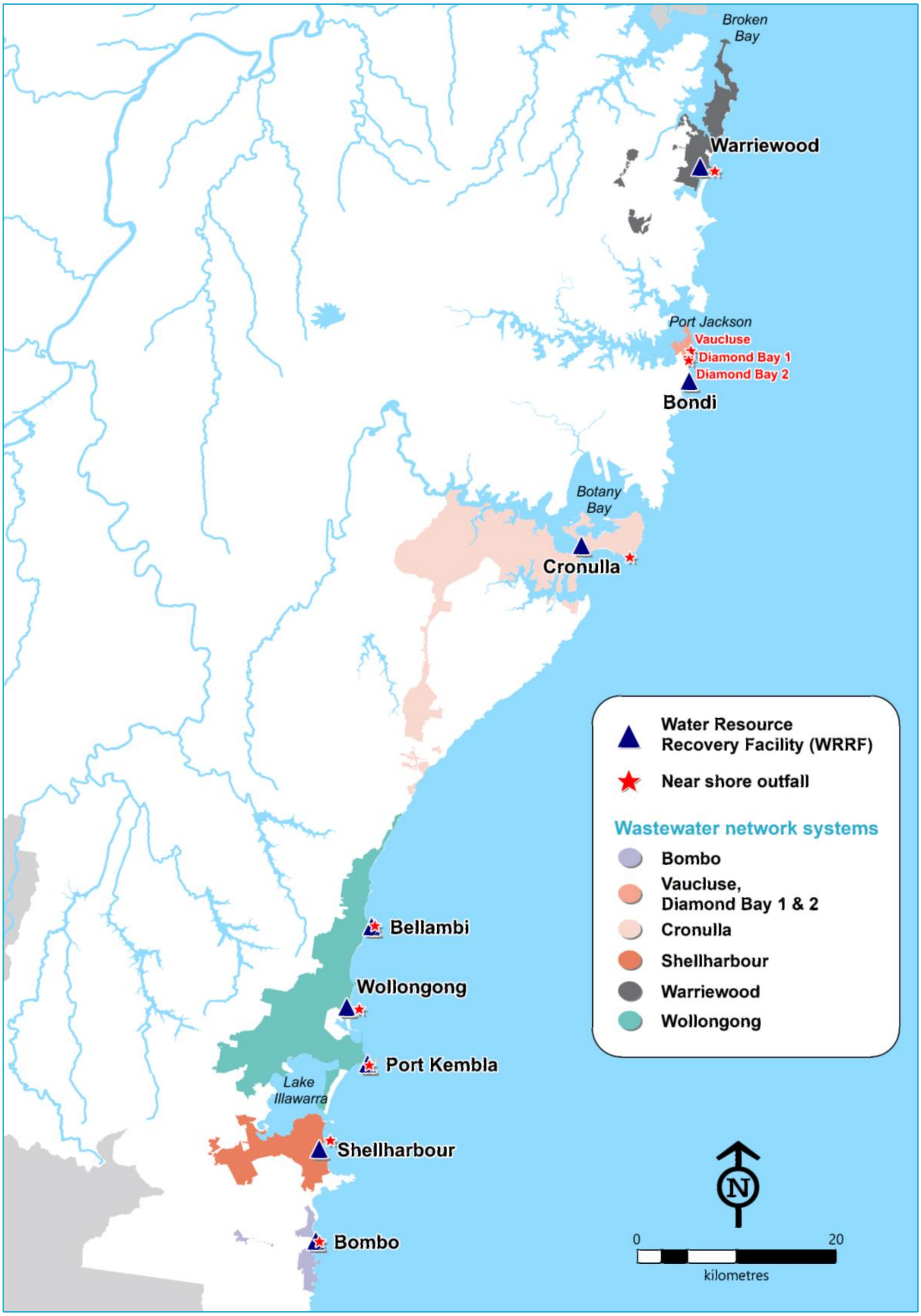


Figure 5-6 Location of WRRFs discharging to the nearshore marine environment (includes nearshore, cliff face and shoreline discharges)

Table 5-12 Summary of discharge information for each nearshore and shoreline outfall (adapted from MHL 1997, Krogh 2000, Rayner et al. 2012). Dilution factors from Sydney Water (2004b)

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

There are two nearshore outfalls that discharge secondary (Shellharbour) and tertiary (Wollongong) treated wastewater. 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), Bondi 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 80m high cliff and discharges ~70% of untreated wastewater. Diamond Bay 1 (DB1) is situated south of Rosa Gully at the base of a 25-30 m high cliff and discharges ~18% of untreated wastewater. Diamond Bay 2 is located 250 m south of DB1 at the base of a 25-30 m high cliff and discharges ~12% of untreated wastewater.

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.

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 3.1.2).

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. These requirements vary between WRRFs and can also be varied for each WRRF from time to time. This could include changes to the analyte suite for assessing discharge quality as a result of comprehensive sampling studies recommended by van Dam et al. (2023).

Aims and objectives

The aim and specific objectives for the sub-program are presented in Table 5-13.Table 4-1

Table 5-13 Aim and objectives for the nearshore marine WRRF effluent quantity, quality and toxicity sub-program

Aim	Objectives
To characterise and assess the quantity, quality and toxicity of the nearshore marine 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.

[a] The aim and objectives are considered interim at this stage and will be assessed in a subsequent review of the SWAM program.

Monitoring approach

Design and sites

The discharge monitoring sites for each WRRF are specified in the relevant EPL.

Analytes, indicators and sampling

Relevant quantity, quality and toxicity indicators and associated parameters and details (eg 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, which is reviewed and updated annually.

5.4.2 Nearshore marine water quality and ecosystem health

Rationale

Treated wastewater is discharged to the nearshore marine environment from eight WRRFs and untreated wastewater is discharged through three cliff face outfalls. There are also emergency releases of wastewater from eight cliff face outfalls.

Current EPLs allow for an impact within the mixing zone for each of these outfalls, but 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.

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), while additional details of the monitoring sub-program methods are to be included in Sydney Water's 'SWAM – Inland to Nearshore Marine Waters monitoring plan'. The plan will be reviewed from time to time to include additional details or modification based on the outcomes from pilot studies and approved negotiation between Sydney Water and EPA.

Aims and objectives

The aims of this sub-program are to:

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).
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).

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 5-14.

Table 5-14 Aims and objectives for the nearshore marine water quality and ecosystem health sub-program

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

Monitoring approach

Design and sites

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

The design focuses 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, nine monitoring sites are required to address Aim 1 (Table 5-15, Figure 5-7). 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

The design 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 are 24 monitoring sites that address Aim 2 (Table 5-15, Figure 5-7). Where possible, water quality, macroalgae 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).

The outfalls discharging from Wollongong and Brooklyn WRRFs are not currently 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 extremely unlikely. However, continued monitoring of the wastewater and toxicity testing is recommended at Wollongong and Brooklyn outfalls. Future inclusion of these outfalls in the SWAM program should be considered on a regular basis (every IPART cycle). Additional environmental monitoring should also be considered if there is a clear trend of exceedances in wastewater monitoring occurring or significant discharge volume, quality or plant changes.

Table 5-15 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
			WQ [a]	Macro algae and invertebrates	WQ [b]	Macro algae and invertebrates [b]		
1	TBC[c]	Shellharbour (WRRF) at Barrack Point	✓	✓			-34.5638	150.8736
2	TBC[c]	Reference location 1: Northern side of Shellharbour Headland	✓	✓			-34.5796	150.8758
3	TBC[c]	Reference location 2: Eastern side of Shellharbour Headland	✓	✓			-34.5800	150.8772
4	TBC[c]	Warriewood	✓	✓			-33.4176	151.1893
5	TBC[c]	Reference	✓	✓			TBC	TBC
6	TBC[c]	Reference	✓	✓			TBC	TBC
7	TBC[c]	Bombo	✓	✓			-34.3911	150.5179
8	TBC[c]	Reference	✓	✓			TBC	TBC
9	TBC[c]	Reference	✓	✓			TBC	TBC
10	TBC[c]	Cronulla			✓	✓	TBC	TBC
11	TBC[c]	50m			✓	✓	TBC	TBC
12	TBC[c]	100m			✓	✓	TBC	TBC
13	TBC[c]	200m			✓	✓	TBC	TBC
14	TBC[c]	500m			✓	✓	TBC	TBC
15	TBC[c]	1km			✓	✓	TBC	TBC
16	TBC[c]	Vaucluse			✓	✓	TBC	TBC
17	TBC[c]	50m			✓	✓	TBC	TBC
18	TBC[c]	100m			✓	✓	TBC	TBC

No.	Site code	Site description	Aim 1 – Intertidal sites		Aim 2 – Subtidal sites		Latitude	Longitude
			WQ [a]	Macro algae and invertebrates	WQ [b]	Macro algae and invertebrates [b]		
19	TBC[c]	200m			✓	✓	TBC	TBC
20	TBC[c]	500m			✓	✓	TBC	TBC
21	TBC[c]	1km			✓	✓	TBC	TBC
22	TBC[c]	Diamond Bay 1			✓	✓	TBC	TBC
23	TBC[c]	50m			✓	✓	TBC	TBC
24	TBC[c]	100m			✓	✓	TBC	TBC
25	TBC[c]	200m			✓	✓	TBC	TBC
26	TBC[c]	500m			✓	✓	TBC	TBC
27	TBC[c]	1km			✓	✓	TBC	TBC
28	TBC[c]	Diamond Bay 2			✓	✓	TBC	TBC
29	TBC[c]	50m			✓	✓	TBC	TBC
30	TBC[c]	100m			✓	✓	TBC	TBC
31	TBC[c]	200m			✓	✓	TBC	TBC
32	TBC[c]	500m			✓	✓	TBC	TBC
33	TBC[c]	1km			✓	✓	TBC	TBC

[a] Sampling is proposed to be done from surface waters using a drone.

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

[c] TBC: to be confirmed.

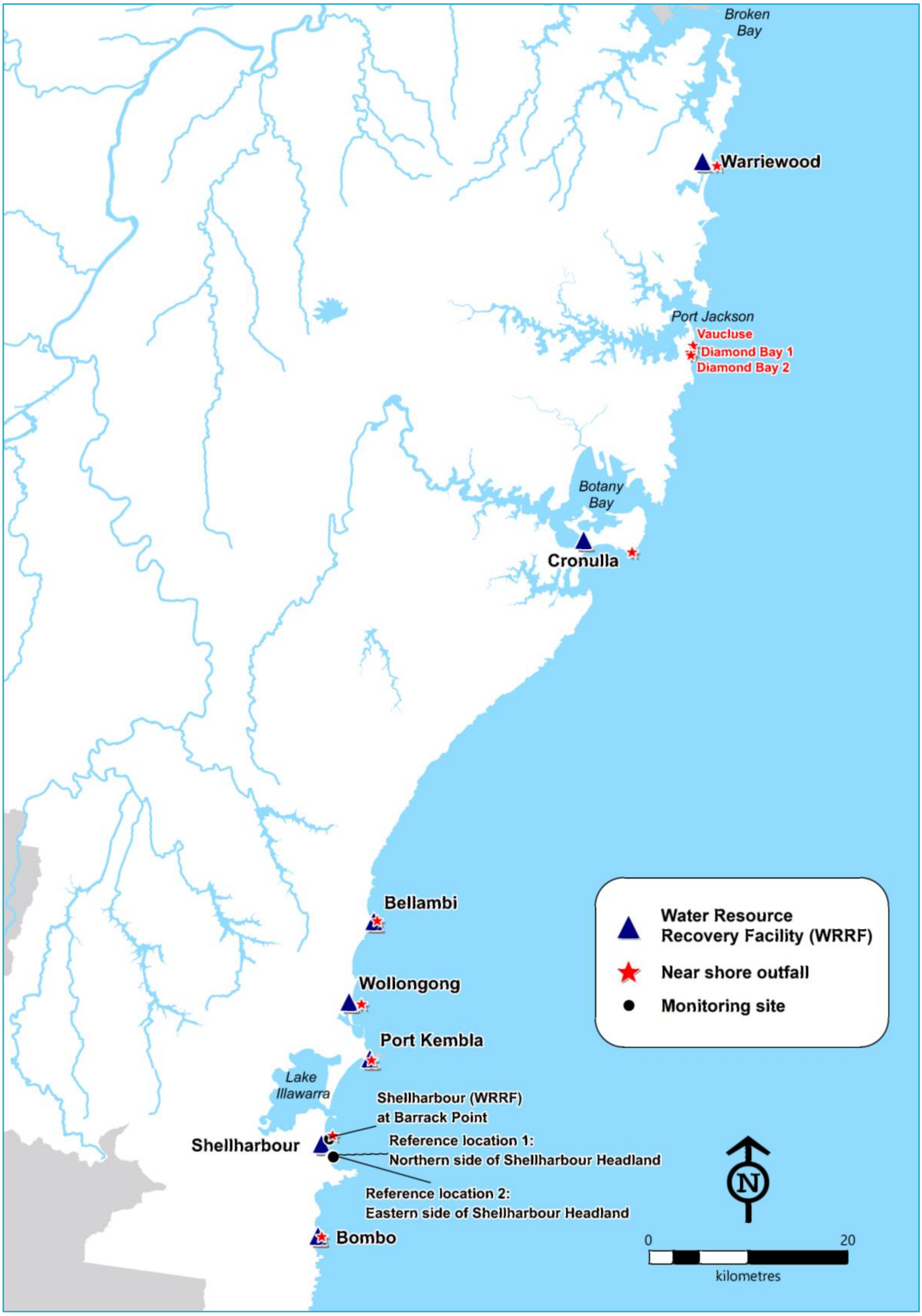


Figure 5-7 Site locations for nearshore marine water quality and ecosystem health sub-program

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-16.

Table 5-16 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the nearshore marine water quality and ecosystem health sub-program [a]

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General water quality	Temperature, DO (% saturation), pH, salinity, turbidity
	Chemical [b]	Nutrients	ammonia nitrogen, oxidised nitrogen, total nitrogen, total phosphorus, soluble reactive phosphorus
	Chemical [b]	Metals	General suite including (but not necessarily limited to) 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 5-15 for details of sites at which analytes/indicators should be measured.

[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.

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

Water quality, macroalgae and invertebrates are monitored, depending on the site, as listed in Table 5-15. 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 the outcomes of a feasibility study). At each site, two samples are collected, where possible, from just below the surface, and combined for a single measurement. Field measurements 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 5-16). 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 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 & Howe (2018). The processing workflow for RGB images includes orthomosaic generation, image classification and quadrat analysis (macroinvertebrate counts/% cover and macroalgal % 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, macroalgae and invertebrates are monitored, depending on the site, as listed in Table 5-15. 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 5-16). 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 & Howe (2018). The processing workflow for RGB images includes orthomosaic generation, image classification and quadrat analysis (macroinvertebrate counts/% cover and macroalgal % cover).

5.5 Offshore marine

5.5.1 Offshore marine WRRF effluent quantity, quality and toxicity

Rationale

Sydney Water discharges wastewater of differing qualities into the marine environment. These outfalls are categorised by the location of discharge and include deep ocean outfalls (discussed here), nearshore outfalls, cliff face outfalls and shoreline outfalls (discussed in section 5.4). Sydney Water's license permits an impact within the effluent mixing zone (i.e. a zone in which the salinity is below that of normal seawater).

There are three deep ocean outfalls that discharge primary treated wastewater (Figure 5-8). 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.

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 3.1.2).

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. These requirements vary between WRRFs and can also be varied for each WRRF from time to time. This could include changes to the analyte suite for assessing discharge quality as a result of comprehensive sampling studies recommended by van Dam et al. (2023).

Aims and objectives

The aim and specific objectives for the sub-program are presented in Table 5-17 Aim and objective for the nearshore marine WRRF effluent quantity, quality and toxicity sub-programTable 4-1

Table 5-17 Aim and objective for the nearshore marine WRRF effluent quantity, quality and toxicity sub-program

Aim	Objectives
To characterise and assess the quantity, quality and toxicity of the nearshore marine 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.

[a] The aim and objectives are considered interim at this stage and will be assessed in a subsequent review of the SWAM program.

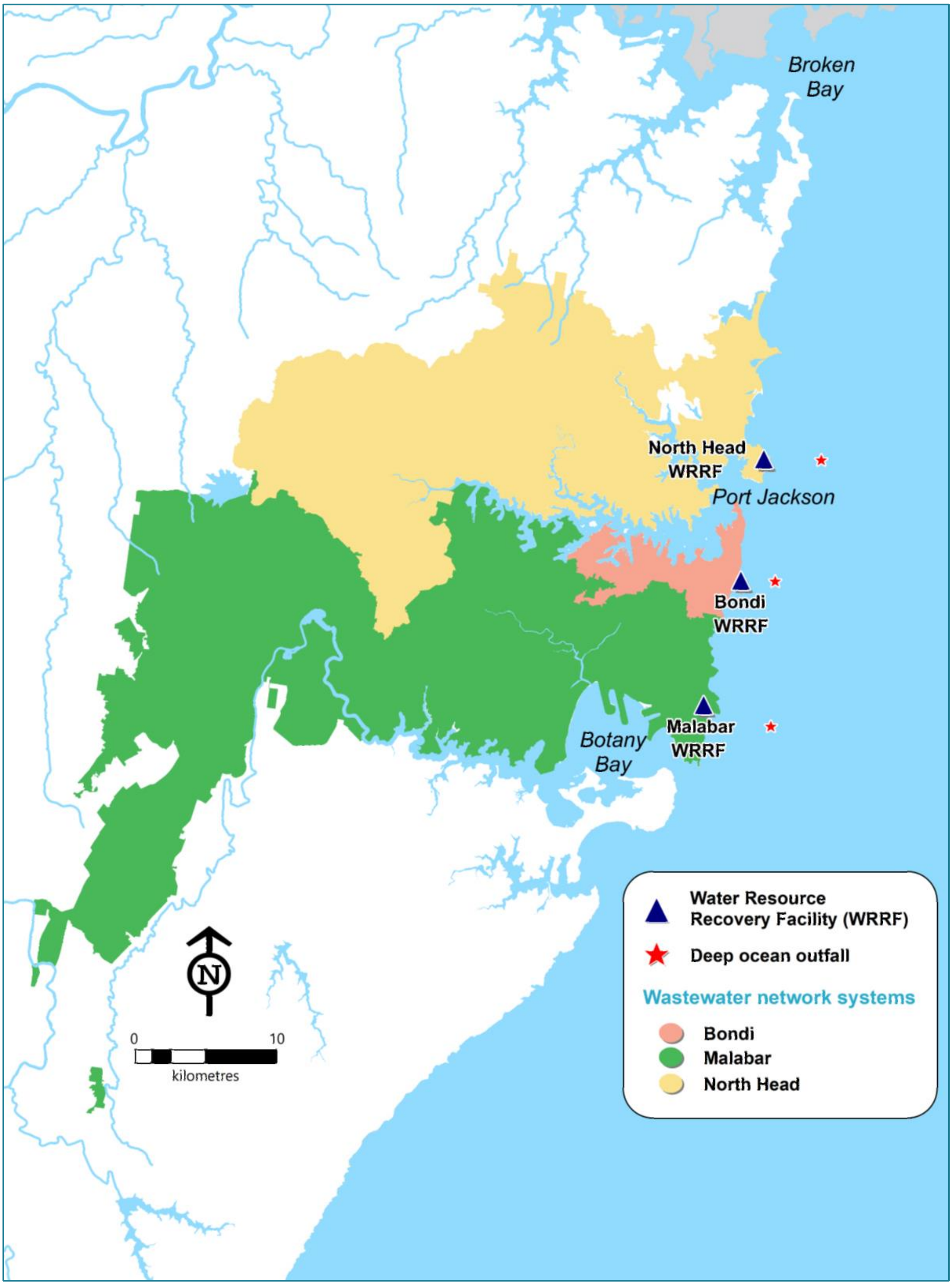


Figure 5-8 Location of WRRFs discharging to the offshore marine environment

Monitoring approach

Design and sites

The discharge monitoring sites for each WRRF are specified in the relevant EPL.

Analytes, indicators and sampling

Relevant quantity, quality and toxicity indicators and associated parameters and details (eg 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, which is reviewed and updated annually.

5.5.2 Ocean receiving water quality

Rationale

Sydney has three deepwater outfalls that are located 2-4 km offshore in 60-80 m of water. These deep 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 in 67 m of water. 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 regional moorings in New South Wales that contribute data to Australia's Integrated Marine Observing System (IMOS).

The ocean receiving water quality sub-program makes predictions of the dispersion and dilution of the wastewater plume from North Head, Bondi and Malabar deep ocean outfalls using numerical modelling of the data collected by the ocean reference station. This enables important stressor information to be predicted by numerical modelling (i.e. concentrations of substances derived from the effluent are calculated from the concentrations in effluent and the dilution factors determined from the numerical modelling). These results are reported as an annual average distribution of concentrations around the outfall, based on monthly runs of the near field models. These data are then interrogated alongside patterns in benthic infaunal communities and the accumulation of contaminants in sediments.

Aims and objectives

The aim of this sub-program is to:

1. 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. the water quality predictions), are presented in Table 5-18.

Table 5-18 Aims and objectives for the ocean receiving water quality sub-program

Aim	Objectives
(i) Assess the oceanographic processes that affect the advection and dispersion of Sydney Water's deep ocean WRRF discharges	**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) 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 measure current speed and direction throughout the water column. d. To measure temperature throughout the water column and estimate the water density profile. e. To assess the oceanographic processes that affect the advections and dispersion of Sydney Water's WRRF deepwater ocean discharges. f. To estimate the location and dilution of wastewater plumes and particle settling with near-field models. g. To compare the interannual variability of waves including maximum wave height, significant wave height and significant wave period. h. To summarise plume dilution and percentage of time exceeded over the current assessment year. i. To model spatial distribution of negatively buoyant particles and time taken to settle during the current assessment year. j. To model sediment movement by currents during the current assessment year. k. To model effluent discharge flows and loads over the current assessment year and relevant historical records

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 now includes a bottom mounted 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 5 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 (Data Warehouse) and transmission to DPE, within approximately two weeks of servicing the system.

The data collected by the ocean reference station 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 deep ocean outfall plumes.

More than 90% of the dispersion of wastewater from the deep ocean outfalls occurs in the near-field. Therefore, the near-field model PLOOM was developed specifically for the Sydney Water deep 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.

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.

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-19.

Table 5-19 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	Aluminium, cadmium, chromium, copper, mercury, lead, selenium, zinc
	Chemical [a]	Organic contaminants	Endosulphan, chlorpyrifos (at North Head), pesticides and PCBs and nonyl phenol ethoxylate

[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.

5.5.3 Offshore marine sediment quality and ecosystem health

Rationale

Sydney has three deep 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 there has been no evidence of an impact from Malabar outfall at southern control locations.

Sydney Water's offshore sediment quality and ecosystem health sub-program is designed to monitor (i) the direct marine environmental impacts of Sydney Water's WRRF discharges, and to investigate (ii) 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), while additional details of the monitoring sub-program methods are to be provided in Sydney Water's 'SWAM – Offshore Marine Waters Monitoring Plan'.

Aims and objectives

The aims of this sub-program are to:

1. Assess the direct impacts of Sydney Waters 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 5-20.

Table 5-20 Aims and objectives for the offshore marine sediment quality and ecosystem health sub-program

Aims	Objectives
(i) Assess the direct impacts of Sydney Water's deep ocean WRRF discharges on (a) sediment quality	**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.

Aims	Objectives
and (b) ecosystem health as measured by responses of sediment infauna.	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.
	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. 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

Aims	Objectives
	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.
(ii) To investigate if any potential impact from Malabar outfall is spreading southwards.	**Surveillance years (annually in between assessment years)** *Ecosystem receptors (sediment infauna):* f. 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 (0km) for the current surveillance year. g. To compare Malabar outfall (0km) 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. h. Where trends in infauna taxa richness, abundances or multivariate community analysis indicate a potential impact at Malabar outfall (0km) for the current surveillance year, further investigate the ecological response and potential drivers (eg by comparing with sediment quality data).
	Assessment years (aligned to IPART cycle) *Ecosystem receptors:* g. 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. h. 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. i. To compare Malabar outfall (0km) with control and gradient (Long Reef, Malabar 3 km, 5 km, 7 km, Port Hacking, Marley) location taxonomic turnover over the relevant historical record. j. 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.

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. 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 are located 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) 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 5-21, Figure 5-9). 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.

Table 5-21 Receiving water monitoring sites 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	0	5	-33.72726872	151.3786946
		LR-2C	60	5	5	0	5	-33.74532758	151.3732145
Outfall	North Head	NH-1C	60	10	5	0	5	-33.80778469	151.3517427
		NH-2C	60	10	5	0	5	-33.82472204	151.3517036
Outfall	Bondi	B-1C	60	10	5	0	5	-33.89472367	151.3065893
		B-2C	60	10	5	0	5	-33.8716801	151.3136225
Outfall	Malabar 0km	M0-1C	80	10	5	5	5	-33.97810419	151.2983515
		M0-2C	80	10	5	5	5	-33.97677202	151.3055366
Control	Malabar 3km	M3-1C	80	0	5	0	5	-34.00006851	151.2824469
		M3-2C	80	0	5	0	5	-33.99914653	151.2847567
Control	Malabar 5km	M5-1C	80	0	5	0	5	-34.01688851	151.2740868
		M5-2C	80	0	5	0	5	-34.0183596	151.2769219
Control	Malabar 7km	M7-1C	80	0	5	0	5	-34.03102797	151.2617666
		M7-2C	80	0	5	0	5	-34.03386952	151.2602759
Control	Port Hacking	PH-1C	80	5	5	0	5	-34.07018599	151.2308685
		PH-2C	80	5	5	0	5	-34.07233234	151.2308238
Control	Marley Beach	MB-1C	80	5	5	0	5	-34.13519402	151.1741488
		MB-2C	80	5	5	0	5	-34.1368761	151.1749733

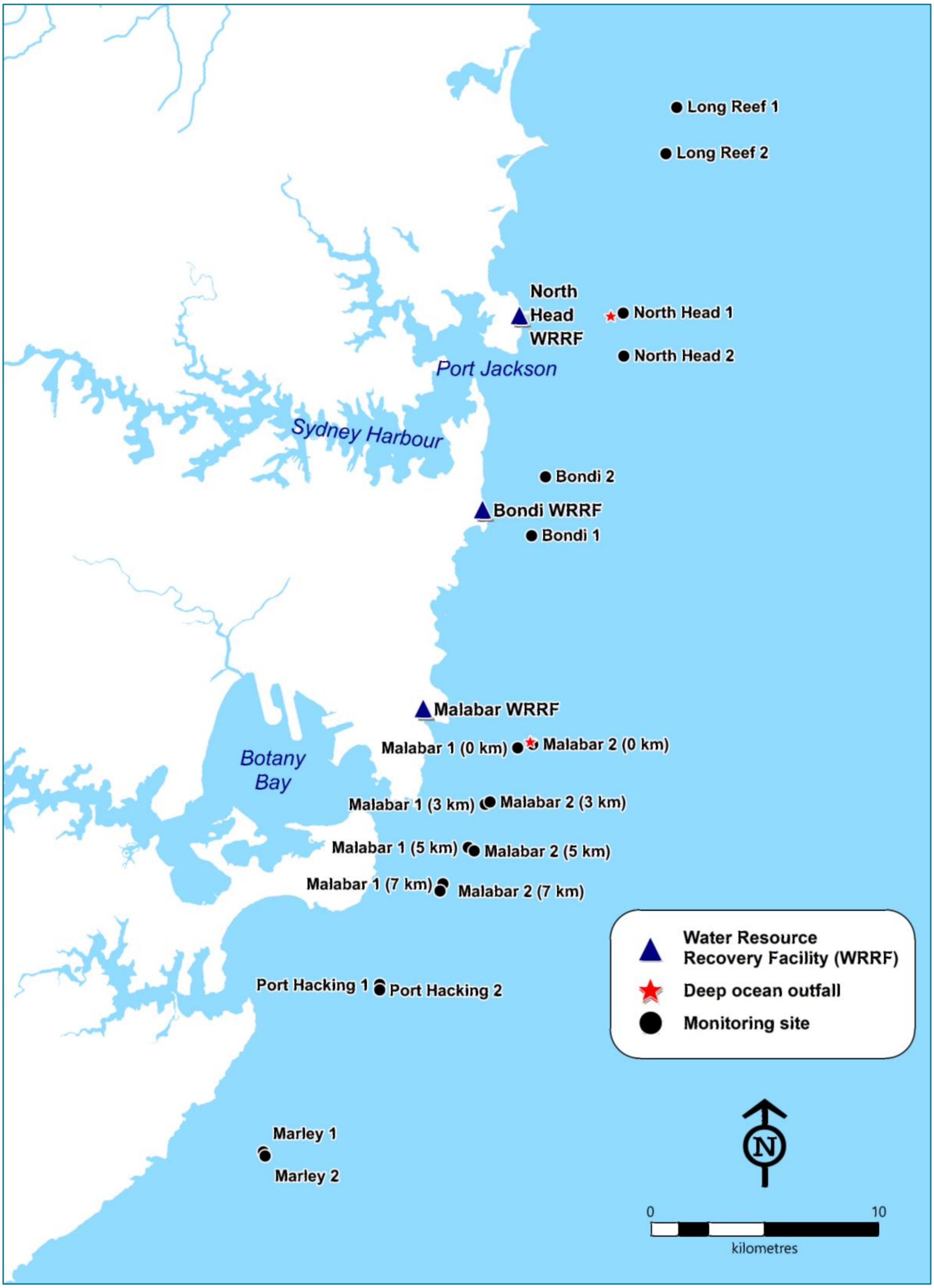


Figure 5-9 Site locations for offshore marine sediment quality and ecosystem health sub-program

Analytes, indicators and sampling

Stressor analytes and ecosystem receptor indicators and associated parameters are listed in Table 5-22.

Table 5-22 Stressor (analytes) and ecosystem receptor indicators and associated parameters for the offshore marine sediment quality and ecosystem health sub-program [a]

PSER element	Line of evidence	Indicator	Analyte / parameter
Stressor	Physico-chemical	General sediment quality	Total organic carbon (TOC), Grain size
	Chemical [b]	Nutrients	Total Kjeldahl nitrogen (TKN), Total phosphorus (North Head, Malabar)
	Chemical [b]	Metals and metalloids	Aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, selenium, silver, zinc
	Chemical [b]	Organic compounds	PAHs (naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(e)pyrene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, ideno(1,2,3-cd)pyrene, perylene, coronene) and m-cresol (all locations) O-cresol, 2-chlorophenol, pesticides and PCBs (North Head, Malabar).
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 5-21 for details of sites at which analytes/indicators should be measured.

[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.

Aim 1 – assessment of direct impacts of WRRF discharges

Sediment quality and infaunal communities are monitored as listed in Table 5-21. 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. 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 sediment quality and infaunal communities, samples are collected at yearly intervals. A “Smith-McIntyre” grab is deployed at the same angle and speed within +/- 5 m of each sub-site to collect the sample. Each grab sample collected is sub-sampled for benthic macrofaunal analysis (1 L) and chemical analyses (500 mL in 2 x 250 mL or 1 x 500 mL glass containers). All samples are analysed in Sydney Water laboratories by NATA (National Association of Testing Authorities) accredited methods for the selected analytes (Table 5-22). Quality control samples are also collected and analysed. Sediment for benthic macrofaunal analysis is wet sieved through a 1 mm sieve and then preserved with 10% Formalin-seawater solution (+ Bierbricht Stain/Rose Bengal). Sediment samples for chemical analyses are placed in a zip-locked plastic bag and stored in at -20^{o}C.

Benthic macroinfaunal analysis involves removing all animals from the sediment after sieving, identifying and counting them. Only animals with a head are included in the counts. Polychaetes, crustaceans and molluscs are identified to family while echinoderms are identified to superfamily.

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

Sediment quality and infaunal communities are monitored, depending on the site and whether it is a surveillance or assessment year, as listed in Table 5-21. Sampling details for sediment quality and infaunal community parameters are the same as described for Aim 1, above.

6 Monitoring of Wet and Dry Weather Overflows and Leakages

Wastewater overflows can occur under dry or wet weather conditions. Ocean systems have higher overflow frequencies and volume because they are much larger systems.

The dry weather wastewater leakage detection program locates leakage points from the reticulated wastewater system and enables repair of faulty assets.

6.1.1 Dry weather overflows – volume, frequency and trends

Rationale

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.

Aims and objectives

The aim of this program are to:

- Assess the volume and frequency of dry weather overflows from sewage networks or pumping station with a particular focus on dry weather overflows reaching the waterways.
- Assess the dry weather overflows by wastewater system and SCAMP as specified in relevant EPLs.

Monitoring approach

Design and sites

Dry weather overflow volumes are calculated 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. The total number of overflows and the overflow volume for each EPL and Sewer Catchment Area Management Plan (SCAMP) are recorded and the portion that reaches the receiving waters via annual returns under EPL condition L7.4 for EPL where applicable are reported.

Analytes, indicators and sampling

Further details are included in each or relevant EPLs;

- Dry weather overflow analytes (i.e. volume and number of incidents) and reporting conditions by each SCAMP, applicable to all EPLs

- Limit conditions on dry weather overflows for 12 of the 23 wastewater network systems are included in relevant EPLs
- Pollution studies and reduction programs for two of the 23 EPLs (North Head and Cronulla)

6.1.2 Dry weather leakage detection

Rationale

Sydney Water has divided its wastewater network into 232 individual Sewer Catchment Area Management Plans (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.

Aims and objectives

The information from this sub-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.

Monitoring approach

Design and sites

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 21 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, Jamberoo etc) or in underdeveloped areas (for example Duffy’s Forest). 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. Currently, there are 211 dry weather leakage detection monitoring sites, although this may change depending on EPL conditions. Further details about these sites are in Sydney Water’s Dry Weather Sewage Leakage Monitoring Plans (Routine and Source detection).

Dry weather leakage monitoring consists of three phases:

- Routine surveillance: All 211 SCAMP sites are sampled at least once every 12 months as per the 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/100mL 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.

When a SCAMP's faecal coliform result exceeds the threshold value three years in a row, the sampling frequency automatically 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 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 an Antecedent Wetness Index (AWI) of less than 5 mm. The AWI is calculated using the following equation:

  AWI (today) = 0.7 * (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 incoming tides. 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.

Analytes, indicators and sampling

General description on analytes, indicators and other associated parameters (eg sampling frequency and method) for the Dry weather leakage monitoring program are specified in each EPL. Further details are included in Sydney Water's Dry Weather Leakage Monitoring Plans (Routine and Source detection), which is reviewed and updated annually. The faecal coliform bacterial indicator is cost effective in detecting the presence of wastewater in SCAMPS and for leakage detection investigations. Table 6-1 contains the list of key analytes monitored for the dry weather leakage detection monitoring program.

Table 6-1 List of key analytes monitored for the dry weather leakage monitoring program

Line of evidence	Indicator	Analyte / parameter
General	Flow	Estimated flow in stormwater channel/waterway
Physico-chemical	General water quality	Temperature, DO (% saturation), pH, conductivity, turbidity
Sewage contamination	Chemical	Field based spot test for ammonia and fluoride Total chlorine
Bacteria	Biological	Faecal coliforms, Enterococci

6.1.3 Wet weather overflows – modelled volume, frequency and trends

Rationale

Wastewater overflows under wet weather conditions occur when the hydraulic capacity of the sewers or treatment capacity of WRRFs are exceeded. The primary cause of wet weather overflows includes the ingress of water through incorrectly plumbed downpipes that cause flooding of sewers, or infiltration of rainwater into a sewer through a public or private line. Saltwater ingress, particularly during large tide events is also known to affect assets located within the intertidal zone. Groundwater is similarly known to infiltrate the wastewater network.

Aims and objectives

The key aim of this sub-program is to assess the wet weather overflows and bypass performance by each wastewater network system. It also conducts investigative activities to improve the performance or close a performance gap.

Modelling Approach

Sydney Water estimates the volume of wet weather overflows via a model 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 2022). Each year the model is updated if significant growth or changes in the geometry or operation of the system has occurred. The model is then recalibrated using rainfall and updated sewer flow and level data.

6.1.4 Water quality and ecosystem health

This section will be updated following Phase 2 of the STSIMP review which will be focused on overflows (dry and wet) and leakages. In the interim, monitoring previously undertaken under the STSIMP has ceased for the reasons outlined in van Dam et al 2023.

6.1.5 Recreational water quality

This section will be updated following Phase 2 of the STSIMP review which will be focused on overflows (dry and wet) and leakages. In the interim, monitoring under the Beachwatch/Harbourwatch program will continue as described in the 2010 STSIMP and recommended in the STSIMP Recommendations Report (van Dam et al. 2023).

Rationale

Sydney Water contributes to the NSW Department of Planning and Environment's (DPE's) Beachwatch Monitoring Program by collecting samples and taking conductivity measurements from the Illawarra beaches. Results from DPE's Beachwatch Monitoring Program are made available to Sydney Water for assessment of potential dry weather wastewater leakage issues.

Aims and objectives

The aim of this sub-program is to:

- Assess the risk to human health from Sydney Water's overflows and leakages in estuaries, beaches and lagoons

Specific objectives for the above aim will be developed as part of Phase 2 of the STSIMP review.

Monitoring approach

Enterococci and conductivity data are collected predominantly by DPE for the Beachwatch program. DPE 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 6-2 as part of the Beachwatch Program. Sydney Water monitors 18 Illawarra coastal beach monitoring sites on behalf of DPE. Location maps for the Beachwatch sites are provided in Figure 6-1, Figure 6-2, Figure 6-3, Figure 6-4 and Figure 6-5.

Sydney and Illawarra coastal beach sites are monitored for *Enterococci* and conductivity 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.

Table 6-2 Receiving water monitoring sites for the recreational water quality sub-program

No.	Catchment	Site name	Aim 1 – overflows and leakages		Coordinates	
			Enterococci	Conductivity	Latitude	Longitude
1	Botany Bay	Brighton Le Sands Bath	✓	✓	-33.963505	151.157101
2		Congwong Bay	✓	✓	-33.989325	151.234813
3		Foreshores Beach	✓	✓	-33.957947	151.197963
4		Frenchmans Bay	✓	✓	-33.987235	151.231264
5		Kyeemagh Baths	✓	✓	-33.951872	151.165512
6		Monterey Baths	✓	✓	-33.975036	151.151707
7		Ramsgate Bath	✓	✓	-33.98542	151.14819
8		Silver Beach	✓	✓	-34.007342	151.207268
9		Yarra Bay	✓	✓	-33.978245	151.228228
10	Georges River	Carss Point Baths	✓	✓	-33.991315	151.119307
11		Como Baths	✓	✓	-33.996858	151.070646
12		Dolls Point Bath	✓	✓	-33.99719	151.14512
13		Jew Fish Bay Baths	✓	✓	-33.98408	151.060023
14		Oatley Bay Baths	✓	✓	-33.987645	151.083994
15		Sandringham Baths	✓	✓	-34.00054	151.14039
16	Port Hacking	Gunamatta Bay Baths	✓	✓	-34.05803	151.14863
17		Gymea Bay Baths	✓	✓	-34.04986	151.093246
18		Hordens Beach	✓	✓	-34.083401	151.150439
19		Jibbon Beach	✓	✓	-34.080661	151.159371
20		Lilli Pilli Baths	✓	✓	-34.069481	151.110795
21	Inner Port Jackson	Cabarita Beach	✓	✓	-33.841448	151.11863
22		Chiswick Baths	✓	✓	-33.847168	151.142892
23		Dawn Fraser Pool	✓	✓	-33.853237	151.172823
24		Greenwich Baths	✓	✓	-33.84176	151.1829
25		Tambourine Bay	✓	✓	-33.828066	151.161315
26		Woodford Bay	✓	✓	-33.831968	151.17254
27		Woolwich Baths	✓	✓	-33.838906	151.169399
28		Camp Cove	✓	✓	-33.839395	151.278758

No.	Catchment	Site name	Aim 1 – overflows and leakages		Coordinates	
			Enterococci	Conductivity	Latitude	Longitude
29	Outer Port Jackson	Clifton Garden	✓	✓	-33.839154	151.253349
30		Hayes St Beach	✓	✓	-33.841715	151.219382
31		Nielsen Park	✓	✓	-33.849925	151.266231
32		Parsley Bay	✓	✓	-33.849889	151.276441
33		Redleaf Pool	✓	✓	-33.871276	151.246974
34		Rose Bay Beach	✓	✓	-33.870027	151.265932
35		Watsons Bay	✓	✓	-33.845115	151.280546
36	Middle Harbour	Balmoral Baths	✓	✓	-33.826888	151.253476
37		Chinamans Beach	✓	✓	-33.814094	151.248971
38		Clontarf Pool	✓	✓	-33.80579	151.25172
39		Davidson Reserve	✓	✓	-33.767929	151.200343
40		Edwards Beach	✓	✓	-33.82138	151.25283
41		Fairlight Beach	✓	✓	-33.800731	151.274778
42		Forty Baskets Pool	✓	✓	-33.803133	151.270604
43		Gurney Cr Baths	✓	✓	-33.793451	151.235278
44		Little Manly Cove	✓	✓	-33.807232	151.286808
45		Manly Cove	✓	✓	-33.79944	151.282519
46		Northbridge Baths	✓	✓	-33.806043	151.222754
47	Pittwater	Barrenjoey Beach	✓	✓	-33.58849	151.32263
48		Bayview Baths	✓	✓	-33.6603	151.29824
49		Clareville Beach	✓	✓	-33.63615	151.31007
50		Elvina Bay	✓	✓	-33.64081	151.27783
51		Great Mackerel Beach	✓	✓	-33.5925	151.30035
52		North Scotland Island	✓	✓	-33.63787	151.29062
53		Paradise Beach Baths	✓	✓	-33.6255	151.31544
54		South Scotland Island	✓	✓	-33.64617	151.29061
55		Taylors Point Baths	✓	✓	-33.63527	151.307026
56		The Basin	✓	✓	-33.60712	151.29137

No.	Catchment	Site name	Aim 1 – overflows and leakages		Coordinates	
			Enterococci	Conductivity	Latitude	Longitude
57	Northern Sydney	Avalon Beach	✓	✓	-33.6377	151.33133
58		Bilarong Reserve	✓	✓	-33.710668	151.286896
59		Bilgola Beach	✓	✓	-33.64809	151.32741
60		Bungan Beach	✓	✓	-33.66766	151.31983
61		Collaroy Beach	✓	✓	-33.73383	151.30251
62		Dee Why Beach	✓	✓	-33.75471	151.29587
63		Freshwater Beach	✓	✓	-33.78261	151.28909
64		Long Reef Beach	✓	✓	-33.74733	151.3046
65		Mona Vale Beach	✓	✓	-33.68174	151.31344
66		Narrabeen Lagoon at Birdwood Park	✓	✓	-33.703876	151.304955
67		Newport Beach	✓	✓	-33.65563	151.3231
68		North Curl Curl Beach	✓	✓	-33.76811	151.29738
69		North Narrabeen Beach	✓	✓	-33.70629	151.30553
70		North Steyne Beach	✓	✓	-33.79268	151.28695
71		Palm Beach	✓	✓	-33.60042	151.32526
72		Queenscliff Beach	✓	✓	-33.788	151.28783
73		Shelly Beach (Manly)	✓	✓	-33.80214	151.29611
74		South Curl Curl Beach	✓	✓	-33.77489	151.29218
75		South Steyne Beach	✓	✓	-33.80017	151.2887
76		Turimetta Beach	✓	✓	-33.69962	151.30971
77		Warriewood Beach	✓	✓	-33.6923	151.30819
78		Whale Beach	✓	✓	-33.6128	151.33117
79	Central Sydney	Bondi Beach	✓	✓	-33.8933	151.27709
80		Bronte Beach	✓	✓	-33.90447	151.26794
81		Clovelly Beach	✓	✓	-33.91482	151.26614
82		Coogee Beach	✓	✓	-33.92202	151.25657
83		Gordons Bay	✓	✓	-33.915646	151.264558
84		Little Bay	✓	✓	-33.97978	151.25132

No.	Catchment	Site name	Aim 1 – overflows and leakages		Coordinates	
			Enterococci	Conductivity	Latitude	Longitude
85		Malabar Beach	✓	✓	-33.96569	151.25131
86		Maroubra Beach	✓	✓	-33.95026	151.25627
87		South Maroubra Beach	✓	✓	-33.951378	151.257322
88		South Maroubra Rockpool	✓	✓	-33.953515	151.258009
89		Tamarama Beach	✓	✓	-33.90222	151.26948
90	Southern Sydney	Boat Harbour	✓	✓	-34.04042	151.20004
91		Elouera Beach	✓	✓	-34.04873	151.15882
92		Greenhills	✓	✓	-34.03877	151.17246
93		North Cronulla Beach	✓	✓	-34.05279	151.15607
94		Oak Park	✓	✓	-34.07116	151.15624
95		Shelly Beach (Sutherland)	✓	✓	-34.05727	151.15425
96		South Cronulla Beach	✓	✓	-34.06566	151.15479
97		Wanda Beach	✓	✓	-34.0451	151.16191
98	Bombo	Bombo Beach	✓	✓	-34.660256	150.854299
99		Boyd's Beach	✓	✓	-34.637465	150.855894
100		Kiama Beach	✓	✓	-34.676155	150.854727
101		Werri Beach	✓	✓	-34.741207	150.832805
102	Shellharbour	Lake Illawarra Beach	✓	✓	-34.544525	150.870706
103		Shellharbour Beach	✓	✓	-34.571488	150.868405
104		Warilla Beach	✓	✓	-34.550024	150.870011
105	Wollongong	Austinmer Beach	✓	✓	-34.306608	150.935519
106		Bellambi Beach	✓	✓	-34.363835	150.921496
107		Bulli Beach	✓	✓	-34.340448	150.925565
108		Coniston Beach	✓	✓	-34.436764	150.901946
109		Corrimal Beach	✓	✓	-34.382577	150.916775
110		Fisherman's Beach	✓	✓	-34.488925	150.916754
111		North Wollongong Beach	✓	✓	-34.414250	150.902224
112		Port Kembla Beach	✓	✓	-34.493071	150.908734

No.	Catchment	Site name	Aim 1 – overflows and leakages		Coordinates	
			Enterococci	Conductivity	Latitude	Longitude
113		Thirroul Beach	✓	✓	-34.316111	150.928447
114		Wollongong Beach	✓	✓	-34.423331	150.906905
115		Wonoona Beach	✓	✓	-34.349185	150.921443

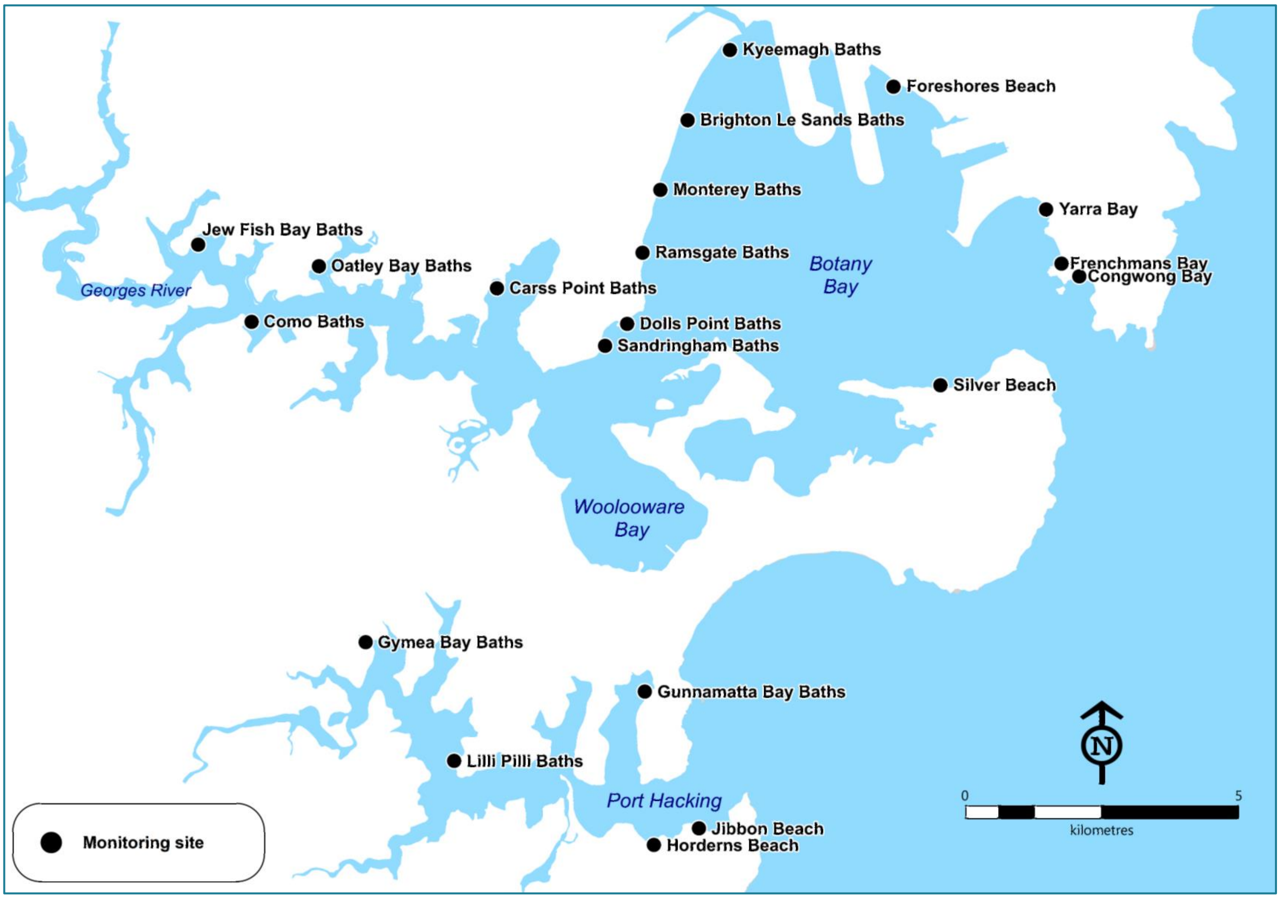


Figure 6-1 Site locations for recreational water quality sub-program: Botany Bay, Georges River and Port Hacking

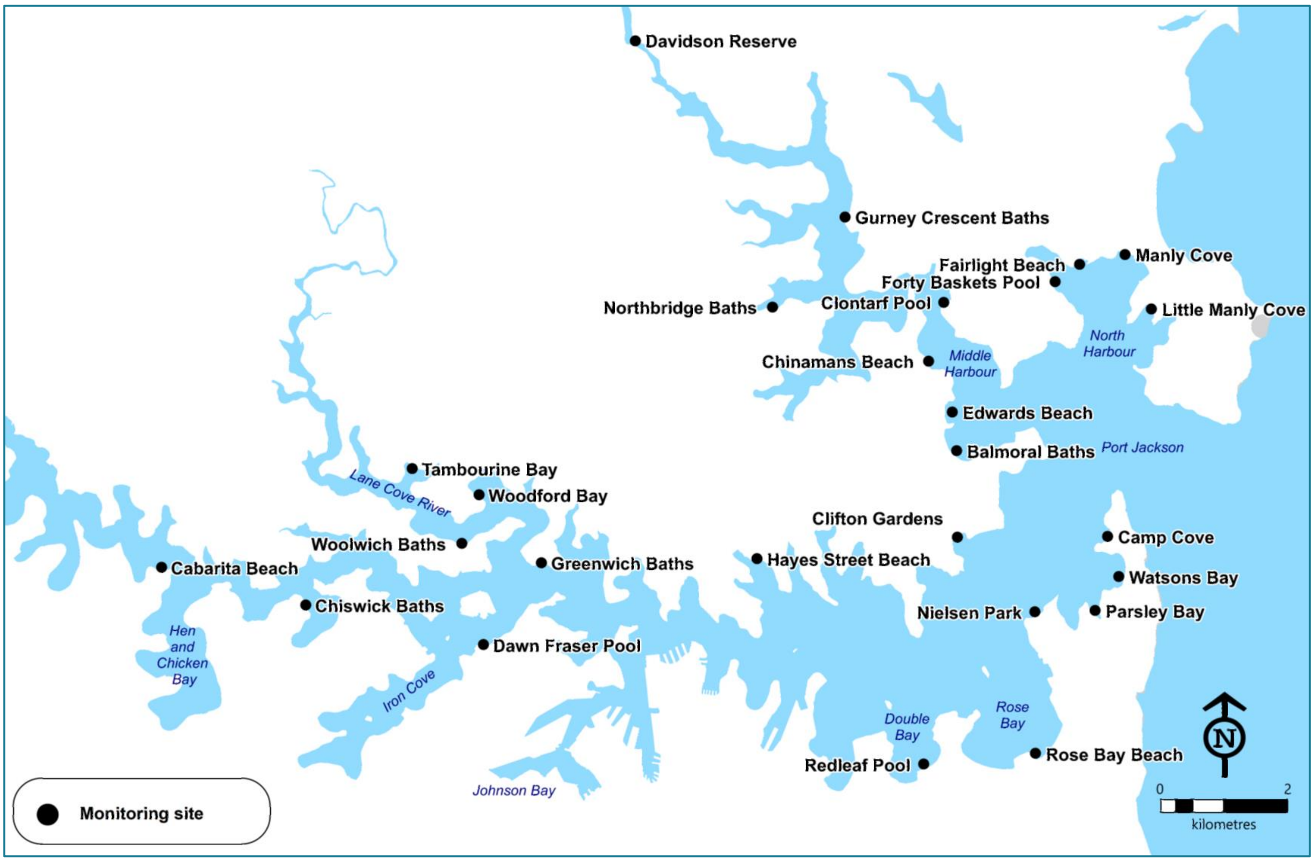


Figure 6-2 Site locations for recreational water quality sub-program: Middle Harbour and Port Jackson

Figure 6-3 Site locations for recreational water quality sub-program: Pittwater

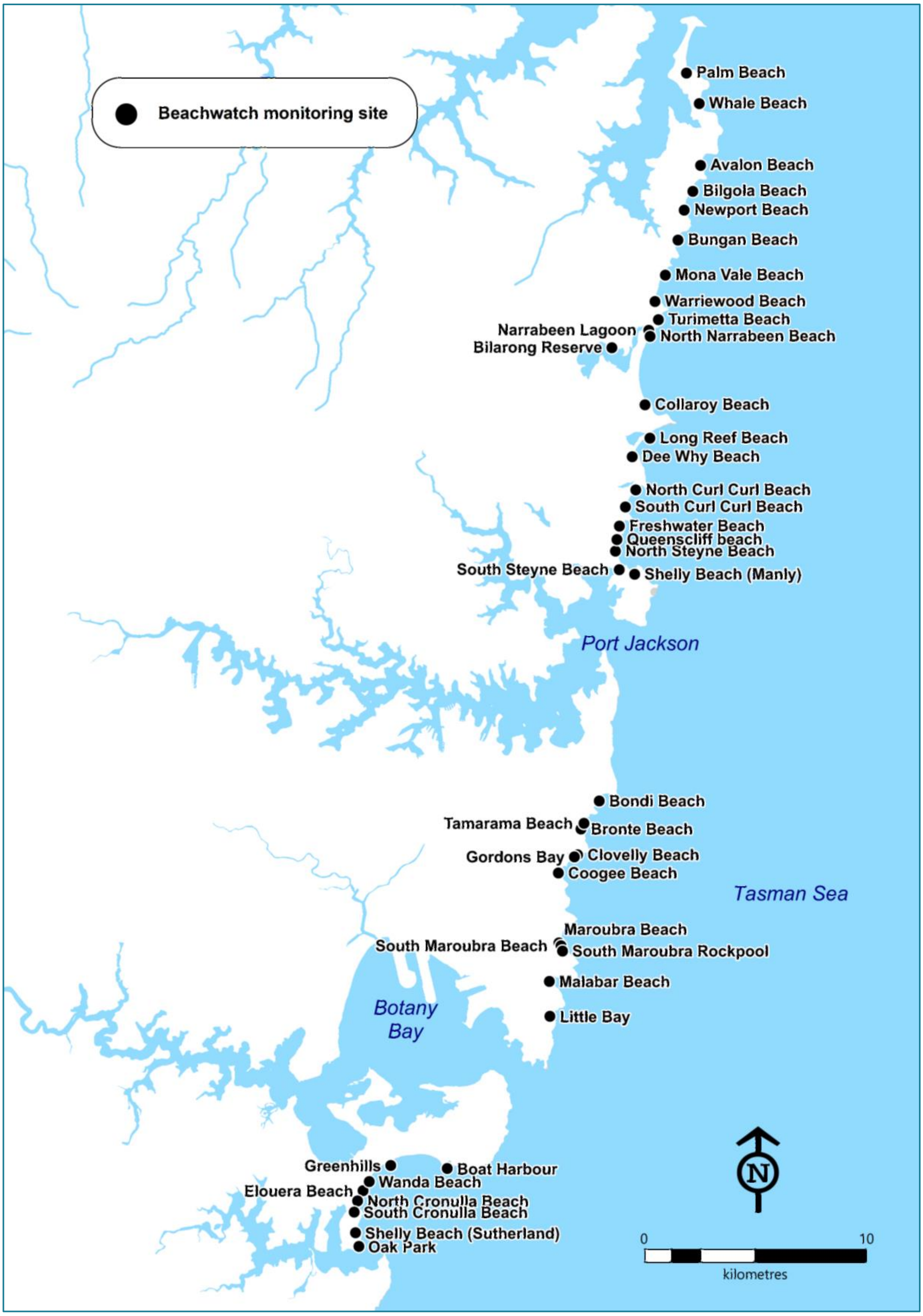


Figure 6-4 Site locations for recreational water quality sub-program: Sydney coastal beach monitoring sites

Figure 6-5 Site locations for recreational water quality sub-program: Illawarra coastal beach monitoring sites

7 Reporting requirements

The reporting and publication requirements for the results of the SWAM program are summarised in Table 7-1. All reports are checked for technical accuracy, style, format and layout through a review process, to ensure quality standards are met.

Table 7-1 Reporting requirements associated with the SWAM program

Reports/ Publications	Description	Timetable
SWAM Annual Data Report: All regions (inland, estuarine, lagoon, nearshore marine and offshore marine waters)	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. A brief commentary commensurate with the results is provided. Follows a PSER approach presenting results by pressure (i.e. WRRF discharges, overflows/leakages) and then by catchment/zone in a 'catchment to coast' order with the gated analysis workflow embedded into the reporting. Where produced in an assessment year for the Ocean Sediment Quality and Ecosystem Health sub-program, includes a brief overview of the results and a reference to the relevant Ocean Sediment Quality and Ecosystem Health Report.	To be provided to the EPA no later than 15 December each year
SWAM Interpretive Report - Inland, estuarine, lagoon and nearshore marine waters	Provides additional analyses identified based on results of the previous annual analyses relating to the response for any pressures. The corresponding results for the identified pressures presented in the Annual data report will also be included for completeness.	Every four years (aligned with the IPART cycle)
SWAM Interpretive Report - Offshore marine waters	The Ocean Sediment Quality and Ecosystem Health Report provides statistical analyses for all sampling undertaken during an Assessment year and makes comparison to previous Surveillance and Assessment years where relevant.	Every four years (aligned with the IPART cycle)

The current SWAM document as well as the associated Annual Data and Interpretive reports are made available via Sydney Water's public website. Sydney Water will continue to report the results of any modified monitoring activities via the same avenue.

8 References

ANZECC/ARMCANZ 2000. Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy Paper No 4, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. Canberra, ACT, Australia.

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT, Australia.

Besley CH & Chessman BC 2008. Rapid biological assessment charts the recovery of stream macroinvertebrate assemblages after sewage discharges cease. Ecological Indicators 8:625-638.

Drummond C & Howe D 2018. Outfall Condition Monitoring using Unmanned Aerial Systems: Warriewood, Diamond Bay and Bombo. WRL Technical Report 2018/01.

Miller BM, Peirson WL, Wang YC & Cox RJ 1996. An overview of numerical modelling of the Sydney deepwater outfall plumes. Marine Pollution Bulletin 33:147-159.

Sydney Water 1995. Environmental Indicators Monitoring Program for Sydney Water. Sydney Water Corporation, Parramatta, NSW.

Sydney Water 2010. Sewage Treatment System Impact Monitoring Program, 2010 December Update. Sydney Water, Parramatta, NSW.

Sydney Water 2022. Sewage Treatment System Licence, Annual Sewage Treatment System Performance Report - Wet Weather Overflow, 2021–22, Sydney Water, September 2022.

Tate PM, Holden C & Tate D 2019. Influence of plume advection and particle settling on wastewater dispersion and distribution. Marine Pollution Bulletin 145:678-690.

Van Dam R, Badcock C-A, Dafforn K & Howden C 2023. Recommendations Report – Findings from the independent review of Sydney Water's Sewage Treatment System Impact Monitoring Program (STSIMP). Final report prepared for Sydney Water, February 2023.

9 Glossary

Acronyms/ Abbreviations	Full meanings
ADCP	Acoustic Doppler Current Profile
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
cfu/100mL	Colony forming units per 100 millilitres
Chl-a	Chlorophyll-a
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
DO	Dissolved oxygen
DPE	Department of Planning and Environment
EIMP	Environmental Indicators Monitoring Program
EPA	Environment Protection Authority
EPL	Environment Protection Licence
ER	Ecosystem receptor
hr	Hours
IMOS	Integrated Marine Observing System
IPART	Independent Pricing and Regulatory Tribunal
km	kilometre(s)
m	metre
mL	Millilitre
ML	Megalitre
ML/d	Megalitre per day
mm	millimetre(s)
NATA	National Association of Testing Authorities
N/A	Not applicable
NSW	New South Wales
ORS	Ocean Reference Station
P	Pressure
PAHs	Polyaromatic hydrocarbons
PCB	Polychlorinated Biphenyls
POEO Act	Protection of the Environment Operations Act 1997.
PSER	Pressure, stressor and ecosystem receptor
QA/QC	Quality assurance/Quality control
RoV	remotely operated vehicle
S	Stressor

Acronyms/ Abbreviations	Full meanings
SCAMP	Sewer Catchment Area Management Plan
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
SRA	State Recreation Area
STS	Sewage treatment system
STSIMP	Sewage Treatment System Impact Monitoring Program
SWAM	Sydney Water Aquatic Monitoring
TBC	To be confirmed
TKN	Total Kjeldahl nitrogen (TKN),
TOC	Total organic carbon
WoE	weight of evidence
WQ	Water quality
WQMF	Water quality management framework
WRRF	Water Resource Recovery Facility
WWOAP	Wet Weather Overflow Abatement Program