DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Towards safer swimming – Rose Bay

Stormwater catchment audit

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Authorship and citation

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Summary

The principal goal of this research was to identify and prioritise the locations of the major potential sources of sewer inputs to Rose Bay via the stormwater network. Enterococci concentrations were measured at drain outlets during wet and dry weather conditions, and at upstream sites in drainage networks of the major sub-catchments during rainfall events. Major drain outlets and their upstream stormwater networks were identified and prioritised according to their estimated enterococci loads and concentrations.

The swimming waters of Rose Bay are impacted by sewage contamination following rainfall. Sewage is being delivered directly to the bay by wet weather overflows from a sewage pump station and indirectly via the stormwater drainage network. This report provides maps showing the areas of the catchment with the greatest sewer infiltration of stormwater and the highest priority sub-catchments for remediation.

The high enterococci concentrations in stormwater and proportions of sewage estimated suggest that even in moderate flows there is substantial contribution of sewage likely due to a significant input from sewerage overflow points or possible system failure, rather than small-scale leaks and infiltration. Further investigation must focus on identification of potential sources of large-scale inputs in addition to small-scale cross connections, leaks and breakages.

Background

The NSW Government's Beachwatch program monitors and reports on recreational water quality in Sydney Harbour in accordance with the National Health and Medical Research Council's *Guidelines for Managing Risks in Recreational Waters* (NHMRC 2008). Waters are tested for enterococci bacteria as an indicator of faecal contamination and graded to provide a guide to potential risk to human health from swimming.

Over the last decade Rose Bay Beach has been routinely graded as Poor in the annual NSW State of the Beaches report (DPIE 2019). This has led to considerable concern by local and state government as well as beach goers, recreational swimmers, and the broader community seeking action to improve water quality.

In 2017, the Rose Bay Beach Working Party was established to find solutions to water quality issues, consisting of representatives from the State Government, including the Department of Planning, Industry and Environment (DPIE), Sydney Water Corporation, Roads and Maritime Services, the Member for Vaucluse, Woollahra Council, and the community. A Water Quality Improvement Action Plan was developed, including an action to use advanced water quality testing techniques to accurately determine the sources of pollution, such as human or dog.

In February 2019 the NSW Government committed $150,000 to address water quality issues at Rose Bay by undertaking a detailed, scientific audit and analysis of the microbial pollution sources to find solutions to improve water quality.

In April 2019, scientists from DPIE, in collaboration with the Ocean Microbiology Group at the University of Technology Sydney (UTS), developed a work program for a water quality audit applying enterococci and genetic marker methods to investigate water quality issues at Rose Bay. The objectives of the research were to:

- determine the spatial extent and temporal persistence of microbial contamination in Rose Bay
- determine if microbial contamination in nearshore waters and stormwater outlets along Rose Bay were from human sewage or other animal (e.g. bird, dog) faeces
- identify and prioritise major microbial source locations in Rose Bay catchment

The purpose of this research is to inform appropriate management actions to improve water quality and ensure the right solutions are delivered. The outcomes of the investigation will be used to focus remediation efforts in the catchment and help Woollahra Council and Sydney Water design and implement management strategies to resolve water quality issues at the beach.

This report is one of three technical reports that describe the results of the NSW Government's Rose Bay water quality audit research.

Objectives

Human sewage entering the network of stormwater drains is the main source of faecal contamination and the principal cause of poor recreational water quality at Rose Bay (Seymour et al. 2019; Seymour et al. 2020). However, the areas in the drainage network where sewage contaminates stormwater are unknown. This information is needed to focus investigation and remediation efforts in the catchment and to implement cost and time efficient management strategies to resolve water quality issues at the beach.

The objectives of this report are to:

- identify specific stormwater networks within sub-catchments of Rose Bay that produce the greatest microbial loads to their respective receiving waters
- produce a map locating priority areas for further investigation of sewerage and stormwater infrastructure to implement remedial actions.

Methodology

Enterococci concentrations were measured in the stormwater network during dry weather and rainfall events to identify and prioritise the locations of the major sources of sewer inputs to receiving water via the drainage system. Major drain outlets and their upstream stormwater networks were identified and prioritised according to their enterococci load. This was calculated by multiplying the mean enterococci concentration during a rainfall event by the volume of water discharged into receiving waters. Prioritised major drain outlets and their upstream stormwater networks were further sampled at accessible locations on the network's upstream branches. Branches within the network were then prioritised in order of branches with the highest enterococci concentrations.

Site selection

Rose Bay has a catchment area of approximately 5.2 square kilometres that drains to Sydney Harbour. The upper catchment comprises steep slopes with medium density developments with few non-residential developments and little open space. The lower part of the catchment comprises flatter slopes occupied by low to medium residential development and a significant area of open space comprising Woollahra and Royal Sydney golf courses. Stormwater is carried largely within an underground pipe network or when exceeded, along roads and private property, as well as the main open stormwater channel through Woollahra and Royal Sydney golf courses (WMAwater 2010).

At Rose Bay there are 38 stormwater drains which discharge directly into bay waters. All stormwater outlets were assessed as potential sources of microbial pollutants. Nineteen of these drain outlets are very small and only drain surface runoff from roads and pathways in their immediate vicinity along the foreshore. A further 10 drain outlets have very small catchments generating only small volumes of runoff. The remaining nine drain outlets

(RBD2, RBD3, RBD4, RBD5, RBD6, RBD7, RBD8, RBD9, RBD10), which drain the largest sub-catchments in Rose Bay and have human derived faecal bacteria during wet and dry weather conditions (Seymour et al. 2020), were selected for assessment in this study. Upstream sites were located where there was access to network junctions within the catchments of selected drains (Figure 1).

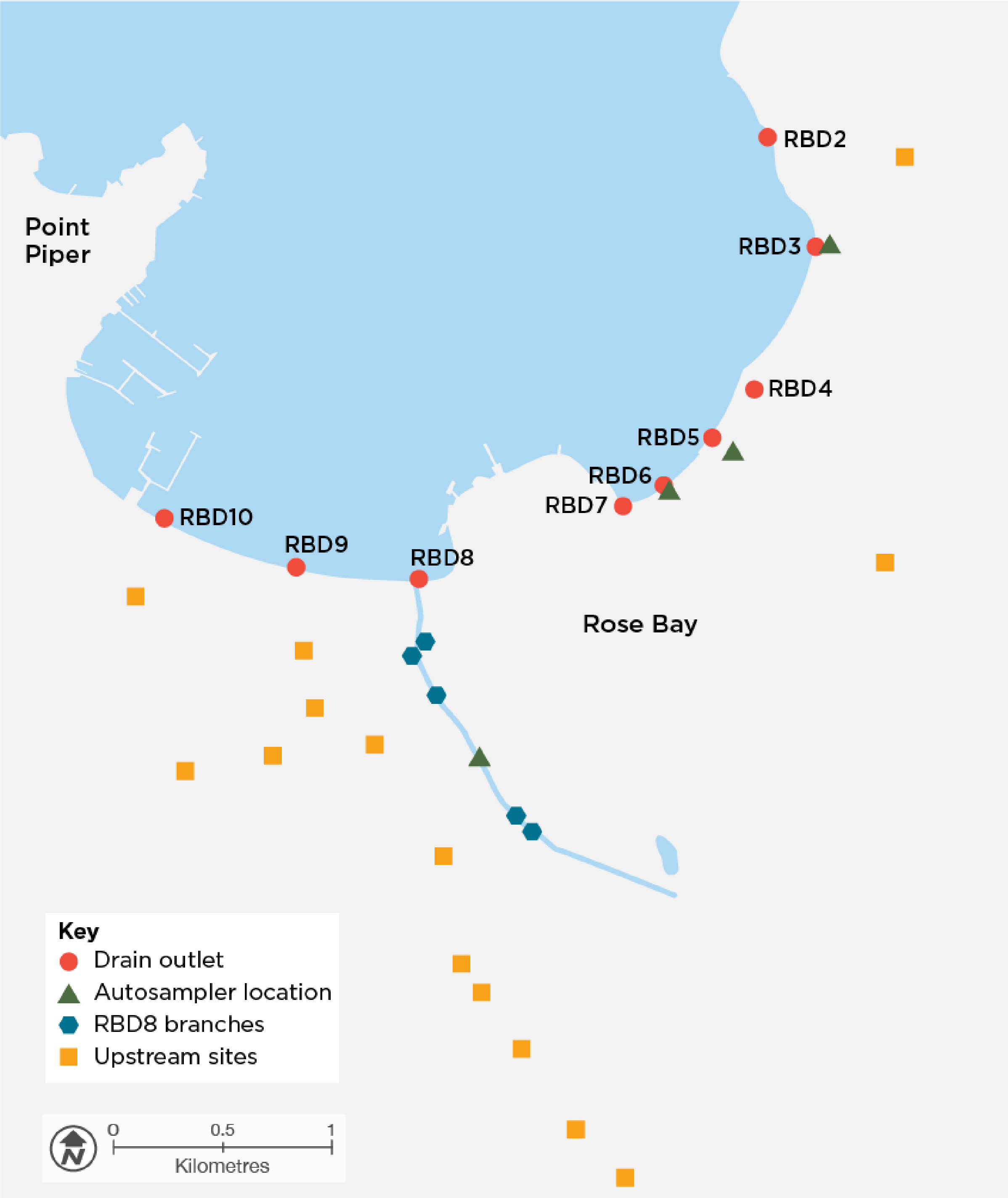

Figure 1 **Map of Rose Bay showing stormwater catchment sampling sites**

Dry weather and rainfall event sampling

Drain outlets were sampled during dry weather conditions (no rainfall in the previous 48 hours) on 21 August 2019, 3 September 2019, 21 October 2019, 1 November 2019, 22 November 2019 and 9 December 2019 (Figure 2). During sampling, estimates of instantaneous flow rates were obtained by measuring stream dimensions and current velocity.

Drain outlets were sampled during rainfall events on 27 August 2019 (12.6 mm), 30 August 2019 (50.0 mm), 17 January 2020 (5.6 mm), 7 February 2020 (64.2 mm) and 5 March 2020 (7.2 mm) (Figure 2). Upstream sites on five major branches in the catchment of RBD8 were sampled on 7 February 2020. Upstream sites on branches 3 and 4 of RBD8, and accessible points on major branches of the RBD2, RBD4, RBD9 and RBD10 catchments, were sampled on 5 March 2020 (Figure 1). Wet weather flow rates were calculated as for dry weather flows on the two sampling occasions in 2019.

One field blank was collected before each sampling event to verify that no significant contamination was caused by residual bacteria.

From November 2019 to March 2020, flow loggers (Sontek IQ and IQ pipe, Xylem Inc.) were installed in drainage pipes upstream from the four largest Rose Bay stormwater drain outlets (RBD3, RBD5, RBD6 and RBD8, Figure 1) which allowed practical access for installation and servicing. These were sited immediately upstream from the level of maximum tidal penetration and allowed more accurate flow calculations on these drains. Flow loggers were run in tandem with automated samplers (SCU Smart Auto Sampler) that collected samples each time water levels changed by 3 centimetres throughout a rainfall event. Autosamplers were equipped to keep enterococci samples chilled until collection. Autosamplers were installed in January 2020 and were operational during wet weather events on 17 January, 7 February and 5 March 2020.

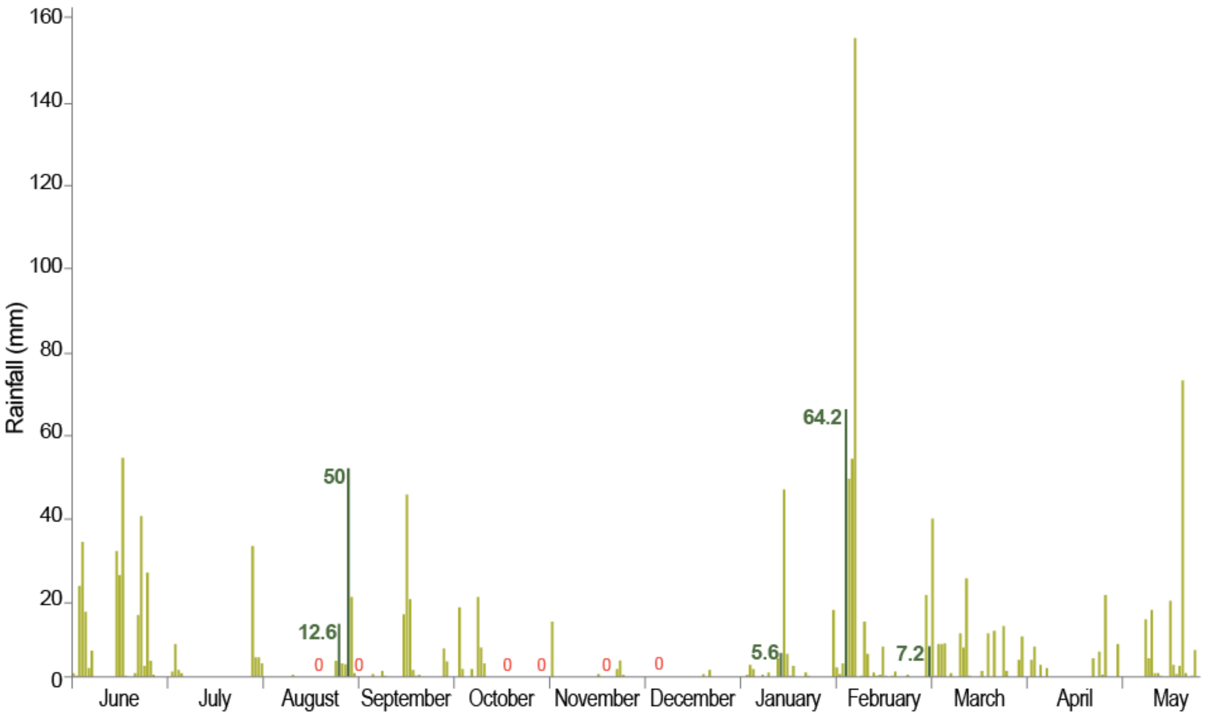

Figure 2 **Daily rainfall at Rose Bay from May 2019 to May 2020**

Sampling days are shown in blue (rainfall event) and red (dry weather) with daily rainfall (mm) above.

Sample collection and analysis

Enterococci samples were collected using aseptic techniques in sterile polypropylene jars during hand sampling at drain mouths and when transferred from autosamplers. Between uses, autosampler tubing and sample bottles were sterilised in 10% bleach for 20 minutes, rinsed in milliQ water and air dried. All water samples for enterococci enumeration were stored on ice after sampling and were delivered to laboratories for analysis within 8 hours of collection. Enterococci levels were obtained using standard membrane filtration techniques (AS/NZS 4275.9:2007) at a NATA accredited commercial diagnostic laboratory.

Fluoride samples were collected on three occasions (21 October 2019, 1 November 2019 and 9 December 2019) in dry weather conditions to identify if there were significant inputs of potable water into the stormwater network. Fluoride samples were collected in brown glass bottles. Fluoride levels were measured using the ion selective electrode method at the Sydney Water laboratory.

Catchment prioritisation

Outlets were ranked based on enterococci loads and enterococci concentrations. Loads are indicative of the magnitude of contamination. Concentrations can be used to determine sites with the greatest impact on enterococci load and proximity of contamination source to the sampling point.

All assessed stormwater outlets were ranked according to average wet weather enterococci loads across sampling events (Table 1). Equivalence of raw sewage is based on an indicative enterococci count of 524,000 cfu/100 mL[1] in raw sewage (Srinivasan et al. 2011).

Table 1 Stormwater outlet priority ranks, associated enterococci loads and equivalent raw sewage flow rates

Priority rank	Enterococci load ('000,000 cfu/s)	Equivalent raw sewage flow rates (L/s)
1	>100	>20
2	30–100	6–20
3	10–30	2–6
4	5–10	1–2
5	2–5	0.4–1
6	<2	<0.4

Drain outlets and upstream sites throughout Rose Bay catchment were then ranked according to average wet weather enterococci concentrations. Only on occasions when flow was present were enterococci concentrations used to calculate averages across events, with nil flow not counted rather than being assessed as zero.

Based on these average enterococci concentrations, sub-catchments were assigned priority rankings describing their degree of sewage infiltration of stormwater (Table 2) and consequently the order in which associated sewage catchments require investigation and remediation.

[1] Enterococci are measured in colony forming units per 100 millilitres of sample (cfu/100 mL).

Table 2 Stormwater sub-catchment priority ranks, associated enterococci concentrations, equivalent raw sewage contribution to flow, equivalent wet weather overflow contribution to flow (1:4 ratio) and potential enterococci source

Priority rank	Enterococci concentration (‘000 cfu/100 mL)	Equivalent raw sewage contribution to flow (%)	Equivalent wet weather overflow contribution (%)	Potential enterococci source
1	>50	>10	>50	Nearby overflows/ system failure
2	30–50	6–10	30–50	Nearby/ major overflow
3	15–30	3–6	15–30	Distant overflow/ major infiltration
4	10–15	2–3	10–15	Distant overflow/ minor infiltration
5	5–10	1–2	5–10	Surface runoff/ minor infiltration
6	<5	<1	<5	Surface runoff

A consequence of the sub-catchment mapping process was that all portions of a stormwater network within a catchment upstream of a sampling point were ranked according to the average enterococci concentration estimated across events at that sampling location, unless there was another sample further upstream within that sub-catchment. Sewerage infrastructure within the sub-catchment has been assigned the same ranking as the stormwater sub-catchment containing it.

Results

Drain outlet flow rates

Most stormwater drains discharged to Rose Bay in wet and dry weather conditions, with flow rates highly variable among locations and responsive to rainfall intensity (Figure 3).

In dry weather, drain outlets RBD7 and RBD9 had no flow. Flow was present in all other drains despite no rain falling in the previous 18 days. The greatest measured flow rate was in the main open stormwater channel through Woollahra and Royal Sydney golf courses (RBD8: 18.5 L/s) discharging to the western side of the bay. Substantial flows were also measured in stormwater outlets at Caledonian Road (RBD4: 8.8 L/s), Percival Park (RBD5: 1.5 L/s) and RBD6 (2.2 L/s) discharging to the eastern side of the bay (Figure 3).

In wet weather, all drains outlets had stormwater flow. The lowest measured flow rate was in RBD7 (13.65±13.65 L/s). The large open stormwater channel had the greatest flow (RBD8: 2784±1101.28 L/s). No flow measures were taken from RBD2 in wet weather due to unsafe access (Figure 3).

The main open stormwater channel through Woollahra and Royal Sydney golf courses (RBD8), and the Caledonian Road stormwater drain (RBD4) were always the dominant inflows to Rose Bay. The open stormwater channel delivered more than twice the inflow of Caledonian Road stormwater drain in dry weather, and over eight times in wet conditions (Figure 3).

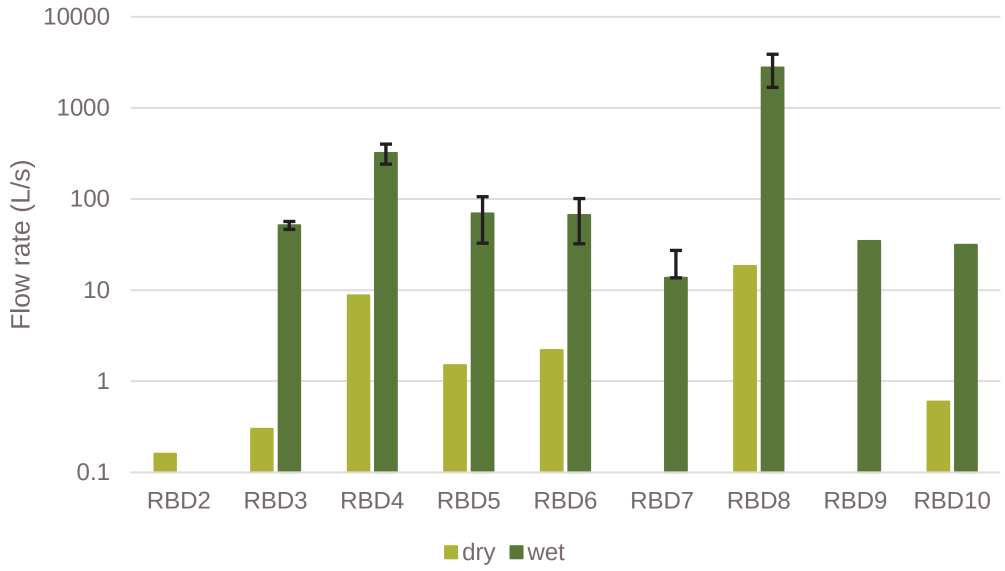

Figure 3 **Rose Bay stormwater flow rates in dry (22 November 2019) and wet weather (mean ±SE for wet weather events on 17 January 2020, 7 February 2020 and 5 March 2020)**

Note: The y-axis uses a logarithmic scale.

Drain outlet fluoride concentrations

Dry weather fluoride concentrations in stormwater outlets were highly variable among locations (df=6, F=9.58, p<0.0005) (Figure 4). The highest mean fluoride concentrations were measured in drain outlets RBD6 ($\bar{x}$ = 0.28±0.02 mg/L), RBD2 ($\bar{x}$ = 0.22±0.04 mg/L), RBD3 ($\bar{x}$ = 0.19±0.04 mg/L) and RBD10 ($\bar{x}$ = 0.19±0.05 mg/L), indicating input of fluoridised water from water mains or sewer. Mean fluoride concentrations were close to or below limits of detection (0.1 ppm) in RBD4 ($\bar{x}$ <0.1), RBD5 ($\bar{x}$ ≤0.1) and RBD8 ($\bar{x}$ = 0.11±0.01 mg/L), as is typical of local natural surface runoff (Figure 4). Dry weather fluoride levels of drains were not measured for RBD7 or RBD9 due to lack of base flow (Figure 4).

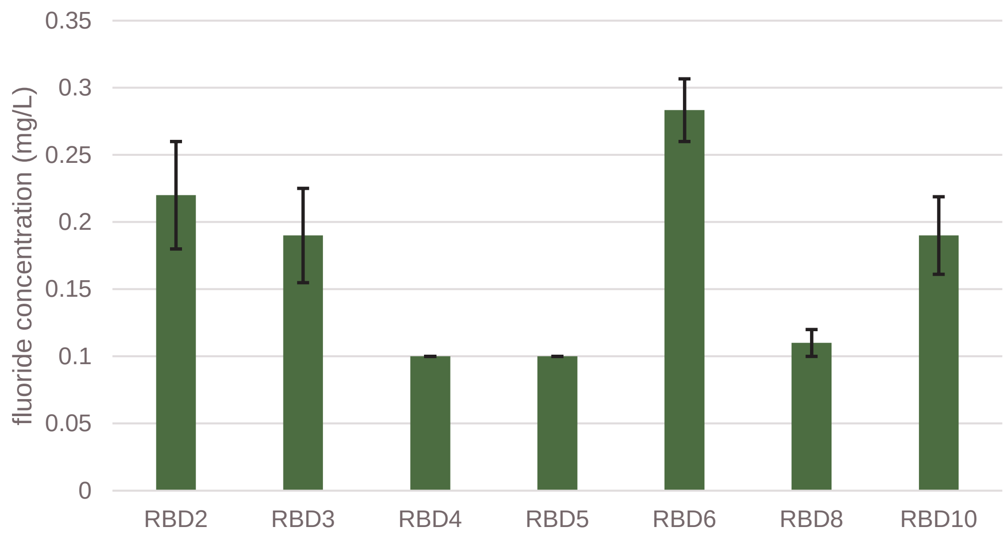

Figure 4 **Mean (±SE) fluoride concentrations in Rose Bay stormwater drains, October to December 2019**

Drain outlet enterococci concentrations

Mean concentrations of enterococci in drain outlets were significantly different between drains (df=7, F=7.73, p<0.0001), and higher in wet weather than in dry conditions (df=1, F=8.00, p<0.01). The highest enterococci concentrations were in Cranbrook Road drain outlet (RBD10) in wet ($\bar{x}$ =54,359±45,455 cfu/100 mL) and dry ($\bar{x}$ =16,539±16,487 cfu/100 mL) weather conditions (Figure 5).

In wet weather, high enterococci concentrations were measured in RBD3 ($\bar{x}$ = 42,700±32,181 cfu/100 mL), RBD4 ($\bar{x}$ = 31,740±24,672 cfu/100 mL), RBD5 ($\bar{x}$ = 27,820±17,865 cfu/100 mL) and RBD8 ($\bar{x}$ = 28,220±20,739 cfu/100 mL). In contrast, despite its relatively high enterococci concentration in dry weather, RBD2 had the lowest concentration in wet weather ($\bar{x}$ = 7,350±4,520 cfu/100 mL).

During wet weather on 30 August 2019, 7 February 2020 and 5 March 2020, sewer overflows from a sewage pump station discharged directly to the bay adjacent to RBD2. This designated overflow point releases untreated sewage directly to Rose Bay, bypassing the drainage network, with high enterococci concentrations (320,000 cfu/100 mL) measured in the eastern part of the bay on 30 August 2019.

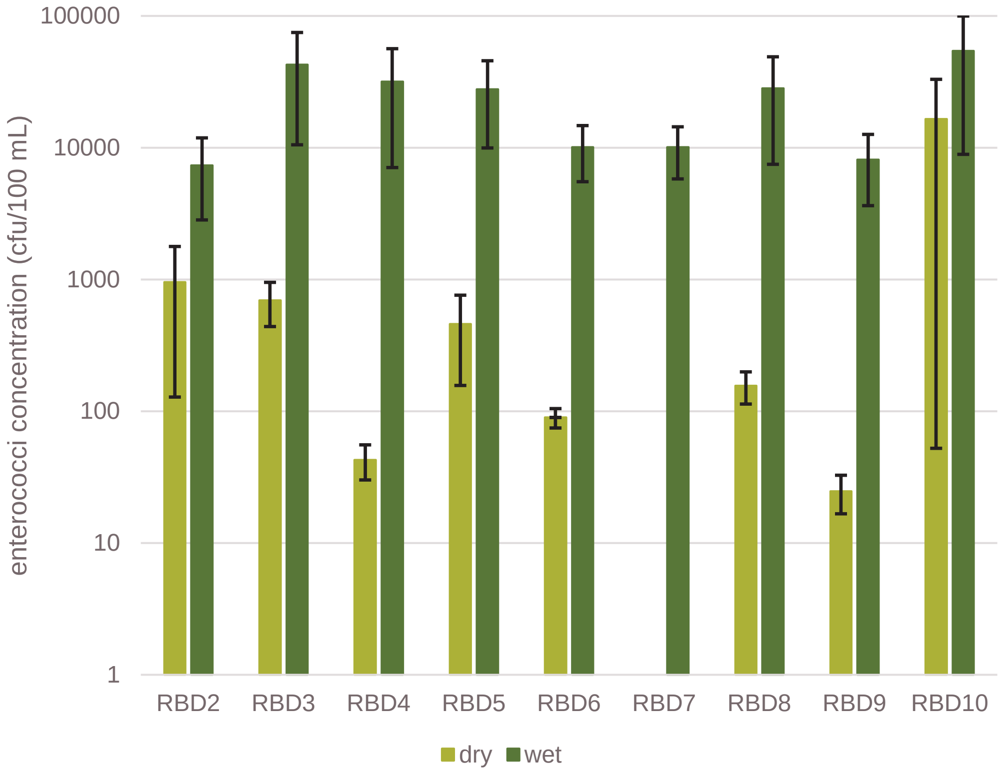

Figure 5 **Mean (±SE) enterococci concentrations in Rose Bay stormwater outlets in dry and wet weather**

Note: The y-axis uses a logarithmic scale.

Drain outlet enterococci loads

During dry weather enterococci loads were highest in Percival Park drain outlet (RBD5: 28,500 cfu/s) and the large open stormwater channel (RBD8: 62,900 cfu/s) due to their high flow rates. Microbial loads in all drains typically increased by three orders of magnitude in response to rainfall (Figure 6). Highest wet weather enterococci loads were found in RBD8 ($\bar{x}$ = 321,000,000±235,252,848 cfu/s) and RBD4 ($\bar{x}$ = 36,700,000±27,473,600 cfu/s). Enterococci loads were not calculated for RBD2 with lack of wet weather flow data due to unsafe access.

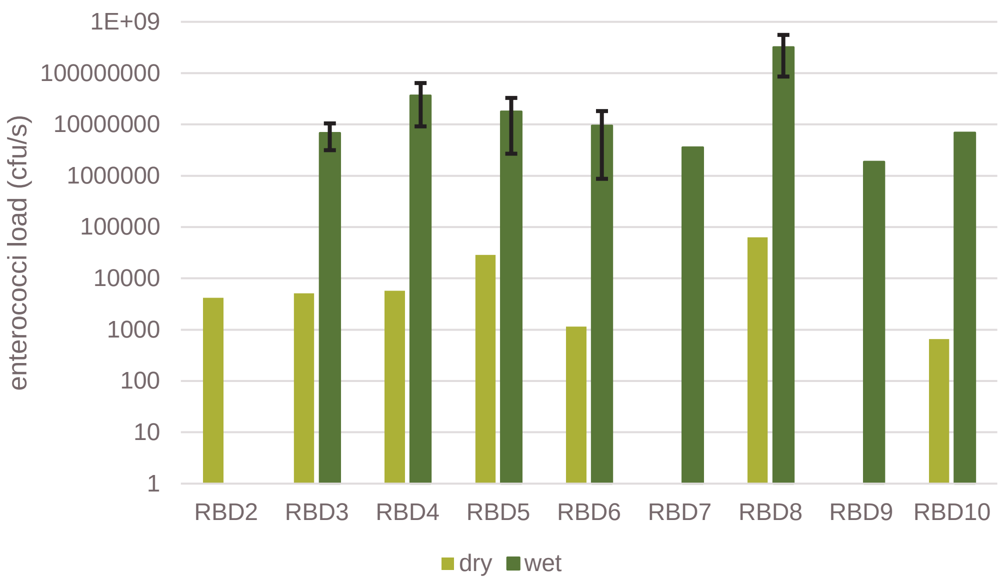

Figure 6 **Enterococci loads from Rose Bay stormwater outlets under dry conditions (22 November 2019) and wet conditions (mean ±SE for wet weather events on 17 January 2020, 7 February 2020 and 5 March 2020)**

Note: The y-axis uses a logarithmic scale.

Flow meter and autosampler assemblies all suffered at times from debris entanglement on cable and pipework or around pumps, inhibiting optimal performance. In RBD3, the relatively large amounts of debris and relatively small pipeline resulted in blockage of the autosampler pump by debris in all sampled events. In addition, autosamplers on RBD5 and RBD8 were incapacitated by debris in the wet weather event of 7 February 2020. When simultaneous data was available, there was no relationship between enterococci concentration and flow rate in RBD5 (Figure 7A) and RBD8 (Figure 7C), indicating episodic flushes of sewage contaminated water. In RBD6 enterococci concentration was significantly correlated with flow rate ($p<0.0004$) (Figure 7B).

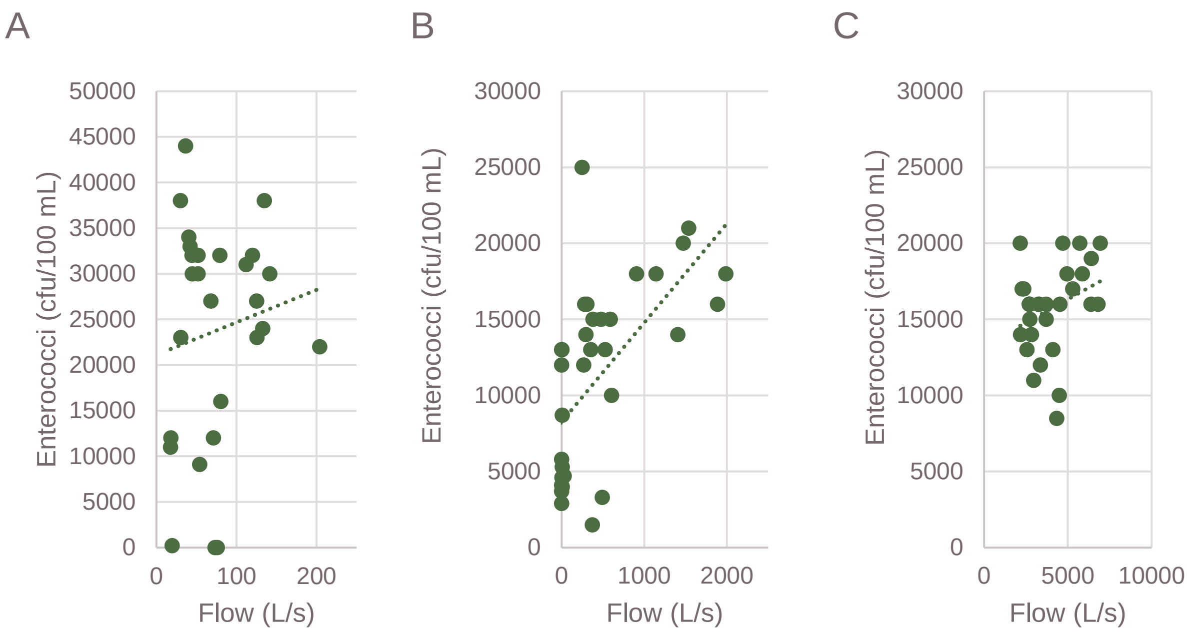

Figure 7 **Changes in enterococci concentration in the drainage network with increasing flow rate during the 5 March 2020 wet weather event**

A: Drain RBD5, B: Drain RBD6, C: Drain RBD8.

Mean enterococci loads across all wet weather sampling events were used to create a priority map of stormwater outlets (Figure 8), indicating the drain catchments with the greatest impact on receiving water microbial water quality. Discharge from the large open stormwater channel (RBD8) was identified as the highest priority (Priority 1), having the greatest impact on receiving waters according to enterococci load ($\bar{x}$ = 321,000,000±235,252,848 cfu/s). Caledonian Road stormwater outlet (RBD4) was identified as the next priority (Priority 2), according to enterococci load (($\bar{x}$ = 36,700,000±27,473,600 cfu/s) discharged to the bay.

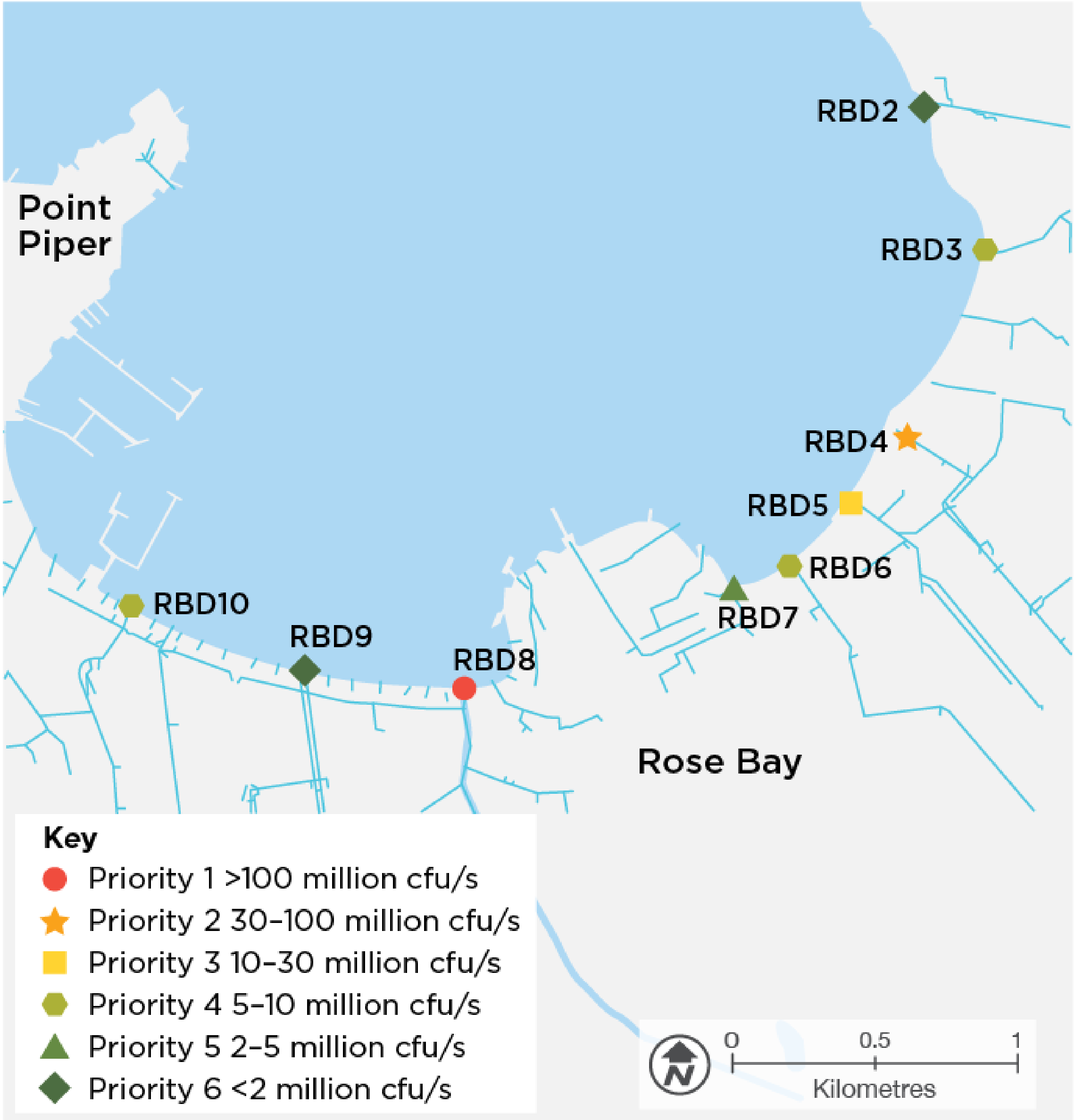

Figure 8 **Map of Rose Bay showing major stormwater outlets prioritised by impact on receiving waters according to calculated enterococci load**

Upstream enterococci concentrations

In the large open channel drainage network (RBD8), the highest enterococci concentrations were in branch 4 (25,000 cfu/100 mL), followed by branch 3 (22,000 cfu/100 mL) and branch 5 (19,000 cfu/100 mL). Lower enterococci concentrations were measured in the lower branches closer to the drain outlet: branch 2 (8,900 cfu/100 mL) and branch 1 (6,600 cfu/100 mL).

The highest enterococci concentrations in upstream sites were found in the second (96,000 cfu/100 mL) and fifth (62,000 cfu/100 mL) sub-branches of branch 4 of the open stormwater channel (RBD8), and in the upper portion of the Caledonian Road (RBD4) stormwater network (50,000 cfu/100 mL).

Priority stormwater drain sub-catchments

Rose Bay catchment map (Figure 9) identifies the areas of the catchment with the greatest sewer infiltration of stormwater. The highest priority sub-catchments (Priority 1 and 2) for investigation and remediation to address sewer infiltration during rainfall are:

- Dumaresq Reserve sub-catchment (RBD3)
- Spencer Lane sub-catchment, which is the likely source for most of the sewer input to the Caledonian Road drain (RBD4)
- Latimer Road and Boronia Road sub-catchments which deliver the bulk of sewer contamination to the large open stormwater channel (RBD8)
- Cranbrook Road sub-catchment (RBD10)

Lack of accessible upstream sites from Dumaresq Reserve drain outlet (RBD3) prevented upstream sampling and refinement of priority areas within this sub-catchment.

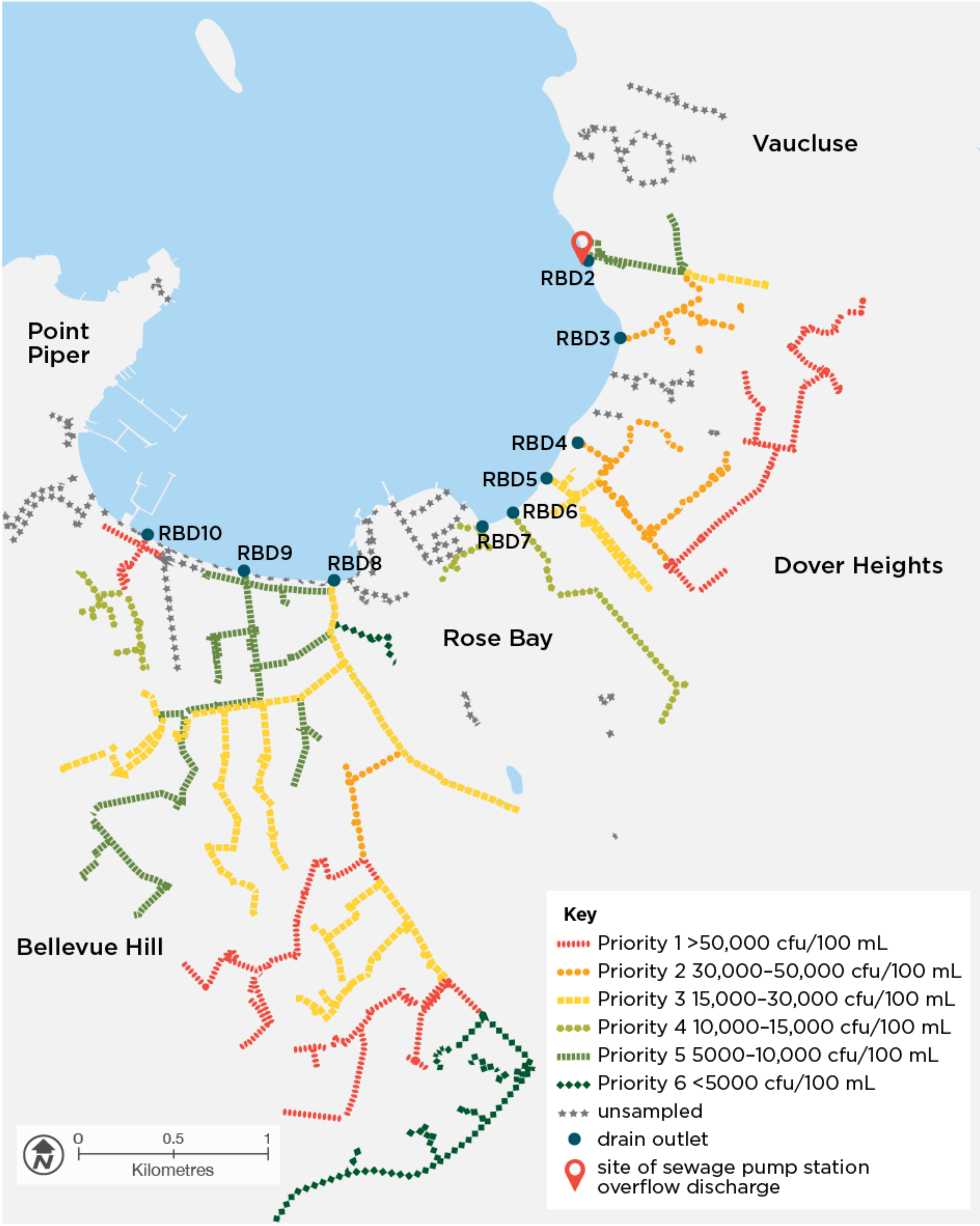

Figure 9 **Rose Bay stormwater sub-catchments prioritised by mean enterococci concentrations in stormwater**

Discussion

The swimming waters of Rose Bay are heavily impacted by sewage contamination following rainfall (Seymour et al. 2019, Seymour et al. 2020), which has been the primary driver of poor ratings reported by statewide recreational water quality monitoring (DPIE 2019). Sewage is being delivered directly to the bay by wet weather overflows from a sewage pump station and indirectly via the stormwater drainage network.

There are several potential mechanisms by which stormwater can become contaminated by sewage. By design, stormwater and sewage infrastructure systems are usually separate despite often being in close proximity. Sewerage is a sealed system between input drains and treatment facility, while the stormwater network is deliberately porous to allow uptake of diffuse source water from surface runoff and groundwater to alleviate flooding in storm events. This porosity in the stormwater system means that sewage infiltration of the stormwater network can occur through any process that allows sewage to escape from the sewer network. Damage to the sewerage system typically results from tree root intrusion, pipe movement, or as a result of material failure due to ageing infrastructure, all of which can cause leakage of sewage that will then infiltrate the stormwater system. In addition, as a sealed system, the sewer has a specified capacity beyond which it will overflow or rupture.

To avoid infrastructure damage or backflow of raw sewage into residences and businesses, deliberate designated overflow points are built into the network to release pressure when required. These designated overflow points are typically located adjacent to waterbodies or stormwater systems to ensure rapid removal of sewage from the discharge site, to safeguard human health. Overloading of sewerage pipelines and associated overflows can occur at any time as a result of pipe blockages due to root intrusion, from build-ups of flushed non-biodegradable solid matter such as wet wipes and congealed grease (fatbergs), or due to infrastructure failure. In addition to these dry weather causes, wet weather overflows are exacerbated by infiltration of stormwater into the sewerage system especially via direct stormwater to sewer connections, poorly situated or badly maintained sewer manhole covers or other damage to sewer infrastructure allowing water ingress during rain events.

While this study did not identify physical sources of sewerage infrastructure failure, it was able to identify priority areas in the sewerage system for further investigation. Further investigation in this study was limited by an atypically dry year in 2019. This was compounded by a lack of accessible upstream sites in some of the drainage networks being assessed. Despite this, identification of highest priority sewer infrastructure for investigation via prioritisation of contamination of stormwater within the sub-catchments, can now focus assessment and remediation. After completion of sewer network assessment and remediation, measurable improvements in swimming water quality should be apparent.

Although many of the stormwater drains discharging to Rose Bay have a base flow during dry weather, most are due to natural groundwater and surface water runoff, with no impact to recreational water quality in the bay. However, evidence of water mains infiltration in the drain outlet near Percival Park, and sewer leaks detected in the drain outlets near Dumaresq Reserve and Cranbrook Road, warrant further investigation. Sydney Water has subsequently located and fixed a sewer choke in the Cranbrook Road sub-catchment, which is likely to have addressed the priority area identified in that catchment.

Under rainfall conditions, most of the sewer inputs to Rose Bay are derived from the large open stormwater channel through Woollahra and Royal Sydney golf courses and the Caledonian Road drainage network. Sewer infrastructure in high priority areas identified in these sub-catchments requires further investigation. In the Latimer Road sub-catchment, the sampled stormwater was likely near a substantial overflow. The enterococci count (96,000 cfu/100 ml) in the sampled stormwater indicates approximately 19% raw sewage contribution (in the absence of large environmental enterococci inputs) based on an indicative raw sewer enterococci concentration of ~0.5 million cfu/100 mL (Srinivasan et al. 2011). Similarly, stormwater sampled from Spencer Lane sub-catchment, which is the likely source for most of the sewer input to the Caledonian Road drainage network, was estimated to be approximately 10% raw sewage, with an enterococci count of 50,000 cfu/100 ml.

Sewer inputs are also delivered directly to Rose Bay during rainfall from the sewage pump station at Bayview Hill Road. The designated sewer overflow point routinely discharged during wet weather, bypassing the drainage network and impacting nearshore waters in the eastern part of the bay. Monitoring of these directed overflows to assess their frequency may help determine if further action is required.

The very large enterococci concentrations and proportions of raw sewage estimated suggest that even in moderate flows there is substantial contribution of sewage that can be explained by a significant input from sewerage overflow points or possible system failure, rather than small-scale leaks and infiltration. Further investigation must focus on identification of potential sources of large-scale inputs in addition to small-scale cross connections, leaks and breakages.

Conclusion

The wet weather domination of sewage contamination in Rose Bay, and a general though discontinuous increase in enterococci contamination with increased drain flow in monitored stormwater lines, implies the bulk of sewer inputs to the bay are a result of wet weather overflows within the identified catchment areas. Inspection of the public and private sewer system in priority sub-catchment areas identified in this report will facilitate remediation in this area to provide measurable reductions in sewage contamination of stormwater.

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