Terrigal Catchment Audit

Initial water quality investigation report

Contents

COVER: ANDY SMITH PHOTOGRAPHY

Glossary of Terms

Ammonia (NH_3): A simple compound of nitrogen which may originate from sewage discharge but may also be a product of decomposition of industrial waste, organic material, pet waste, wildlife waste, fertilisers or atmospheric inputs (Brady & Well, 1996; Wetzel, 2001, Brady & Well, 1996, Brasseur et al., 1999). Ammonia can be toxic to aquatic organisms (e.g. fish) under certain circumstances and is a source of nitrogen for plants including algae. In nature, ammonia is rapidly converted to other nitrogen compounds.

Bather shedding: Shedding of faecal material from bathers/ swimmers.

Closed-circuit television (CCTV): A remote controlled video camera with wheel attachment that is driven inside underground stormwater and sewer pipes to investigate defects. The camera can pan, tilt and rotate for easy identification of defects, along junctions and around manholes.

Catchment: An area of land that drains towards a waterway, whether that is a creek, river, lagoon, estuary or the ocean.

Diffuse source pollution: Pollution that arises from a range of different contributing sources in a catchment. This can include runoff from urban areas, agricultural lands and forestry, especially during heavy rainfall when surface flow is more likely to occur.

Effluent: Liquid waste.

Enterococci: A type of bacteria that grows in the gut of warm blooded animals – whilst it could come from humans, it could also come from wildlife and birds, dogs, cats, rabbits, pigs or livestock that are farmed in the local catchment area.

Erosion: Wearing away of earth or rock by the effects of rain, wind, sea or rivers or by the action of toxic substances.

Eutrophication: The enrichment of water by nutrients, especially compounds of nitrogen and/ or phosphorus, which cause accelerated growth of phytoplankton, macroalgae and higher forms of plant life. This excess growth upsets the natural balance and ecological processes within a waterway.

Groundwater: Water that occupies pores and crevices in rock and soil, below the surface and above a layer of impermeable material. Groundwater flows slowly through the ground towards natural waterways.

Groundwater intrusion: Groundwater seeps into damaged, dislodged or cracked pipes and increases the volume of water within the stormwater or sewer network.

Illegal connections to sewer: Where sewer pipes from private land are connected to the stormwater system instead of the sewer system. Illegal connections can be difficult to detect and owners may not even know they exist.

Latent pollution: Pollution that lays dormant in the environment, but may be reintroduced through natural processes such as resuspension by wind and wave action.

NATA accredited: National Association of Testing Authorities, accredited testing as a rigorous basis for proving compliance with the RCM, C-tick and international EMC regulations.

Nutrient: An element or chemical essential for growth, e.g. phosphorus, nitrogen, silica, oxygen, carbon.

On-site sewer management (OSSM): Any system that processes wastewater and disposes of the effluent within the premises. The main types of on-site sewage management systems are pump-out systems, aerated wastewater treatment systems, septic tank systems, commercial systems and other miscellaneous systems such as composting systems. There are over 8000 OSSM systems on the Central Coast.

Overflows (see sewer overflows)

pH; The acidity or alkalinity of a substance, often water.

Private sewer pump station: A sewage pump system located on private land that discharge to a nominated discharge point into Council's sewer main.

Point source pollution: Pollution that arises from a well-defined point, typically the end of a discharge pipe, but may include other significant sources from a single location.

Potable water: Treated and drinkable tap water.

Relining pipes: Old or damaged sewer pipes can be relined to renew them and increase the life of the asset.

Receiving waters: A natural waterbody within a catchment.

Salinity: Both soil and natural waters can become saline. Hence, salinity can be described as either soil salinity or water salinity. Water salinity changes in concentration over space and time due to salt sources, water dilution and water movement.

Sewer: An underground pipe for conveying domestic water and waste material.

Sewer dry weather overflow: Failures within the sewer network during dry weather can result in untreated effluent being discharged to the environment.

Sewer wet weather overflow: Failures within the sewer network during rainfall can result in untreated effluent being discharged to the environment. In some cases, the sewer network has designated sewer overflow points.

Sewer choke: A blockage in the sewer network. This can be caused for example, by items being incorrectly flushed, like nappies, paper towel and wet wipes.

Sewer cracks: Aging infrastructure and natural ground movement can affect the integrity of sewer pipes. This can result in cracks or dislodged joints between pipes. Being underground, these are difficult to detect and can be challenging and costly to rectify.

Sewage: Domestic wastewater originating from our homes and businesses. This includes water from kitchens, laundries, bathrooms and toilets. Sewage is collected through Central Coast Council's 2490km network of sewer pipes and 324 pumping stations for treatment at one of eight treatment plants. Most sewage undergoes secondary treatment and is discharged into the ocean at Winney Bay in the south or Norah Head or Wonga Point ocean outfalls in the north.

Stormwater: Water from urban areas, that flows through a series of gutters and drains often discharging to a natural waterway. Stormwater can carry with it a range of different pollutants.

Systematic sampling: Sampling in a logical pattern, moving throughout an investigation area over time to establish a clear understanding of the patterns observed in the variables being measured.

Trace pharmaceuticals: Tiny amounts of pharmaceuticals, such as caffeine, antibiotics and other medications present in sewage. Measuring trace pharmaceuticals in stormwater can be an indicator of sewer contamination.

Turbidity: A measure of water clarity or cloudiness. Elevated turbidity is caused by increased amounts of sand, silt, clay and microalgae suspended in the water. Long periods of high turbidity will negatively affect waterway health.

Water quality guidelines: A set of expected water quality values for specific waterway types/uses, including water for recreation and natural waterways. In NSW, these include the National Health and Medical Research Councils Guidelines for Managing Risks in Recreational Water (NHMRC 2008) and Australian and New Zealand Environment and Conservation Council (ANZECC) guidelines.

Executive summary

Central Coast Council participates in the NSW Beachwatch Partnership Program (Beachwatch) – a water quality monitoring program designed to provide information on recreational water quality (swim safety). Data collected by Council as part of the program are used to inform the annual *NSW State of the Beaches Report*.

Since 2011-12, Terrigal Beach has received a "Poor" rating in the *NSW State of the Beaches Report*. Beachwatch uses long-term environmental trends to highlight areas of concern, which may then trigger further investigation. The program is not comprehensive enough to determine the source or scale of the factors affecting water quality.

In January 2019, Council commenced the Terrigal Catchment Audit. The aim of the audit is to assess microbial contamination as a risk to swim safety. Although microbial contamination may correlate with other factors that affect environmental health (e.g. elevated nutrient levels and suspended solids), the current report does not address broader environmental health concerns. These aspects will be captured as part of the ongoing investigations undertaken in tandem with the NSW Government.

This report provides background information on the Beachwatch program and provides key concepts and terminology to understand microbial risk, water monitoring and management. The report then provides the scope of the initial, and major, audit programs.

The initial audit establishes a robust monitoring program at 12 locations– one in Terrigal Lagoon, six along Terrigal Beach stretching from the lagoon to the "7 drains", one in the rockpool and four along Terrigal Haven. Samples taken from the stormwater pipes that discharge to the beach are paired with immediately adjacent ocean samples to assess the impact of stormwater on ocean microbial contamination. This report will provide a summary of results of enterococci count samples collected on 20 separate days from each of the 12 paired locations between January and May 2019. The intention is to collect 100 days of samples to achieve an adequate sample size as required by the *Guidelines for Managing Risks in Recreational Waters 2008* (NHMRC 2008).

Between January and May 2019, samples were collected on 20 separate days. This data set informs the initial audit.

Outcomes from the initial audit indicate:

- Between January and May 2019, Terrigal Beach and Terrigal Haven were rated as "Good" for swimming 94% and 84% of the time during dry and wet weather respectively.

- During dry weather, stormwater flows can occur for a variety of reasons including but not limited to garden watering systems, car washing, natural groundwater and underground springs. To date, dry weather flows were found to have some degree of microbial contamination at all stormwater pipes discharging to the beach, however this contamination varied and did not correspond to elevated results at the paired ocean locations (the beach). Consequently, there was minimal risk to swim safety associated with dry weather flows from stormwater drains. This is likely a result of low discharge volumes and effective dilution with ocean waters. Investigations are ongoing to assess if this remains the case long-term (a larger sample size is required) and during localised increases in population (e.g. long-weekends and school holidays). The NSW Government program will build upon this information by using more sophisticated methods to estimate volumes and potential sources of contamination (human, other animal).

- Regardless of the initial results which indicate minimal to no impact on recreational swim safety (swimming, surfing, canoeing etc) in dry weather, catchment water quality and infrastructure investigations are being undertaken to assess potential sources of microbial contamination in stormwater, and where possible reduce the likelihood of cross-contamination between sewer and stormwater networks by upgrading infrastructure as required.

- Initial water quality samples from the catchment have led to the development of a *Priority Sub-catchment Sampling and Investigation Works Program* which is detailed in the report. Major investigations of stormwater will continue throughout the 2019-2020 financial year. The priorities identified in this document may change in future as more information comes to hand.

- As a result of initial CCTV inspections of stormwater and sewer networks, a number of pipes in the Terrigal Beach and Terrigal Haven catchment areas have been identified as being in poor condition. Details are provided in the *Infrastructure outcomes* section. Whilst these pipes did not increase beach microbial presence and therefore did not pose a swim safety risk, they have been placed on a works program for upgrade.

- Council recommends that people do not swim within 3 days of rainfall at Terrigal Beach. Lagoon openings often coincides with rainfall events which increases the likelihood of beach microbial contamination. During wet weather, the ocean sites adjacent to the stormwater drains at Terrigal Beach T3-T9 (“7 drains”) showed an increase in microbial contamination. Also when the lagoon was opened there was increased microbial contamination along Terrigal Beach.

The current report comments on initial outcomes only. Initial outcomes are based on a small sample size of 20 days between January and May 2019, continuing investigations may find new and unpredicted results which may change the outcomes of the audit. Consequently, although minimal to no risk to swim safety from stormwater pipes has been detected in the initial audit, further data may prove this outcome to be incorrect. Council is continuing to sample and assess the water quality at Terrigal Beach and Terrigal Haven to build a detailed understanding of water quality under different conditions, and is working alongside the NSW Government to build a larger monitoring program.

The currently initial report does not report on other environmental impacts from stormwater, having a major focus on microbial contamination to assess swim safety. However, reducing microbial input into stormwater and receiving waters also reduces the other chemicals present in sewer such as excess nutrients, cleaning liquids (Aboul-Kassim and Simoneit 1993), micro-plastics (Napper and Thompson 2016), hormones (Adeel *et. al.* 2017), all which can have a negative environmental impact if they enter receiving waters.

Background information

Beachwatch water quality monitoring on the Central Coast

Since 2002, the former Gosford City and Wyong Shire Councils participated in the Beachwatch Partnership Program (Beachwatch) – which was established and is overseen by the NSW Government (former Office of Environment and Heritage - OEH). Beachwatch is guided by the Australian Government's National Health and Medical Research Council's *Guidelines for Managing Risks in Recreational Waters 2008* (NHMRC 2008). Central Coast Council has continued this involvement since its inception in 2016.

Council currently monitors 32 designated swimming sites, including 15 ocean beaches, three ocean baths/rock pools, four coastal lagoons and 10 estuarine netted baths. At each swimming site, water samples are collected by Council staff and tested for Enterococci, a group of bacteria common to the faecal matter of warm blooded animals. These bacteria indicate stormwater, sewage or animal faecal contamination. Sampling occurs once a week during the swimming season from September to April, and fortnightly outside of the swimming season.

After sampling, quality controlled and accredited laboratories analyse the samples, taking 24-48 hours to process and culture the bacteria. Based on the results, a grade is calculated for each site and the information is then uploaded to Central Coast Council's website: centralcoast.nsw.gov.au/beachwatch.

The data from this monitoring program are provided to the NSW Government and each year the *NSW State of the Beaches Report* is produced for all participating NSW Council areas. The data is available from the NSW Government website at: environment.nsw.gov.au. The *NSW State of the Beaches Report*, grades each swimming site as "Very Good", "Good", "Fair", "Poor" or "Very Poor" (NHMRC 2008). These Beach Suitability Grades provide a long-term assessment of how suitable a beach is for swimming (Table 1). The grades are determined from the most recent 100 water quality results (two to four years' worth of data depending on the sampling frequency) and using an estimated risk assessment of potential pollution sources (sanitary inspection). The *NSW State of the Beaches Report* highlights areas where further investigation may be required. It does not measure the impact or scale of a problem, nor specific pollution sources and how they influence recreational swim safety.

Based on water quality results from past data, the NSW Government uses rainfall to predict the likelihood of microbial contamination at all beaches and displays these predictions daily on their website: environment.nsw.gov.au/beachmapp/

Table 1: Beach suitability grading in the Australian Government's National Health and Medical Research Council's *Guidelines for Managing Risks in Recreational Waters 2008*.

Rating	Enterococci category(colony forming units per 100ml)	Category	Description
* * * *	<41	Good	Good: microbial levels are safe for bathing according to NHMRC guidelines.
* * *	41–200	Fair	Fair: microbial levels indicate an increased risk of illness to bathers, particularly those with lower immune function such as the elderly and young children.
* *	201–500	Poor	Poor and Bad: microbial levels indicate a substantially increased risk of illness to bathers.
*	>500	Bad	

General catchment pollution sources

Stormwater network

A catchment is an area of land that surrounds and slopes towards a waterway. When rain falls in a catchment, it flows downhill by force of gravity from the upper hills and slopes, through valleys and across floodplains in small streams, creeks and rivers, into lagoons, estuaries and the ocean. Water from catchments can also travel through the ground, moving slowly via groundwater aquifers to the receiving waters.

Historically, rain would have fallen in forested or wetland areas, filtered into the ground and flowed slowly across the land bringing only small amounts of soil and debris. Landuse, including clearing of land, agriculture, industry and urbanisation can affect the quality and quantity of water coming from a catchment. Nowadays, the intensity of development, loss of vegetation and increases in hard surfaces means that water flows more quickly, and collects more pollution than would naturally occur, depositing these pollutants into downstream waterways.

The runoff from urban areas is known as stormwater. Stormwater runoff transports a range of different pollutants such as pet and wildlife droppings, loose soil, grass clippings, fertiliser from gardens, detergents and car oils to the receiving water. It is the cumulative effect of our daily activities that has the greatest effect on water quality. The pollution from each household or business may seem insignificant, but multiplied by thousands of households and businesses, the concentration of pollution reaching our waterways quickly magnifies. In many locations, stormwater is untreated, meaning that catchment pollution flows directly to our waterways and swimming sites.

Dry weather stormwater flows

During dry weather, stormwater drains may flow for a number of reasons. Groundwater and underground springs can naturally seep into stormwater drains, particularly in aging suburbs with permeable or cracked stormwater infrastructure. In addition, drinking quality water may make its way into the stormwater network. Watering grass/gardens, hosing paths/driveways, washing cars on driveways instead of lawns, draining pool water into stormwater, pumping out underground water storage sumps from large buildings and carparks, and discharging drinking quality water from fire sprinkler tests can all cause dry weather flows. These flows may occur intermittently, resulting in some dry days and some flowing days. Each stormwater pipe is influenced differently by these baseline flows. The quantity and quality of water depends on catchment characteristics and the uneven distribution of flow among culverts due to their varying hydraulics. Although these are potential sources of general catchment pollution and act as a conduit, they are not the cause of microbial contamination.

In any urban catchment it is possible that illegal sewer connections are present where sewage flows untreated into the stormwater network. These would also result in dry weather flows, however, these instances are relatively rare and such connections should show signs of waste debris such as toilet paper and faeces. It is more likely that sewer lines (private or public) can be cracked, where sewage solids remain within the sewer system but sewage liquids flow into groundwater or the stormwater system.

Sewer network – public and private

The network of stormwater drains and pipes is separate to the sewer system. On the Central Coast, sewage is transported through a 2490 km network of sewer pipes and 324 pumping stations for treatment at one of eight treatment plants. Sewer pipes carry domestic, commercial and industrial wastewater from bathrooms, laundries, kitchens and toilets to a treatment plant (or septic tank) where harmful contaminants are removed before the treated effluent is released into the environment. Most sewage undergoes secondary treatment and is discharged into the ocean outfalls at Winnie Bay (south of Avoca), Norah Head or Wonga Point.

Raw sewage contains pollutants such as bleach, drain and toilet cleaning liquids and hormones from ‘the pill’, all of which can have a negative environmental impact if entering receiving waters untreated (Aboul-Kassim and Simoneit 1993, Adeel *et. al.* 2017, Napper and Thompson 2016). This initial report does not comment on other environmental impacts from stormwater, having a major focus on microbial contamination to assess swim safety. Environmental impacts of contaminated stormwater may be addressed in later reports by Council alongside the NSW Government as part of the overall audit program.

There are a number of possible sources of microbial contamination at any beach, estuary and lagoon environment, and these may directly affect the Beachwatch results.

Microbial pollutants may enter the environment from point or diffuse sources, or may be latent in the system:

- Sewer overflows – overflows that occur on private land or from a Council system, generally as a result of system blockages (can be caused by tree roots or flushing of inappropriate items) or overloads.
- Whilst Council has approved systems and processes in place to maintain the sewer network, overflows can happen from time to time. Sewer overflows from public infrastructure can occur within Council's sewer network due to a fault or at planned overflow locations. In exceptional cases, sewer systems are designed to overflow with the effluent being discharged to specific locations where it soaks into the ground, or is diluted by the receiving water and treated by the sun. Overflows can occur due to blackouts affecting pump stations, due to sewer pipe infiltration from groundwater, illegal connections from private buildings with stormwater connected to sewer, or due to blockages caused by materials.
- Sewer chokes – Private overflows occur in private sewer systems on private land, and are thus managed privately, however, if Council becomes aware of a private overflow, Central Coast Council may become involved to help prevent environmental impact. In private infrastructure, overflows often occur due to blockages of the sewer network which may be caused by incorrectly flushed items (sanitary items, wet wipes and rubbish), tree roots and sediment or debris, and cause sewage to be discharged to the environment.
- Private and public sewer mains – damaged underground pipes, due to aging or dislodgement, which then allow sewer to infiltrate groundwater or cross contaminate nearby pipes.
- Illegal connections – where private sewer infrastructure is illegally connected to the stormwater network and bypasses the sewer network (unlikely but possible).
- Groundwater infiltration – where slow sewer leaks make their way through groundwater and can seep into stormwater drains, or directly into waterways.
- Private septic systems – improperly managed or serviced on-site sewer management systems (OSSM) can result in effluent being discharged to the environment. Council monitors over 8000 on-site sewage management systems on the Central Coast however due to the number of systems, not every system can be monitored every year.
- Animals – domestic and wild animal excrement is a source of microbial contamination (Antilles *et al.*, 2015; Cody *et al.,* 2015; Cox *et al.,* 2005; Ramonaite *et al.,* 2015).

- Sediment – sediment can be a reservoir for Enterococci bacteria. During wet or windy weather, sediment and latent bacteria can be resuspended in the water. It is not currently known how long bacteria can persist in sediment. Recreational users may also resuspend sediment, through disturbance of sediment from watercraft (Bishop, 2007) feet movement or bather shedding where bathers provide the source of microorganisms (Elmir *et al.,* 2007; Graczyk *et al.,* 2010; Stewart et al., 2008). Sediment may also provide bacteria with an opportunity to grow if provided with in favourable conditions (Field & Samadpour, 2007; Muruleedhara *et. al.* 2012; Stewart *et al.,* 2008; Boehm *et al.,* 2009).
- Seaweed and seagrass - seaweed such as kelp and seagrass may also be a reservoir for Enterococci bacteria. These can be dislodged naturally or during rough seas and bring those contaminants to the shore. It is not currently known how long bacteria can survive on seaweed (reviewed in Muruleedhara *et. al.* 2012).
- Sewage pumping stations (SPS) do not normally pose a water quality risk under normal dry weather operating patterns. Abnormal weather conditions such as thunderstorms and high intensity rainfall events provide a greater risk as high flows into the sewer catchment (due to infiltration and illegal stormwater connections to the sewer) can exceed the pump capacity at the SPS creating an overflow to the environment. Additionally power supply failures during thunderstorms can also result in an overflow to the environment as no electricity supply is available to operate the pumps at the SPS. The storage time of the SPS is less than the time required to restore power to the site and consequently an overflow occurs. The greater risk during dry weather and wet weather conditions exists within the sewer network itself due to unidentified tree root ingress and obstructions created by foreign objects such as wet wipes, rags and nappies that have been discharged to the sewer. All these objects act to block or reduce the hydraulic capacity of the sewer main and create the risk of generating an overflow to the environment.
- Private sewage pump stations (PSPS) provide a risk due to the fact that they are generally not monitored by Council's SCADA system, so any deterioration in performance can't be identified. A further risk is that the owner of the PSPS may adopt a 'run to fail' maintenance strategy, which could potentially create an overflow to the environment when a failure occurs, e.g.: pump failure and consequent wet well overflow or a switchboard failure.

Performance of Terrigal Beach and comparison to other beaches in NSW

NSW State of the Beaches Report

Of the 15 ocean beaches monitored on the Central Coast, Terrigal Beach is the only site which has frequently received a Beach Suitability Grade of "Poor". In addition to this, of the 139 ocean beaches monitored and tested throughout NSW, Terrigal

Beach has consistently performed the worst, compared to other NSW ocean beaches which have intermittently received a "Poor" grade in the last eight years (Table 1).

The NSW Office of Environment and Heritage's *State of the Beaches Report* provides the following information in relation to the results for Terrigal Beach:

> *"The Beach Suitability Grade of Poor indicates microbial water quality is susceptible to faecal pollution, particularly after rainfall and occasionally during dry weather conditions, with several potential sources of faecal contamination including discharge from Terrigal Lagoon. Enterococci levels increased with increasing rainfall, occasionally exceeding the safe swimming limit after little or no rainfall, and often after 5mm or more of rainfall." (OEH, 2018).*

Terrigal compared to other beaches in NSW

In dry weather, Terrigal Beach performs slightly worse than Avoca Beach, slightly better than Rose Bay and Malabar Beach and similar to Coogee Beach (See Table 2: Dry weather samples suitable for swimming).

During wet weather Terrigal Beach, like many other beaches in NSW has reduced water quality. The adjacent coastal lagoons, Terrigal Lagoon and Wamberal Lagoon, have the potential to have a major influence on Terrigal Beach water quality when they are opened. Coastal lagoons are separated from the ocean by a sand beach barrier or berm, and can be open or closed depending on prevailing conditions. Lagoons naturally open during large inflows or heavy seas, however Council may manually open the lagoons to prevent flooding in the surrounding suburbs during heavy rainfall. After heavy rainfall, water quality in the lagoons can reduce as a result of stormwater inputs and sewer overflows from the surrounding catchments (DPI, 2019).

During wet weather, and particularly when one or both lagoons are open, the likelihood of microbial contamination along the Terrigal and Wamberal coastline increases in the short-term OEH (2018). As water drains from the lagoon/s, it can enter Terrigal Bay where microbial counts are diluted by oceanic currents and may be treated through sun and salt exposure over time (Kyung *et. al.* 2010). Of the beaches receiving a "Poor" grading (Table 2), Terrigal is the only beach with a coastal lagoon, all other beaches are sheltered ocean sites, except for Rose Bay in Sydney Harbour. The presence of the lagoon and the frequent lagoon opening may be significantly contributing to poor water quality at Terrigal in the *State of the Beaches Report*.

As a general precaution, the Beachwatch program recommends not swimming at any ocean beach sites for one day, or up to three days for estuarine and lagoon sites after heavy rainfall to avoid any effects of stormwater pollution. Council has installed permanent signage at Terrigal Beach to ensure this recommendation is available for

users of Terrigal Beach. The cumulative effect of lagoon opening on beach water quality is the subject of the current NSW Government investigation.

Table 2: Ocean beach suitability grades from the State of the Beaches Reports for Terrigal Beach compared with other similar NSW Ocean Beaches 2011 to 2018. Dry weather samples suitable for swimming are currently only available in the State of the Beaches Report from 2016-2017 onward.

Site	Year	95% percentile Enterococci cfu/100mL	Dry weather samples suitable for swimming	Beach Suitability Grade
Terrigal Beach	2017/2018	220	87%	Poor
	2016/2017	310	85%	Poor
	2015/2016	310		Poor
	2014/2015	280		Poor
	2013/2014	280		Poor
	2012/2013	310		Poor
	2011/2012	350		Poor
Rose Bay	2017/2018	380	79%	Poor
	2016/2017	290	78%	Poor
	2015/2016	190		Good
	2014/2015	185		Good
	2013/2014	220		Poor
	2012/2013	160		Good
	2011/2012	85		Good
Malabar Beach	2017/2018	280	78%	Poor
	2016/2017	380	76%	Poor
	2015/2016	330		Poor
	2014/2015	186		Good
	2013/2014	195		Good
	2012/2013	155		Good
	2011/2012	690		Poor
Coogee Beach	2017/2018	140	85%	Good
	2016/2017	200	94%	Good
	2015/2016	260		Poor
	2014/2015	200		Good
	2013/2014	150		Good
	2012/2013	170		Good
	2011/2012	145		Good
Avoca Beach	2017/2018	165	91%	Good
	2016/2017	220	93%	Poor
	2015/2016	220		Poor
	2014/2015	210		Poor
	2013/2014	160		Good
	2012/2013	180		Good
	2011/2012	195		Good

Water quality and guidelines

Microbial contamination in stormwater is common in Australia and globally

It is well documented that stormwater can be affected by both diffuse and point sources of pollution which originate from natural processes and/or the general activities of the community. Microbial contamination occurs both in developed as well as developing countries (Clark 2003, Schiff and Kinney 2001) and poses a major challenge to water quality management worldwide (WHO 2003). The research undertaken on microbial contamination from Australian and international research provide a basic understanding on the temporal and spatial variability seen in microbial presence. Stormwater can be highly variable spatially (from one place to another), temporally (hour to hour, day to day, month to month) and in response to rainfall (first flush, light rain, heavy rain, flood). Studies have shown that during rainfall, stormwater microbial contamination increases significantly (Schijven & de Roda Husman, 2005; Schijven *et al.*, 2013, Passerat *et al.*, 2011; Khan *et al.*, 2014). Enterococci can also vary spatially due to input location. For example the impact of contaminated stormwater can be highly localised and correlate with distance to pipe (Rippy *et al.*, 2014). This is particularly evident in enclosed embayment's where circulation and thus dilution is reduced (Rippy *et al.*, 2014, Schiff and Kinney, 2001).

Receiving water guidelines

The concentration of pollution in stormwater is generally higher than that found in the receiving waters (fresh or marine) (Davies-Colley, Bell, Donnison 1994, Muruleedhara *et. al.* 2012). because of the effect of dilution and sun/salt treatment. Ideally, water quality in the ocean should be suitable for both environmental and recreational needs. This can be assessed by comparing a range of water quality indicators, to threshold levels set by relevant guidelines. In NSW these include:

The following water quality guidelines can be used to assess water quality for recreational and environmental health in receiving waters such as rivers and oceans:

- NHMRC 2008, Guidelines for Managing Risks in Recreational Water, National Health and Medical Research Council, Canberra. See guidelines in Table 3.
- ANZECC & ARMCANZ 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra. Publications superseded by the revised Water Quality Guidelines, released in 2018 as an online resource.
- There are no universal guidelines or trigger values for stormwater on the Central Coast. Generally, runoff guidelines should address overall pollutant loads (volumes) rather than concentrations as a single point within the catchment.

Table 3: Extract from the National Health and Medical Research Councils Guidelines for Managing Risks in Recreational Water (NHMRC 2008: Page 72. Table 5.7 Basis of derivation of percentile values for determining microbial water-quality assessment categories)

Category[a]	95th percentile value for intestinal enterococci/ 100 mL (rounded values)	Basis of derivation	Estimation of probability
A	≤40	This value is below the NOAEL in most epidemiological studies.	GI illness risk: < 1% AFRI risk: < 0.3% The upper 95th percentile value of 40/100 mL relates to an average probability of less than one case of gastroenteritis in every 100 exposures. The AFRI burden would be negligible.
B	41–200	The 200/100 mL value is above the threshold of illness transmission reported in most epidemiological studies that have attempted to define a NOAEL or LOAEL for GI illness and AFRI.	GI illness risk: 1–5% AFRI risk: 0.3–1.9% The upper 95th percentile value of 200/100 mL relates to an average probability of one case of gastroenteritis in 20 exposures. The AFRI illness rate would be 19 per 1000 exposures or approximately 1 in 50 exposures.
C	201–500	This represents a substantial elevation in the probability of all adverse health outcomes for which dose–response data are available.	GI illness risk: 5–10% AFRI risk: 1.9–3.9% This range of 95th percentile values represents a probability of 1 in 20 to 1 in 10 risk of gastroenteritis for a single exposure. Exposures in this category also suggest a risk of AFRI in the range of 19–39 per 1000 exposures or a range of approximately 1 in 50 to 1 in 25 exposures.
D	> 501	Above this level there may be a significant risk of high levels of illness transmission.	GI illness risk: > 10% AFRI risk: > 3.9% There is a greater than 10% chance of illness per single exposure. The AFRI illness rate at the guideline value of 500 enterococci per 100 mL would be 39 per 1000 exposures or approximately 1 in 25 exposures.

Modified from WHO (2003a); see Kay *et al.* (2004) for further discussion and formulae.
AFRI= acute febrile respiratory illness; GI = gastrointestinal; LOAEL = lowest observed-adverse-effect level;
NOAEL = no observed-adverse-effect level.

a Categories A–D are the corresponding microbial assessment categories used as part of the classification procedure

Notes:

1. The 'exposure' in the key studies was a minimum of 10 minutes bathing involving three immersions. This is envisaged to be equivalent to many immersion activities of similar duration but it may underestimate risk for longer periods of water contact or for activities involving higher risks of water ingestion (see also note 7).
2. The 'estimated risk' refers to the excess risk of illness (relative to a group of nonbathers) among a group of bathers who have been exposed to faecally-contaminated recreational water under conditions similar to those in the key studies. The functional form used in the dose-response curve assumes no excess illness outside the range of the data (ie at concentrations above 158 faecal streptococci/100 mL). Thus, while a plateau effect is to be expected, the estimates of illness rate reported above are likely to be underestimates of the actual disease incidence attributable to recreational-water exposure unless the plateau actually occurs at the extremity of the data range.
3. This table relates to protection of 'healthy adult bathers' exposed to marine waters in temperate north European waters.

Stormwater water quality guidelines

The Australian water quality guidelines for receiving waters (rivers, lakes, lagoons) ***cannot*** be used to assess stormwater.

> *"The Water Quality Guidelines are not intended to directly apply to contaminant concentrations in industrial discharges or stormwater quality (unless stormwater systems are regarded as having relevant community value)"* (http://www.waterquality.gov.au/anz-guidelines/about)

Central Coast Council does not recommend that people have direct contact with stormwater.

There are no universal guidelines for stormwater water quality, however, there are processes for determining a guideline for stormwater quality that protects local environments. Stormwater guidelines, when developed, take into account the values being protected, dilution, natural resilience and sensitivity of receiving environments.

Specific guidelines need to be developed based on catchment conditions and the required level of service from the water, for example stormwater harvesting for irrigation or greywater.

Central Coast Council is in open discussions with the NSW Government about developing guidelines for stormwater for the Terrigal area. This process requires site specific research and will take time to develop.

Community concerns

Terrigal Beach is one of the best known beaches on the Central Coast, and is popular with locals and tourists for a range of reasons. Terrigal offers good recreational swimming opportunities, with a Surf Life Saving Club and a sheltered aspect from southerly winds and swell. The beach is very close to amenities such as toilets, showers and a diverse range of cafes, takeaway food shops and restaurants. Nearby, Terrigal Haven contains a boat ramp, fishing charters, picnic and BBQ facilities, sports field, café and restaurants and the iconic Skillion headland. This location is often used for scuba diving and snorkelling along the rock platform. Local swimming groups also swim from Terrigal Beach to Terrigal Haven on a regular basis.

Anecdotal community concerns regarding water quality within the Terrigal Beach area include illness, chemical smell, taste and residue when swimming, increased turbidity, increased algal blooms, loss of aquatic vegetation, notable impacts when the lagoon is opened, and die back of the Norfolk Island Pines (thought to be due to airborne surfactants blowing onshore). These concerns fall into two categories; environmental and human health, however both affect each other. For example, any microbial contamination from sewage can affect human health through increased

exposure to e.g. viruses, however, chemicals in sewage such as detergents and faecal matter also provide nutrients, which can affect the health of marine ecosystems. Consequently, addressing microbial contamination has both a positive effect for the environment and for human health.

Developing a new audit program for Central Coast Council

As a result of the poor water quality rating at Terrigal Beach, a closer investigation is considered necessary. Previous actions have focused on general improvements to Council infrastructure in the Terrigal catchment including improvements to the major sewage transfer system servicing Forresters Beach and Terrigal, as well as the permanent replacement of the temporary sewer main across Terrigal Lagoon to improve the amenity of the lagoon and minimise potential environmental impacts.

More recently, Council has developed the Terrigal Catchment Audit to respond to the long-term poor enterococci results at Terrigal Beach. Planning began in the 2017-18 financial year, with a dedicated staff member appointed in October 2018 to manage the Beachwatch Program as well as design, undertake and manage the new audit program.

In March 2019 the NSW Government joined Council in conducting the audit program, developing a citizen science program and undertaking a specialty regime to compliment the work undertaken by Council.

Based on the investigation design, implementation process and lessons learnt throughout the audit, The Terrigal Catchment Audit will act as a model for future water quality programs aiming to investigate and resolve microbial contamination in catchments identified throughout the *State of the Beaches Report*.

Method

Audit process and adaptive management needs

The process of an audit and water quality improvement program is complex and requires clear steps and processes to track changes in water quality, which in this case includes:

1. Establishing a robust water quality monitoring program to provide a comprehensive understanding of conditions and hotspots for further interrogation.
2. Developing an understanding of the factors driving poor water quality and identifying appropriate actions to address these.
3. Implementing priority actions to address poor water quality.

4. Undertaking a follow-up monitoring program to determine if priority actions have improved water quality.

To assess the levels of microbial contamination, Council along with the NSW Government have designed a sampling and investigation program with the following aims.

1. Determine if stormwater pipes are affecting microbial water quality in the ocean and reducing swim safety at the beach.
2. Determine if, and to what extent, the lagoon openings are affecting swim safety.
3. Determine if stormwater throughout the suburbs is contaminated with microbes from sewer (assess if there are areas of high contamination and areas of low contamination).
4. In areas of high microbial contamination, assess the chance of cross-contamination or illegal connections in stormwater and sewer networks.
5. Undertake remediation actions if issues are found.

The current program takes an adaptive management approach - as results are received from laboratories, and new information comes to hand, the program priorities and actions may shift in response. For example, if the audit detects increased contamination in a specific location, that location will be escalated in the priority list. A detailed breakdown of activities is provided in the Audit Process Flow Chart shown in Figure 1. A number of activities in the flow chart have been started earlier than anticipated and consequently a number of steps in the process are happening concurrently. As discussed, this is subject to change in response to new information. Throughout the audit process the NSW Government are involved in a range of activities, working alongside, and providing advice to, Council. Based on the advice from the NSW Government, the flow chart will be adapted and expanded as the program progresses.

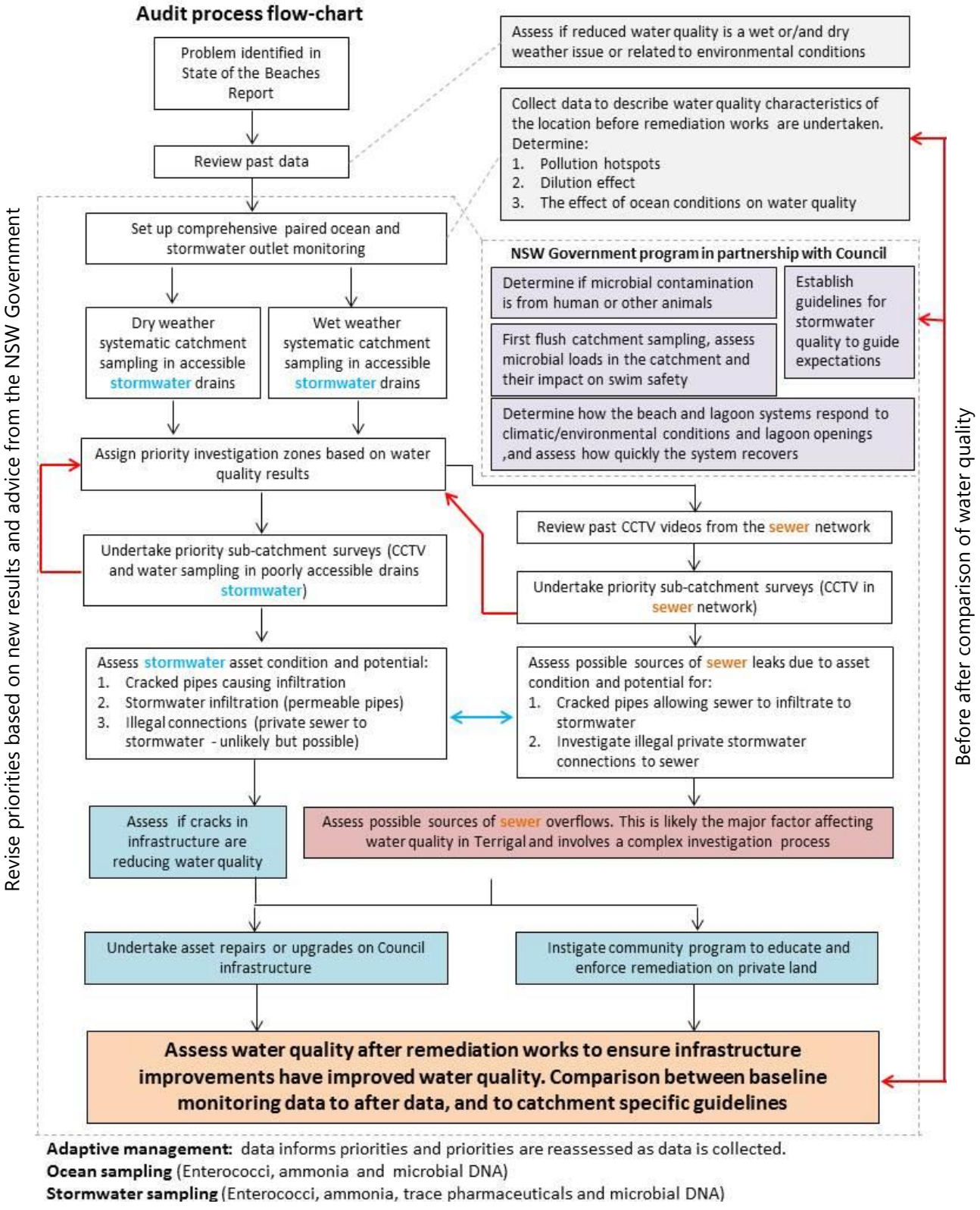


Figure 1: Flow chart of the audit process, investigating microbial sources. This flow chart will be adapted and expanded on as the program progresses and will include more details on the NSW Governments involvement in later reports.

Terrigal catchments

In Terrigal there are three main catchments Terrigal Beach catchment covers an area of approximately 0.6 km^2, Terrigal Haven covers 0.1 km^2 and the catchment of Terrigal Lagoon covers approximately 9.5 km^2 (Figure 2). These catchments are separate from one-another and each have their own characteristics. Stormwater is retained within each of the discrete catchments, and flows via the stormwater network of drains and pipes existing to either the beach or the lagoon. The water from the lagoon catchment does not travel to beach pipes, but instead flows to Terrigal Lagoon, and then on to Terrigal Bay when the lagoon is opened.

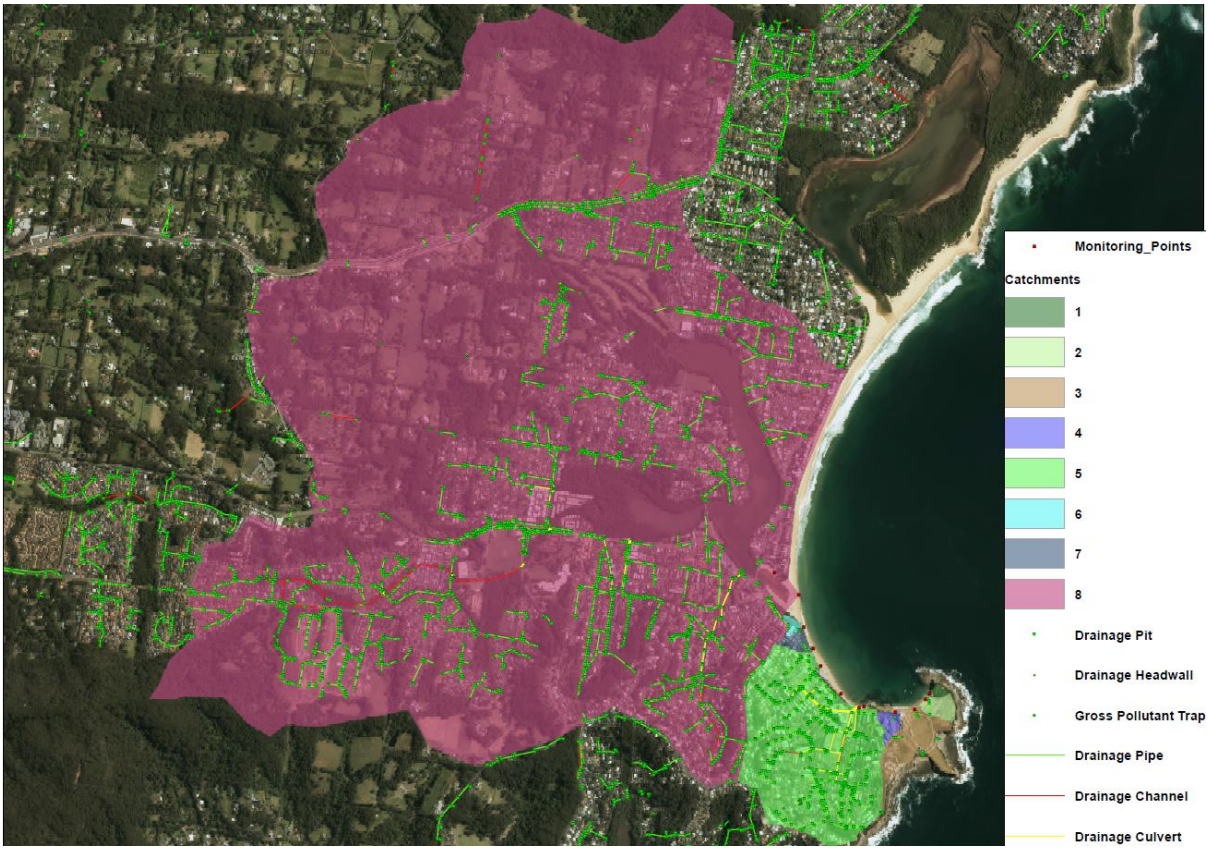


Figure 2: Map of Terrigal indicating eight distinct catchments. One large catchment flows to Terrigal Lagoon (Label 8) and seven smaller catchments (Labels 1-7) that flow to Terrigal Beach and Terrigal Haven.

Terrigal Beach: The Terrigal Beach catchment (Figure 2 Label 5) includes cleared land and urban development, including the town centre. The town centre contains a range of commercial outlets, including restaurants, cafes, bars, cafes and restaurants, medical facilities, a bowling club, and holiday accommodation as well as general and low density residential.

Terrigal Haven: The Terrigal Haven catchment comprises of a minor portion of residential apartments, café's and public recreation area which includes a sports field, boat ramp and dog exercise area (Figure 2 Labels 1, 2, 3, 4).

Terrigal Lagoon: The Terrigal Lagoon catchment comprises of a mix of rural, recreational open space and low density residential development fronting directly to the lagoon foreshore (Figure 2 Label 8).

Possible sources of microbial contamination

Microbial contamination can arise from a range of different sources. According to the State of the Beaches Sanitary Inspection (Figure 3), the following sources may be present:

- discharge from boats
- bather shedding and beach showers
- private and public toilet facilities such as those located at the Terrigal Haven sports field and the Surf Live Saving Club (SLSC)
- sewer overflows/discharges
- sewer chokes
- stormwater - old or damaged stormwater infrastructure which can be cross-contaminated by sewage
- Terrigal Lagoon discharge - the Terrigal Lagoon suitability grade has been classed as Poor to Very Poor for the past six years. The lagoon berm is opened regularly both by Council operations or natural processes to protect low-lying property from localised flooding. Whilst the impacts of opening Terrigal Lagoon, movement of pollutants into Terrigal Bay and resuspension of latent sediment and microbes in Terrigal Bay are poorly understood, this warrants further investigation.

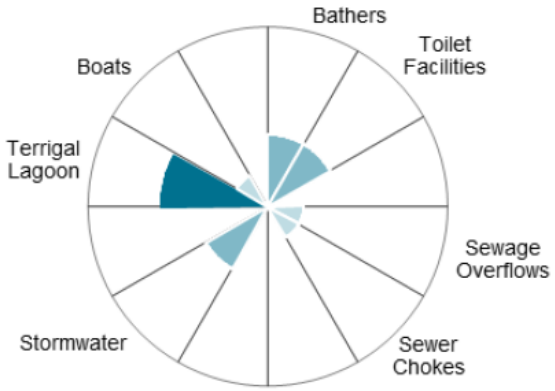


Figure 3: State of the Beaches Report sanitary inspection for Terrigal Beach 2017-2018.

In addition to these possible sources of microbial contamination, the following sources are also possible within a catchment:

- cracked, damaged or dislodged sewer or stormwater pipes in the catchment which may result in sewer ingress to stormwater
- contaminated groundwater, which also may make its way into stormwater or directly to receiving waters
- possible illegal connections of private sewer to stormwater

- on-site sewer management (OSSM) – whilst there are no OSSM systems within the Terrigal Beach catchment, there are OSSM systems in the Terrigal Lagoon catchment
- organic fertilisers applied to gardens, lawns and ovals in the catchment and washed into stormwater during rain
- wildlife and domestic animals – many pelicans, seagulls, ducks, rabbits, bats, cats and dogs are present in the Terrigal Beach and catchment area.
- pet exercise areas – designated dog areas are located in the Haven park area and along the beach between Terrigal and Wamberal beaches
- seaweed – which is thought to be a reservoir for Enterococci bacteria and is regularly suspended in the water and/or deposited on the beach (Muruleedhara et. al. 2012)
- sediment – the action of sediment resuspension in both the lagoon and Terrigal Bay may also generate temporary spikes in microbial levels as microbes such as Enterococci can survive and grow in sediment in suitable conditions (Field & Samadpour, 2007; Muruleedhara *et. al.* 2012; Stewart *et al.,* 2008; Boehm *et al.,* 2009)
- a general observation on the Terrigal sewer network catchments indicate that the overall catchment for the sewer pump station known as SPS Terrigal Major (TMJ) is approximately nine times the size of the Terrigal Beach catchment, which is encompassed by SPS C01 and C02. SPS TMJ transfers sewage from properties in the vicinity of Wamberal Lagoon as well as its own upstream catchment. Parts of the SPS TMJ catchment have been recommended for relining due to sewer chokes and surcharges that have previously occurred. The low lying areas of the sewer network adjacent to Terrigal and Wamberal Lagoons also present the opportunity for groundwater infiltration to the sewer network due to the higher water table generally experienced in coastal areas between sea level and 10m AHD
- in terms of the overall surface catchment for Terrigal Lagoon a portion of the western and north-western catchment is semi-rural, which increases the potential for nutrients related to septic tanks or agricultural use (fertilisers) to migrate to Terrigal Lagoon via surface or overland flow paths.

Due to the long history of development in the Terrigal catchment, it is feasible that microbial contamination is originating from a range of minor diffuse sources throughout the catchments. Old and damaged underground infrastructure can act as a conduit for background levels of pollution to make their way from the suburbs to the beach. It is also feasible that the results are less driven by these background levels, and more closely related to occasional high concentration flows. Pinpointing the source, scale and solutions to the current problem is complex and will take time. It is fundamental to do this well, so that investment in remediation is targeted and effective.

Stormwater pipes in Terrigal Beach and Terrigal Haven

There are twelve stormwater outlets that discharge to the beach within the Terrigal Beach catchment area. Seven are located at the south end of Terrigal Beach near the rockpool, two more discharge onto Terrigal Beach north of the Surf Life Saving Club carpark, and three are located on Terrigal Haven beach.

Terrigal Beach and stormwater outlets

Figure 4: Terrigal Beach Flagged area outside the Surf Life Saving Club

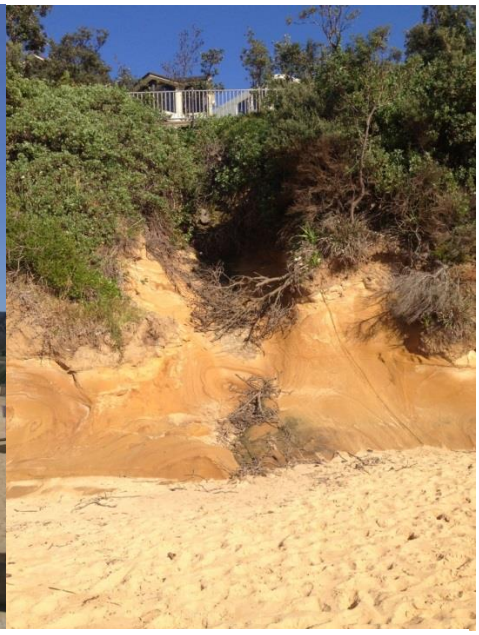


Figure 5: Stormwater drain from Terrigal Drive.

Figure 6: Large stormwater culverts where the majority of stormwater from the catchment exits onto Terrigal Beach.

Terrigal Haven stormwater outlets

Figure 7: Photograph of Terrigal Haven Beach showing moored boats, boat ramp and staff sampling in the audit.

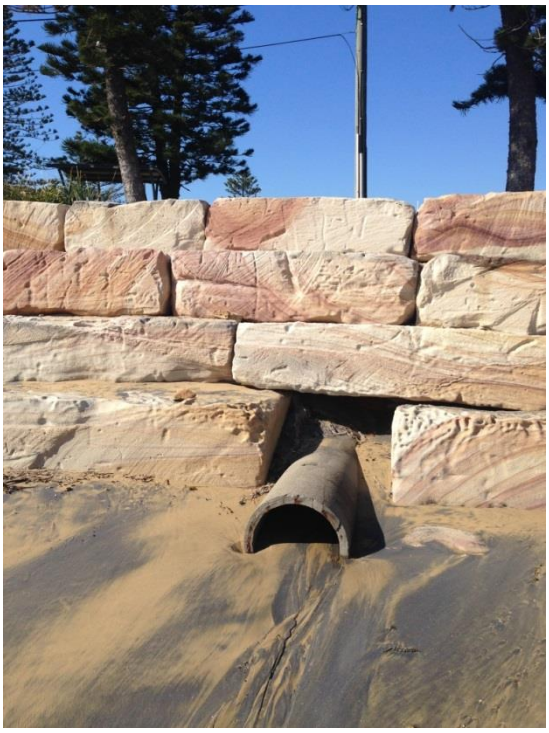


Figure 8: Central stormwater drain entering Terrigal Haven Beach from carparks, streets, oval and beach shower.

Figure 9: Eastern stormwater culverts entering Terrigal Haven Beach from Scenic highway and residential areas.

Figure 10: Western stormwater culvert entering Terrigal Haven Beach from carpark and Terrigal Haven streets near the dog off-leash park.

Detecting possible sources of microbial contamination

Microbial contamination testing methods

Enterococci bacteria – Sampling and analysing Enterococci is undertaken following the *NHMRC (*2008) guidelines. Testing Enterococci is an indicator only and microbes detected using this method could come from humans, it could also come from dogs, cats, rabbits, pigs or livestock that are farmed in the local catchment area. Testing is assessed in a laboratory under the ISM-Quality Assurance for Microbiology program.

Ammonia – Ammonia is a possible indicator of sewage when tested alongside Enterococci and trace pharmaceuticals. Testing ammonia cannot differentiate between environmentally derived ammonia (Brady & Well, 1996; Wetzel, 2001, Brady & Well, 1996, Brasseur et al., 1999) and sewage sources ammonia. Testing is assessed in a laboratory under the ISM-Quality Assurance for Microbiology program.

Trace pharmaceuticals – Trace pharmaceuticals are a direct indicator of sewage, as pharmaceuticals are excreted into the sewer system through toilets and showers. These tests are useful in stormwater pipes, not ocean samples. Trace pharmaceuticals are tested under the EPA approved method 1694, and directly tests for the following chemicals: 4-acetamidophenol, Atenolol, Atrovastin, b-Estradiol, Caffeine, Carbamazepine, Diclofenac, Dilantin, Estriol, Estrone, Ethynylestradiol, Fluoxetine, Gemfibrozil, Ibuprofen, Ketoprofen, Mestranol, Naproxen, TCEP, Triclosan, Trimethoprim. Testing is assessed in a laboratory accredited by the National Association of Testing Authorities (NATA).

Microbial DNA – This test assesses if microbial contamination is associated with wildlife etc. or sewage input such as *Lachnospiraceae* and *Bacteroidales* bacteria. These tests do not identify individual human DNA, but instead identifies microbes common to the digestive systems of humans or other animals. These tests are being undertaken by the NSW Government and University of Technology Sydney.

Methods used to detect broken infrastructure if contamination is present in stormwater

Stormwater pipes and culverts are inspected through CCTV to identify any defects (cracks, breakages and joint displacements etc.) or illegal connections which may allow contaminants to enter into the stormwater systems. The severity of any defects found are analysed by reviewing the CCTV reports/videos using Water Services Association of Australia (WSAA) codes and Institute of Public Works Engineering Australasia Incorporated (IPWEA) guidelines. Pipes that are identified as poor and very poor and pose high risk, are prioritised for maintenance/renewals or upgrades.

Another method often used to assess catchment contaminant loads input is a paired flow gauge and water auto sampler. This flow gauge attached to the stormwater pipe and can estimate volume rates of water travelling through the pipes. The autosampler is triggered by changes in water height in the pipe measured by the

flow gauge to then take discrete water samples through the hydrograph. Staff collect the water samples and deliver to laboratories for analysis. The use of flow gauges will be a joint effort between Council and the NSW Government and will form a major part of the audit investigation.

Methods used to repair broken infrastructure

Stormwater and sewer infrastructure can be repaired through a process of pipe relining. Relining of pipes is performed to restore the original integrity, and extend the serviceable lifespan, of the main. Relining is performed where the original integrity has been compromised due to tree root intrusion, ground movement (settling and consolidation of the surrounding soil) resulting in joint displacement or outright failure of the pipe material (cracking is common in vitreous clay pipe). The lining can be a resin impregnated fabric that is fed into the pipe and cured in place using hot water or steam. Alternately the lining may be wound PVC products, which are grouted in place inside the parent pipe. The lining is thin so the designed hydraulic capacity (flow rate and flow velocity) is not reduced once the lining of the pipe is completed. Where pipes cannot be relined, they can be dug up and replaced. This ensures sewer pipe capacity is not affected by groundwater intrusion, sewer pipes do not leak underground and stormwater pipes are not susceptible to contamination from groundwater.

Investigation design

Monitoring recreational waters at the beach

As discussed, Beachwatch is designed to highlight a concern using long-term environmental trends. However, the program takes a single sample at a single location on the beach once per week (swimming season) or fortnight (winter). This limited sampling program is not adequate to assess the variability in the water quality experienced by recreational swimmers at Terrigal Beach. For example, different areas of a beach may experience different levels of pollution, due to varying proximity to pollution sources, such as the lagoon or stormwater outlets.

The Terrigal Catchment Audit aims to comprehensively monitor water quality at six ocean beach locations along Terrigal Beach, stretching from the lagoon south to the rock platform. The audit also samples the children's ocean bath (rockpool). In addition, the audit monitors four ocean beach locations at Terrigal Haven (Figure 11).

Comprehensively sampling of the beach and embayment provides detailed information on the variability in swimming conditions at the beach. The NSW Government is providing Council with samples from off-shore as a part of a larger study of swimming conditions in the embayment. The study undertaken by the NSW Government will also account for nutrient input, turbidity and algae blooms to assess the broader environmental aspects of the Terrigal area.

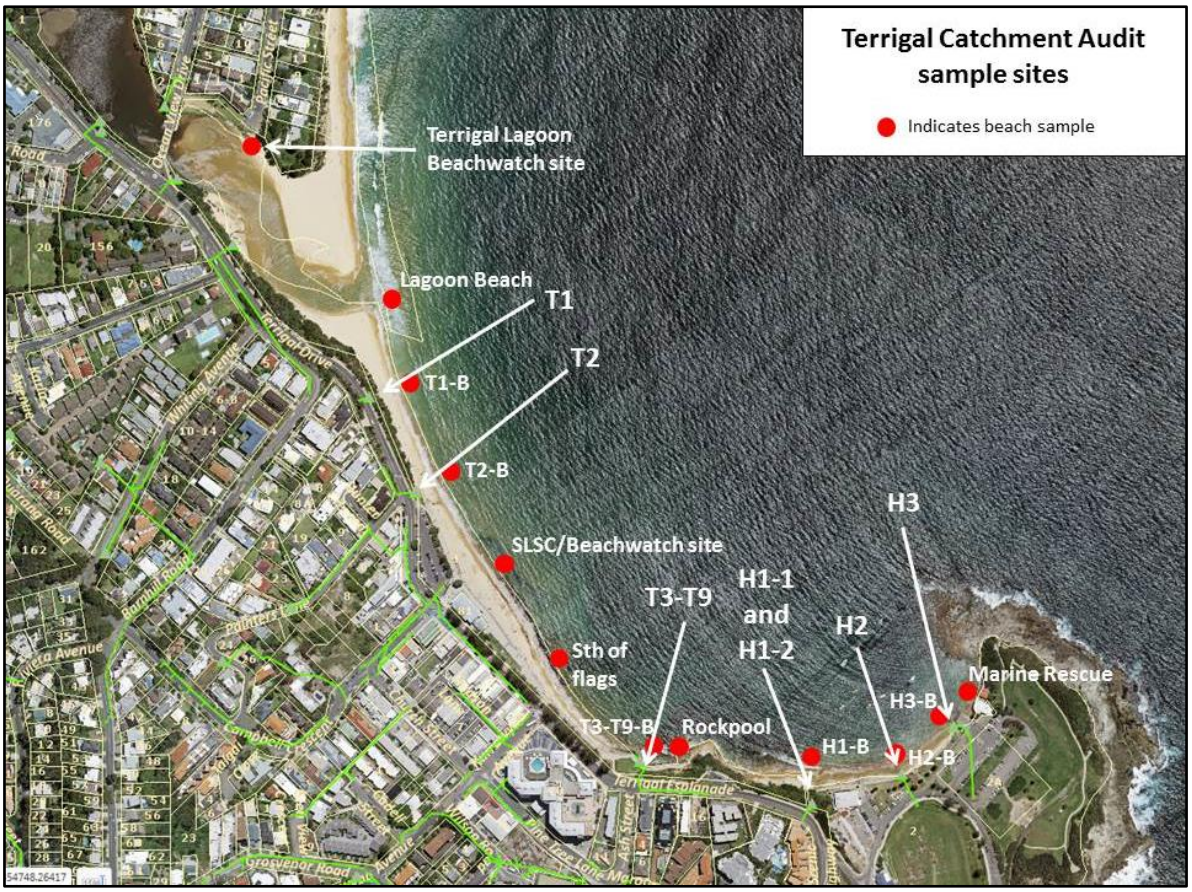


Figure 11: Sample locations for the Terrigal Catchment Audit.

In addition to sampling at Terrigal Beach, Council samples scientific controls (reference sites). These controls enable us to compare the variability in water quality in Terrigal to prevailing conditions experienced along the coastline, such as tide, rainfall and wave conditions. The Terrigal Catchment Audit's control sites have been balanced with north and south aspects, as well as sanitary inspection ratings which assess the potential sources of pollution (OEH 2018). For example, Terrigal Beach and Avoca Beach receive moderate sanitary inspections ratings and are both on the southern end of a beach (Figure 12: Appendix 1). Forresters Beach and North Avoca Beach receive low (good) ratings for sanitary inspections due to lower development pressures and are both on the northern end of the beach stretch (Figure 12: Appendix 1).

Both the Avoca Beach and north Avoca Beach controls are also situated closer to the nearest sewage outfall (Winney Bay) which is south of Avoca Beach. This allows Council to assess community concerns that the outfall is affecting adjacent beaches such as Terrigal. The discharge of sewage from Kincumber Sewage Treatment Plant at Winney Bay is covered by a licence from EPA and is accessible to the community: apps.epa.nsw.gov.au/prpoeoapp/ViewPOEOLicence.aspx?DOCID=76837&SYSUID=1&LICID=1802. The purpose of the licence is to sets limits on what and how much

pollution can be discharged to limit the environmental impact to nil, or if not nil, to limit it to a very small area around the discharge point.

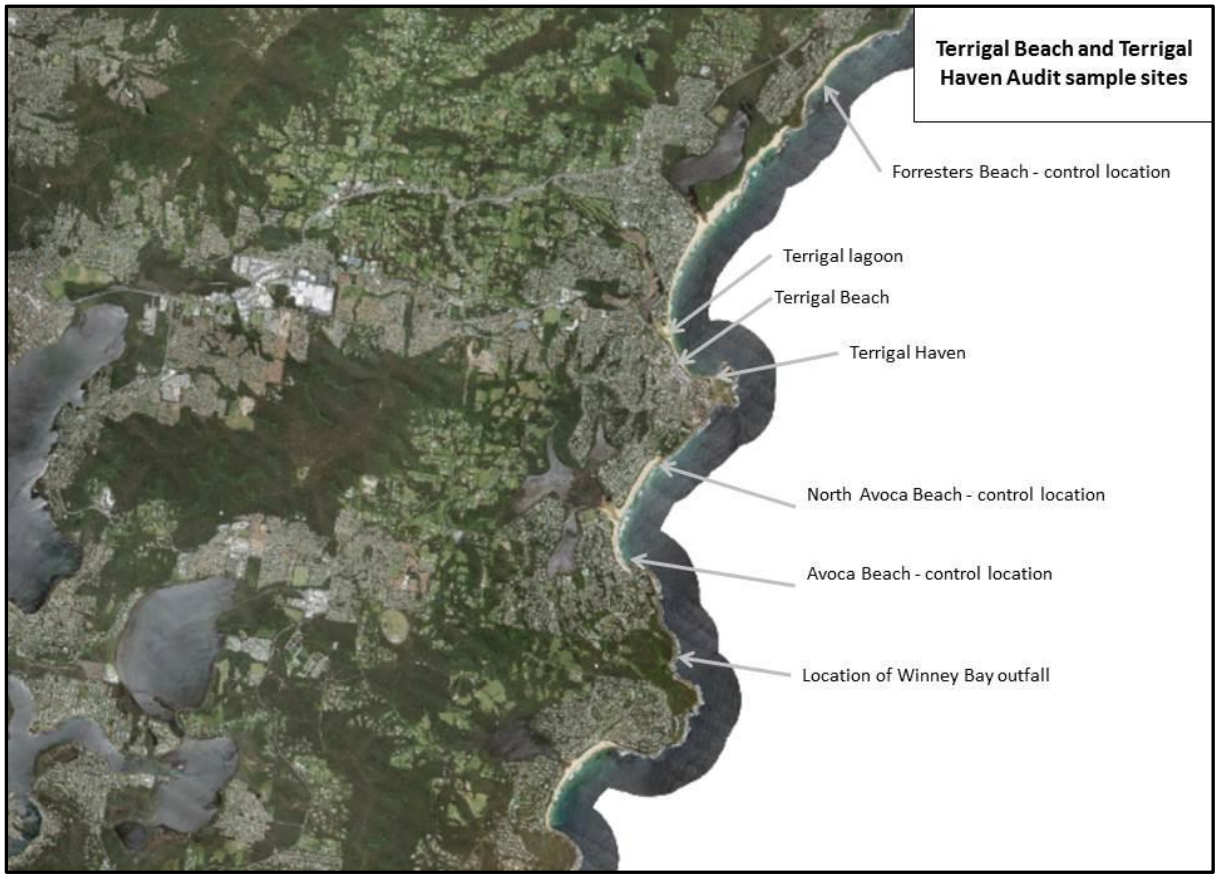


Figure 12: Location of control sites relative to the Terrigal Beach and Haven area.

Number of sampling days at the beach in the Terrigal Catchment Audit

The Terrigal Catchment Audit aims to undertake approximately 100 days of ocean sampling to assess how variable the water quality is at Terrigal Beach under different environmental conditions. The NHMRC guidelines indicate the analysis may be incomplete when using limited microbial data i.e. using less than 100 data points.

> *"The importance of using a sufficiently large sample size is illustrated when analysing less than 20 data points. Using the Hazen method, the corresponding value for the 95th percentile is the largest value of the data set (i.e. the 20th ranked value). Using the ranked method, the second largest value is used (i.e. the 19th ranked value). Due to the normally high variation in microbiological concentrations this can lead to large differences in the results obtained using the two methods." (NHMRC 2008, P. 71, Box 5.3. V)*

A. Initial audit: Under the *NHMRC (*2008) guidelines, 20 samples is considered an absolute minimum sample size for monitoring recreational waterways. With 20

samples, the initial audit is able to assess the preliminary suitability of each beach site for recreational swimming safety. Sampling is undertaken through a range of different weather conditions to establish dry, wet and first flush trends. The sampling program also aims to investigate conditions before and after lagoon openings to assess any impacts of this activity on the beach water quality. As sampling transitions into the catchment, the systematic sampling program aims to determine if individual pipe outlets are affecting beach swim safety. Pairing Enterococci, and ammonia comparable to guidelines. Lagoon openings.

B. Major audit: Under the *NHMRC (*2008) guidelines 100 days of samples is considered a robust enough data set to establish long-term trends for beach swim safety. This allows the establishment of baseline conditions, against which future conditions can be compared. All sampling programs must account for natural variability before true patterns and trends can be extracted. The major audit program will continue to expand on both the beach, bay, lagoon opening and catchment data sets to further examine the initial observations. This program will also review the claims that Winney Bay outfall is affecting Terrigal water quality and will work towards establishing a water quality improvement program. Pairing Enterococci, ammonia and trace pharmaceuticals.

Monitoring stormwater outlets

A. Initial Audit: To detect if microbial contamination is entering Terrigal Beach through stormwater, the audit also samples water from all stormwater drains entering the beach when water is flowing (T1-9 and H1-3). These samples are taken at the same time that beach samples are taken, to asses if the stormwater is causing microbial contamination in the ocean. The initial audit sets up a sampling regime to assess basic water quality contamination concentration. Assess the types of contaminants entering the system. Assess variability in contaminant concentrations under different weather events, for example dry and wet weather flows may vary in concentration due to dilution with rainfall. Locating key stormwater pipes to sample to identify priority pipes for further sampling. Provide priority map. Majorly on week days. Pairing Enterococci, ammonia and trace pharmaceuticals.
B. Major audit: Maintain sampling to assess variability. Extend sampling to weekends and public holidays. Extend the audit to Terrigal Lagoon. Pairing Enterococci, ammonia and trace pharmaceuticals.

Systematic catchment sampling

A. Initial Audit: Start investigating major stormwater drain lines to identify priority pipes for further sampling instigate CCTV infrastructure investigations. Provide priority map. Pairing Enterococci, ammonia and trace pharmaceuticals.
B. Major audit: Continue further into the catchment to refine the priority zones for sampling and continue CCTV infrastructure investigations. Extend sampling

to weekends and public holidays. Extend to Terrigal Lagoon. Pairing Enterococci, ammonia and trace pharmaceuticals.

Council is working closely with the NSW Government on the Terrigal Catchment Audit. The NSW Government has a team of scientists and funding dedicated to helping Council with a number of complex and difficult scientific questions, including but not limited to:

- determine if microbial contamination at Terrigal is from human or other animals
- assess off-shore microbial water quality where many community members swim, as beach samples are not adequate to assess the variability in water quality experienced by off-shore recreational swimmers at Terrigal Beach
- determine how the beach and lagoon systems respond to climatic/environmental conditions and lagoon openings, and assess how quickly the system recovers using hydrodynamic modelling
- undertake first flush catchment sampling to assess microbial loads entering the ocean and how this affects swim safety
- establish guidelines for stormwater quality to guide expectations
- assess broader concerns about environmental water quality in the embayment
- assess other possible microbial reservoirs such as seaweed and sediment.

This report focuses on the initial program undertaken by Central Coast Council. Results of the work of the NSW Government and Council will be presented in future joint reports.

Outcomes of the Initial Terrigal Catchment Audit

These values are derived from 20 sampling surveys from January to May 2019. This is a short period of time and may not reflect the full variability in weather or stormwater events seen in the stormwater or ocean. The audit is an ongoing investigation and the direction will change as more data is collected and the audit progresses. These outcomes give a snapshot of swim safety and the works being instigated to reduce contamination in stormwater pipes.

Beach water quality

Dry Weather

Throughout the first 20 sampling surveys 13 days were considered dry weather. Terrigal as a whole was considered good for swimming 94% of dry weather samples*.

If we assess Terrigal Beach separately from Terrigal Haven, Terrigal Beach was considered "Good" for swimming 96% of the time (using all seven ocean sample sites outliers included)*. During dry weather, Terrigal Haven was considered "Good" for swimming 88% of the time (using all four ocean sample sites outliers included)*.

Terrigal Lagoon was considered good to swim 84.6% of the time in dry weather*.

At the sample location on Terrigal Beach directly outside the T3-T9 drains (also known as the "7 drains"; Appendix 2), the drains were often flowing in dry weather, and 84.6% of the ocean samples directly outside the drains were considered "Good" for swimming (Figure 11: Appendix 2)*. The reduced percentage of good swimming days directly outside the drains was due to two days where Enterococci was elevated, however, during these increases in Enterococci all other locations at Terrigal Beach and Terrigal Haven were considered "Good" for swimming including the locations directly beside the drain. The low levels of Enterococci bacteria at these adjacent locations indicate that during dry weather, any minor elevated levels detected outside the drains were diluted and not affecting the swim safety of the beach. Further testing is underway in the off-shore zone where swimmers cross to Terrigal Haven to assess if water in the embayment is being affected by minor levels seen at T3-9B and will be included in subsequent reports.

The sample average shown in this image excludes one Enterococci outlier which occurred at the *Marine Rescue* boat ramp (Appendix 3 includes outliers). This was not associated with any overflows on Council records. Further monitoring is required to assess if this is a stand-alone event or a reoccurring event and the infrastructure in the location has been placed on a list for further investigation. For ease of viewing graphed raw data points, outliers were removed in Appendix 4 to show finer details in data points. With the *Marine Rescue* outlier removed (Appendix 4 excludes

outliers), the *Marine Rescue* site generally showed low Enterococci results, with a maximum of Fair (121mpn/100ml) in dry weather.

*These values are derived from 20 samples January to May 2019. This is a short period of time and may not reflect the full variability in weather or stormwater events. The audit is an ongoing investigation and values will change as the audit progresses.

Figure 11: Average water quality 20 sampling days 17 January – 31 May 2019 (average excludes a single outlier at the Marine rescue which is discussed in-text).

Wet Weather

Council does not recommend that people swim at Terrigal Beach within three days of rainfall. Throughout the first 20 sampling surveys, six surveys were considered wet weather, Terrigal as a whole was considered good for swimming 84% of the time*.

Assessing Terrigal Beach separate from Terrigal Haven, Terrigal Beach was considered "Good" for swimming 86% of the time, and Terrigal Haven was considered "Good" for swimming 83% of the time (Table 1 shows definitions for "Good", "Fair", "Poor" and "Bad")*.

Terrigal Lagoon was considered good to swim 50% of the time in wet weather*.

During rainfall, elevated levels of Enterococci bacteria occurred at three locations, outside Terrigal Beach drains T3-T9 ("7 drains") (Appendix 2) and at the beach directly north of the drains at Sth of Flags, and at the Marine Rescue. On Terrigal Beach directly outside the T3-T9 drains, 33% of the ocean samples were considered "Good" in wet weather, Sth of Flags was considered good to swim 83% of the time. During this period, the Rockpool was considered good to swim 100% of the time*. Visual comparison of Figure 11 and Figure 12 between dry and wet weather samples shows that during wet weather some microbial contamination enters Terrigal Beach at T3-9B, elevating Enterococci bacteria and affecting nearby Sth of Flags. However during wet weather the Rockpool, SLSC and all samples north of the SLSC were considered Good" to swim.

Marine Rescue boat ramp (Appendix 3 and 4). This was not associated with any overflows on Council records. These results are being further investigated.

*These values are derived from 20 samples January to May 2019. This is a short period of time and may not reflect the full variability in weather or stormwater events. The audit is an ongoing investigation and values will change as the audit progresses.

Figure 12: Average water quality 20 sampling days 17 January – 31 May 2019.

Lagoon opening

During the lagoon opening on the 2/4/2019, the Terrigal Catchment Audit took samples before (1/4/2019) and after (3/4/2019) the lagoon was manually opened. Rainfall over the day of and three days prior to lagoon opening was 44.5mm. Ocean conditions resulted in the lagoon water moving south, in front of the SLSC and evidence of turbid water was seen at the sample site known as Sth of Flags. Enterococci sampling indicated that beach sites were not suitable for swimming, and despite water being dark brown with large volumes of froth forming on the beach (Figure 13 and 14), a number of community members were swimming despite permanent warning signs about swimming after rainfall and despite the unappealing conditions at the beach. Water samples as of the 9/4/2019 showed that the beach was considered "Good" for swimming at 100% of Terrigal Beach and 75% of Terrigal haven Beach.

Figure 12: Water quality (single day sample 3/4/2019).

Figure 13 and 14: Poor conditions and unappealing appearance of Terrigal Beach after lagoon opening. Photos taken on the 3/4/2019.

Recent pollution event – June 2019

Between 24 June and 27 June 2019, a large storm event resulted in significant stormwater runoff from the catchment and the opening of Terrigal Lagoon. As a result of this event, high bacterial counts were recorded at multiple sampling points at Terrigal Lagoon, Terrigal Beach and Terrigal Haven. The control sites at Forresters, North Avoca and Avoca beaches did not see a significant rise in bacteria levels, indicating this event was associated with Terrigal only. As a result, Council closed Terrigal beach, Haven and lagoon on 25 June until bacterial levels returned to a safe level on 1 July 2019.

Analysis of results show the lagoon opening caused minimal impact on the beach water quality initially, indicated by the low levels of bacteria at the Lagoon Beach, T1-B and T2-B sites on the first sample day (24 June - Figure 15). This indicates that the lagoon water plume had not yet reached the SLSC or the south of the beach.

At the same time the bacterial counts at the stormwater pipes known as the "7 drains" (T3-T9) were extremely high. The sites directly outside the drain at the rockpool and T3-9B and further up the beach showed high concentrations of bacteria (Figure 15). This indicates that the major source of pollution at the southern end of the beach on the first day was microbial contaminant in the stormwater. Samples from Terrigal Haven also showed high concentrations at the beach and stormwater pipes.

Results after the initial rainfall event from the 25, 26, 27 and 28 show a decrease in Enterococci over time for all ocean sites and stormwater pipes and a return to safe swimming conditions at all ocean locations by the 28 June 2019.

Terrigal Beach, Terrigal Haven were not opened until 1 July as the testing takes 24-48 hours to complete.

Investigation of the impacts of large wet weather events is ongoing. With more information, it may become clearer that the triggers for elevated bacterial loads under high rainfall conditions are different from those experienced under dry weather and light-moderate rain events. Council, in partnership with the NSW Government, with continue to investigate the impacts of large events and lagoon openings and report back to Council and the community in future reports.

Figure 15: Water quality after large rainfall event and lagoon opening (single day sample 24 June 2019).

Priority Sub-catchment Sampling and Investigation Works Program

The direction of the Terrigal Catchment Audit is being driven by scientifically accurate water quality results. Based on the water quality results obtained from the catchment, there is no indication of direct sewage sources in dry weather throughout the current dataset (20 survey days). Results have shown that the Terrigal catchment does have dispersed sources of microbial contamination, and that on the 24/6/2019 there was a large pollution event, and bacteria counts suggest a sewage overflow occurred. Using the concentrations of dispersed contamination, the following catchment priority list in Figure 15 has been developed to direct CCTV investigations for both stormwater and sewer networks (Figure 16). Later stages of the audit with the NSW Government will reassess the priority sub-catchment map based on microbial load.

Figure 16: Priority sub-catchment zones scheduled for works in the 2018-2019 and 2019-2020 financial year based on stormwater quality. Later stages of the audit with the NSW Government will reassess the priority sub-catchment map based on microbial load.

In Terrigal Haven and Terrigal Beach CCTV investigations have started (Zone 1 Figure 16) and zone 2 (A) ("7 drains" T6-T9) (Table 4). The details in the work schedules will change, adapting to water quality results. Currently the works schedule extends until

the end of September, however, it is expected that the scheduled works will instigate a number of other investigations and new schedules for these extra investigations will be shown in later reports.

Table 4: Priority pipe CCTV investigation and pipe relining schedule. The schedule is responsive to changes in water quality results and priority zones may be brought forward or pushed back dependent on water quality results found in the catchment (Refer to Figure 1 for details for adaptive management processes). Throughout this process water quality sampling continues every week at the beach and within the catchment.

Priority zone	Location/ pipe	Approximate timeframe (month)	Activity in stormwater	Activity in sewer network
1	Terrigal Haven	April 2019	Preliminary assessment of stormwater pipes and sewer network	Preliminary CCTV assessment of sewer mains in Terrigal Haven Catchment 95% complete
1	Terrigal Haven	May 2019		Sewer CCTV investigation of Terrigal Haven
1	Terrigal Haven	June 2019	Further mapping stormwater pipes, looking for other sources of water, assessing asset condition for potential groundwater and sewer infiltration	Relining of 1 pipe recommended to commence as soon as realistically possible. Contractor engaged and works to commence in the first quarter of the 2019-2020 financial year.
2 (A and B)	Terrigal Beach	June 2019	2 (A) Assessing stormwater asset condition and looking for illegal connections at "7 drains" T6-9.	Recommendation - 2 (A and B) - Relining of 13 pipes recommended to commence as soon as realistically possible. Contractor engaged and works to be undertaken during the first and second quarters of 2019-2020 financial year.
1	Terrigal Haven	July-Sept 2019	Relining of stormwater drain H2	Relining of sewer pipe in Terrigal Haven.
2 (B)	Terrigal Beach "7 drains" T3-5	July 2019	Assessing stormwater asset condition and looking for illegal connections	Reviewing choke history for relevant sewer sub-catchments and conducting additional CCTV surveys. Assessing sewer network condition.
2 (C)	Terrigal Beach "7 drains" T6-9	August 2019	Assessing stormwater asset condition and looking for illegal connections	Reviewing choke history for relevant sewer sub-catchments and conducting additional CCTV surveys. Assessing sewer network condition.
2 (D) and 3	Terrigal Beach "7 drains" T6-9 and the Scenic Highway	September 2019	Assessing stormwater asset condition and looking for illegal connections	Reviewing choke history for relevant sewer sub-catchments and conducting additional CCTV surveys. Assessing sewer network condition.

Infrastructure outcomes

Private infrastructure investigations and outcomes

Currently Council is not releasing data due to the sensitive nature of the project. The data may directly or indirectly identify houses or businesses with known or unknown breaks in sewer pipes or illegal connections. If private property is implicated throughout the audit, Council is looking to help people do the right thing. It is hoped that bringing these issues to light with the landowners will instigate fixes through information and education. If private landowners do not fix illegal connections or cracks affecting stormwater, Council will commence regulatory actions. These actions will be reported as number of investigations undertaken, number of issues detected and number of issues rectified.

Number of investigations undertaken on private infrastructure	Three
Number of issues detected	No private infrastructure issues currently detected
Number of issues rectified	No private infrastructure issues currently in need of rectification

Summary of Council infrastructure investigations

Where Council infrastructure is identified as a source of pollution, these locations will be immediately scheduled for infrastructure refurbishment, and outcomes of this process will be officially reported and made public.

Number of investigations undertaken on public infrastructure	**Terrigal Beach catchment:** two minor issues detected **Terrigal Haven catchment:** two major issues detected
Number of issues detected in public infrastructure	**Terrigal Beach catchment:** Infrastructure integrity investigation of entire sewer network in Terrigal CBD undertaken A) One issue detected which has the potential to affect water quality at T9, however water quality here is considered a low priority as the pipe is predominantly dry and there is no current indication of stormwater infiltration. Investigations are ongoing. B) One minor issue has been detected in a sewer pipe which may be causing a smell in Pine Tree Lane. **Terrigal Haven catchment** A) H2 stormwater pipe integrity poor B) Sewer pipe integrity poor (crossing under H2)
Number of issues rectified in public infrastructure	**Terrigal Beach catchment:** Investigations are ongoing and methods to fix issues are being investigated. **Terrigal Haven catchment:** Investigations are ongoing and works are scheduled to rectify infrastructure.

Detailed assessment of Council infrastructure

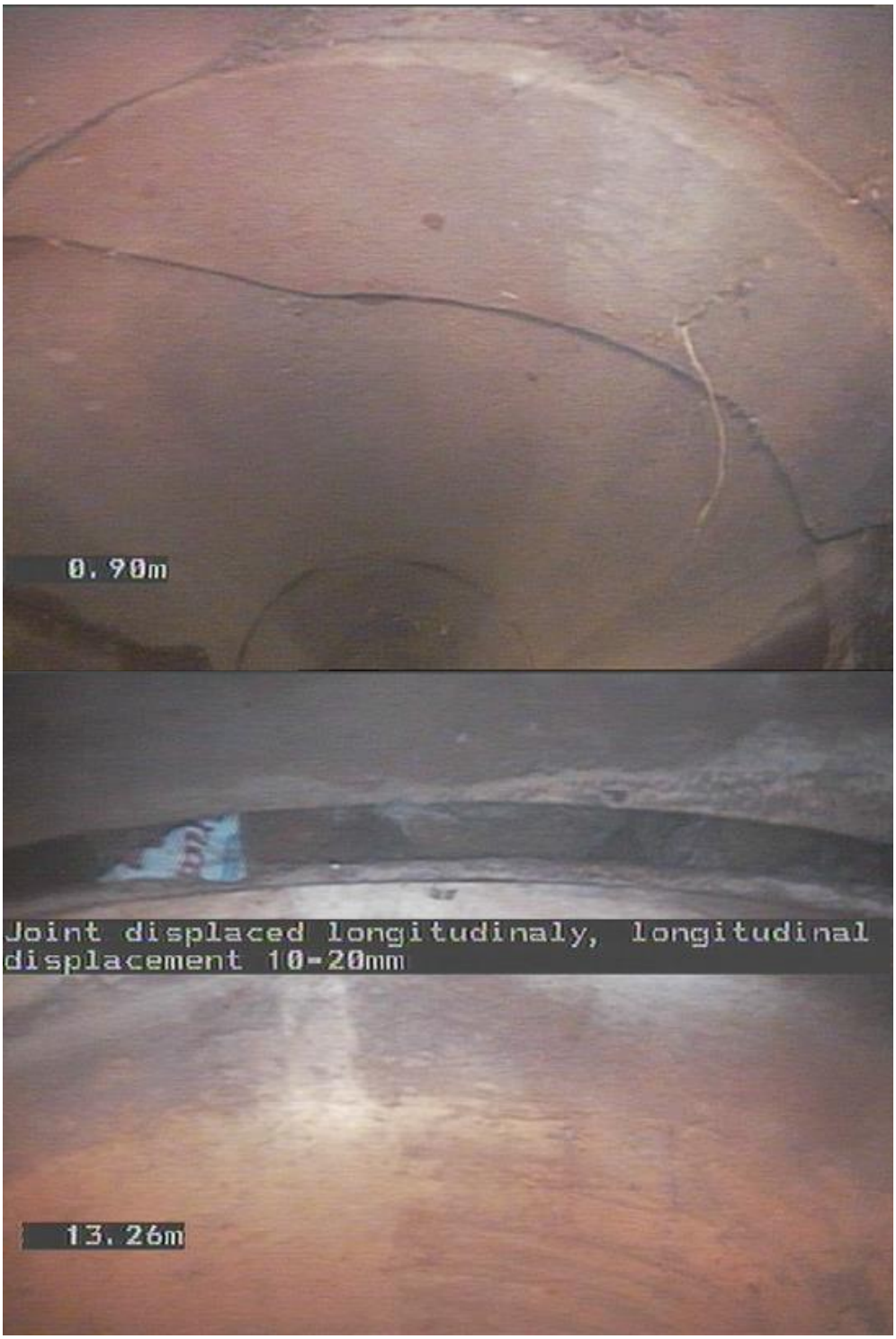
Terrigal Haven

<table>
<tr><th colspan="2">Stormwater Pipe H2</th></tr>
<tr><td>Audit information</td><td>Investigations at the drain H2 have direct indictors of sewage input. A possible source includes infiltration from the underground sewage network which may infiltrate into the stormwater system. To cover other possible sources of discolouration further analysis was undertaken.
   </td></tr>
<tr><td>Response to audit data</td><td>A) Once water quality was confirmed as poor, the audit program assessed the beach water quality directly outside the pipe. Water quality at the beach did not have elevated levels of Enterococci, and swim safety was not affected by poor stormwater quality. The pipe H2 has minimal water flow during dry weather, and is intermittent, having very low flow at the time that the audit was undertaken. These low volumes of poor water quality were not affecting swim safety, however, the infrastructure required investigation and works to prevent sewage from entering stormwater. Organic fertiliser is not used on the oval and therefore cannot be a source of Enterococci.
B) CCTV works were immediately undertaken assessing infrastructure condition stormwater pipe H2 and the sewer main directly crossing underneath the stormwater pipe. Both stormwater and sewer were determined to be in poor condition and in need of immediate works (See photographs below). It is</td></tr>
</table>

	uncertain if the poor condition of the pipes is causing poor water quality at the exit if H2, other inputs in the catchment may also contribute to the poor water quality such as cracks in pipes further up the system or presence of minor and intermittent overflows. Follow-up CCTV works were undertaken to map all possible sources of contamination in Terrigal Haven. Water samples were taken at the same time where water was available to assess if the pollution source could be fully or partially caused from upstream (further up the catchment).
Works scheduled	Relining of both stormwater and sewer to be undertaken in first quarter of the 2019-2020 financial year. Instant recommendation for rehabilitation of the sewer (relining) by Asset Management. Neighbouring sewer lines are to be assessed as well and recommend immediate rehabilitation if their condition is sub-standard.
Remaining investigations	A) Continuing to assess if other sources of microbial contamination are present in the catchment. B) Further investigation is required to assess the environmental implications of high nutrient input from H2 (Council and NSW Government ongoing program).
Issues and limitations	The audit monitoring program is designed to both detect issues and monitor changes in water quality after rectifications to infrastructure have been made. Pipe H2 has been blocked with seaweed which acts as a reservoir for Enterococci bacteria, as such the pipe is currently contaminated and samples cannot be taken. Due to the weed presence, the audit is unable to thoroughly assess before and after effect of infrastructure improvements. To fix this issue the installation of a metal grate to prevent weed from entering the pipe is being investigated.

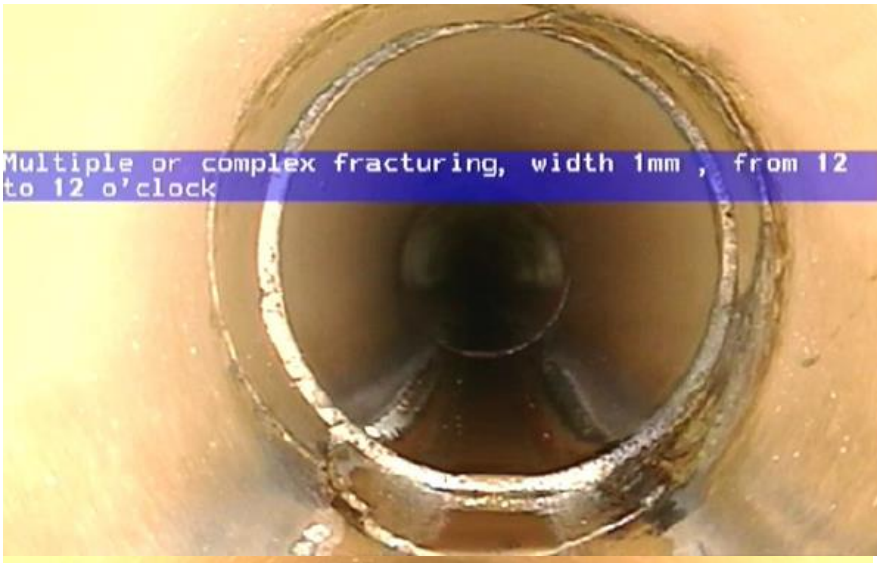
Photographs

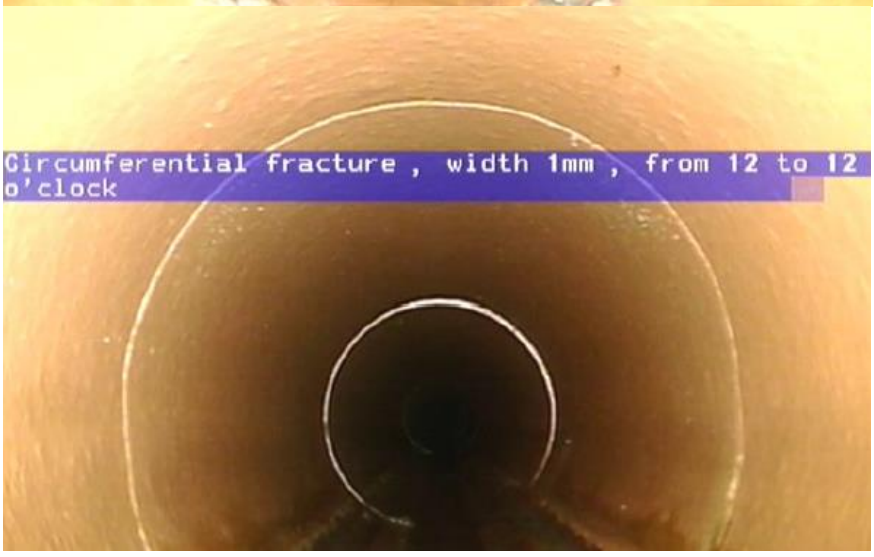
Examples of stormwater pipe issues at H2




Deposit is Hard or compacted material in the invert, at joint , Obstruction: 5-20% , from 4 to 6 o'clock
1.35m
Breaking, some pieces are missing, at joint, length of break 100 , from 9 to 10 o'clock
10.79m

Examples of sewer pipe issues

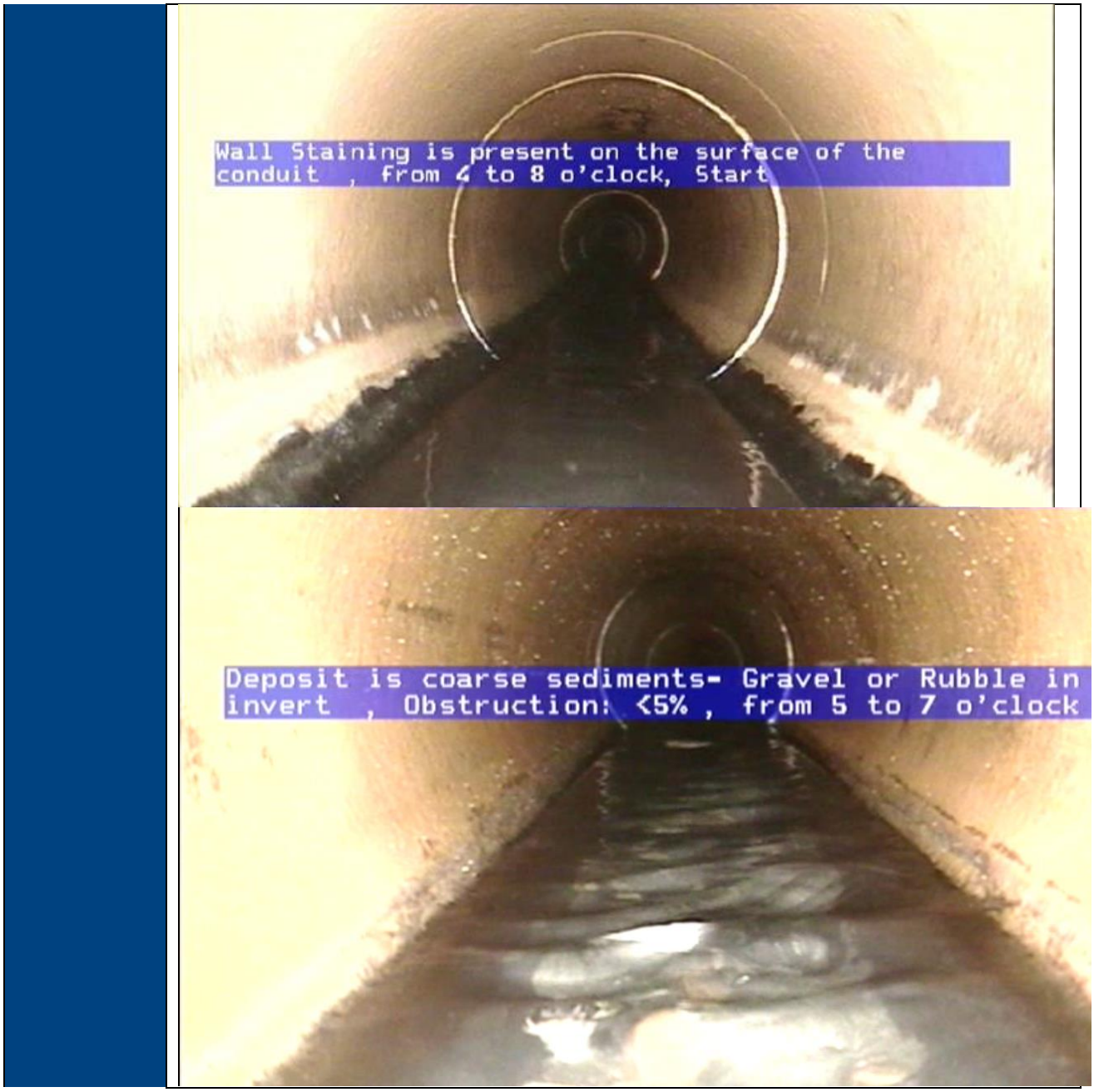




Sewer pipes leading to stormwater Pipe T9	
Audit information	General sewer CCTV work throughout the catchment detected minor structural issues in a sewer pipe. There is currently no evidence to suggest that the sewer pipe is affecting stormwater quality. The stormwater pipe in close proximity (T9) does not have dry weather flows suggesting there is little to no cross-contamination. T9 is a small catchment unlikely to receive regular catchment water in dry weather e.g. car washing/sprinklers, as other pipes in the "7 drains" do.
Response to audit data	Not applicable - There is currently no evidence to suggest the sewer pipe is affecting stormwater quality.
Works scheduled	Relining of sewer mains identified as being in poor condition due to commence in the first quarter of the 2019-2020 financial year and completed at the end of second quarter of the 2019-2020 financial year.
Remaining investigations	A more detailed investigation into possible infiltration from the sewer pipe to the stormwater pipe is advised. The audit program will continue monitoring the water quality from T9 when available. Further CCTV survey work to be performed in the upstream sewer sub-catchments that relate to sections 2A and 2C in Figure 15 to assess sewer network condition. Whist T9 does not experience regular dry weather flow, T8 does. It is currently not known if T8 and T9 are connected underground. Works are scheduled to determine if these stormwater pipes are connected and assess their current condition.
Issues and limitations	The stormwater pipe network is large and may not always be mapped clearly. Where these issues are identified, Council is working to accurately map the infrastructure.
Photographs	***Example of sewer pipe issue***

Sewer smell Pine Tree Lane	
Audit information	During the Terrigal Catchment Audit a sewer smell was noted on Pine Tree Lane. Samples taken from stormwater close by did not indicate direct influence of sewer to stormwater.
Response to audit data	Persistent sewage odour on the corner of Kurrawbya Ave and Pine Tree Lane can now be attributed to changes in the grade of the sewer as well as rubble in the sewer line. The combined effect holds sewage and the pipe is approximately 40% full even under dry weather flow conditions.
Works scheduled	Repairs yet to be scheduled. Discussions continuing to co-ordinate Council resources to clear sewer main.
Remaining investigations	Not applicable
Issues and limitations	The pipe is particularly difficult to access.
Photographs	***Sewer pipe issues***


Wall Staining is present on the surface of the conduit , from 4 to 8 o'clock, Start
Deposit is coarse sediments- Gravel or Rubble in invert , Obstruction: <5% , from 5 to 7 o'clock

Indicates 40% full. Rubble and slumping possible cause of smell.

Grease traps and sewer/stormwater infrastructure	
Audit information	Assessing possible sources of overflows. Grease traps are a pumping device used to separate fats oils and greases (FOG's) and from private infrastructure such as food businesses, before the wastewater goes to sewer. Sewer exposed to high levels of FOG's can become blocked and can then cause sewer overflows.
Response to audit data	Assessment of the inspection program for grease trap maintenance of restaurants/ cafes in Terrigal CBD. The maintenance of the grease traps in the CBD has improved considerably in the last 2 years.
Works scheduled	Ongoing monitoring to be performed by Council's Trade Waste Compliance Team.
Remaining investigations	Ongoing monitoring to be performed by Council's Trade Waste Compliance Team.
Issues and limitations	Not applicable
Photographs	Not applicable

Limitations to the study and next stages of the audit

The Terrigal Catchment Audit is an adaptively managed program, where audit direction is dictated by water quality results. The catchment size and the number of developments in Terrigal along with the age of the suburb pose challenges when investigating infrastructure, however investigations have been scheduled. Furthermore, identifying and accessing private infrastructure will be challenging, however this will be comprehensively assessed as the audit progresses.

Based on the Australian Government's National Health and Medical Research Council's *Guidelines for Managing Risks in Recreational Waters 2008* (NHMRC 2008), 100 samples is recommended to assess swim safety. When the sample size (number of sampling days) in the Terrigal Catchment Audit has increased, the data from the audit will more adequately represent varying water quality such as varying weather, ocean and stormwater conditions. Further sampling on weekends and long weekends will be undertaken to increase sample size and to sample stormwater when the population of Terrigal increases due to visitors. This will include more sampling on weekends, long weekends and school holidays. Adequately sampling these varying conditions takes time.

Catchment sampling will continue to be undertaken and new sewer and stormwater infrastructure investigated with CCTV until the catchment has been thoroughly assessed.

The current report does not assess content which forms a part of the major audit, such as testing the off-shore zone where swimmers cross to Terrigal Haven, hydrological mechanisms driving microbial movement, reservoirs for bacteria and their response to environmental conditions, volume and microbial load or broader environmental impacts from other pollution sources in the catchment. It is evident that further sampling of ocean conditions is needed to understand the hydrodynamics of Terrigal Beach and Terrigal Haven in response to lagoon openings. The movement of lagoon discharge is likely affected by wind speed, wind direction, swell direction, long-shore drift and the discharge interaction with tide. Further testing is needed to assess how long water quality declines after lagoon opening under different environmental conditions and how this may it affect swimming safety. It is also evident that Terrigal Haven water quality at the Marine Rescue requires more investigation and shows the need to assess how water quality responds to a lack of water flushing due to the adjacent rock platform. The effect of reduced flushing at Terrigal Haven will be assessed as a part of the major audit and may be assisted by hydrodynamic modelling. Sampling at Terrigal Lagoon both in the receiving waters and the catchment will be addressed as a part of the major audit. Central Coast Council alongside the NSW Government are addressing these issues, and these will be reported on as a part of the major audit. These data are complex and will take time to collect and scientifically analyse.

Conclusions

The Terrigal Catchment Audit is a complex monitoring, investigation and research program, which combines work undertaken by the Central Coast Council and the NSW Government. Programs investigating catchment pollution input take time to ensure funding is spent based on robust data and intelligent, not rushed decisions.

The *Initial Water Quality Investigation Report* for the Terrigal Beach Catchment Audit is designed to provide background information on water quality issues, provide an update on ocean water quality and the outcomes of infrastructure investigations.

The program establishes a robust monitoring program at 12 ocean locations over 20 separate days, assessing the impact of stormwater on ocean microbial contamination. Terrigal was often considered good for swimming, being safe for swimming 94% of the time in dry weather. Haven and Terrigal beach have similar water quality being considered "Good" for swimming at Terrigal Beach 96% and Terrigal Haven 88% of the time. Sampling is continuing.

Dry weather stormwater flows have been associated with microbial contamination at all stormwater pipes discharging to the beach at varying concentrations, which is a common occurrence in catchments in Australia and globally. Some impact is seen on water quality directly outside the stormwater pipes at the "7 drains", however directly adjacent to the drains at the rockpool and south of the SLSC flags were considered good for swimming, indicating dilution of microbial contamination and minimal risk to swim safety. Sampling is continuing.

Investigations have begun to assess possible sources of microbial contamination in order to schedule improvements to infrastructure. A clear *Priority Sub-catchment Sampling and Investigation Works Program* provides the systematic sampling and infrastructure inspection regime, and the *Infrastructure outcomes* section indicates that infrastructure improvements can be made on 14 sewer pipes and one stormwater pipe which may or may not contribute to microbial presence, however further investigations are required to detect other sources within the Terrigal Catchment. No compliance issues have currently been detected in private infrastructure. Investigations are continuing.

Investigation of the impacts of large wet weather events is ongoing and may prove to be the major source of microbial pollution in Terrigal.

Sampling for the Terrigal Catchment Audit is ongoing and the current report comments on initial outcomes only. Initial outcomes are based on a small sample size of 20 sampling days and continuing investigations may find new and unpredicted results, which may change the outcomes of the audit. Consequently, although minimal to no risk to swim safety from stormwater pipes has been detected in the initial audit, further data may prove this outcome to be incorrect. Council is continuing to sample and assess the water quality at Terrigal Beach and Terrigal

Haven to build a detailed understanding of water quality under different conditions, particularly large wet weather events, and is working alongside the NSW Government to build a larger monitoring and water quality improvement program.

References

Aboul-Kassim T. A. and Simoneit B. R.T. (1993) Detergents: A review of the nature, chemistry, and behavior in the aquatic environment. Part I. Chemical composition and analytical techniques, *Critical Reviews in Environmental Science and Technology*, **23** (4), 325-376.

Adeel M., Song X., Wang Y., Francis D., Yang Y. (2017) Environmental impact of estrogens on human, animal and plant life: A critical review, *Environment International*, **99,** 107-119.

Antilles, N., Sanglas, A. and Cerda-Cuellar, M. (2015) Free-living Waterfowl as a Source of Zoonotic Bacteria in a Dense Wild Bird Population Area in Northeastern Spain. *Transboundary and Emerging Diseases,* **62** (5)*,* 516-521.

ANZECC. (2000) Australian water quality guidelines for fresh and marine waters. Canberra. Australian and New Zealand Environment and Conservation Council, Australian Government Publishing Service.

Bishop, M. J. (2007) Impacts of boat-generated waves on macroinfauna: Towards a mechanistic understanding. *J. Exp. Mar. Biol. Ecol.,* **343** (2)*,* 187-196.

Boehm, A. B., Ashbolt, N. J., Colford, J. M., Dunbar, L. E., Fleming, L. E., Gold, M. A., Hansel, J. A., Hunter, P. R., Ichida, A. M., McGee, C. D., Soller, J. A. and Weisberg, S. B. (2009) A sea change ahead for recreational water quality criteria. *Journal of Water and Health,* **7** (1)*,* 9-20.

Brady, N. C., & Well, R. R. (1996) The nature and properties of soils. New Jersey: Prentice Hall, Inc.

Brasseur, G. P., Orlando, J. J., & Tyndall, G. S. (1999) Atmospheric chemistry and global change. Oxford: Oxford University Press.

Clark A., Turner T., Padma K.Dorothy, Goutham J., Kalavati C., Rajanna B. (2003) Health hazards due to pollution of waters along the coast of Visakhapatnam, east coast of India, *Ecotoxicology and Environmental Safety,* 56 (3), 390-397.

Cody, A. J., McCarthy, N. D., Bray, J. E., Wimalarathna, H. M. L., Colles, F. M., van Rensburg, M. J. J., Dingle, K. E., Waldenstrom, J. and Maiden, M. C. J. (2015) Wild bird-associated Campylobacter jejuni isolates are a consistent source of human disease, in Oxfordshire, United Kingdom. *Environmental Microbiology Reports,* **7** (5)*,* 782-788.

Cox, P., Griffith, M., Angles, M., Deere, D. and Ferguson, C. (2005) Concentrations of pathogens and indicators in animal feces in the Sydney watershed. *Appl Environ Microbiol,* **71** (10)*,* 5929-5934.

Davies-Colley R. J., Bell R. G., Donnison A. M. (1994) Sunlight Inactivation of Enterococci and Fecal Coliforms in Sewage Effluent Diluted in Seawater *Applied and Environmental Microbiology* **60** (6) 2049-2058.

Department of Primary Industries (2019) https://www.dpi.nsw.gov.au/fishing/habitat/aquatic-habitats/wetland/coastal-wetlands/management-of-coastal-lakes-and-lagoons-in-nsw.

Elmir, S. M., Wright, M. E., Abdelzaher, A., Solo-Gabriele, H. M., Fleming, L. E., Miller, G., Rybolowik, M., Peter Shih, M. T., Pillai, S. P., Cooper, J. A. and Quaye, E. A. (2007) Quantitative evaluation of bacteria released by bathers in a marine water. *Water Res,* **41** (1), 3-10.

Field, K. G. and Samadpour, M. (2007) Fecal source tracking, the indicator paradigm, and managing water quality. *Water Res.,* **41** (16), 3517-3538.

Graczyk, T. K., Sunderland, D., Awantang, G. N., Mashinski, Y., Lucy, F. E., Graczyk, Z., Chomicz, L. and Breysse, P. N. (2010) Relationships among bather density, levels of human waterborne pathogens, and fecal coliform counts in marine recreational beach water. *Parasitology research,* **106** (5), 1103-8.

Khan, S. J., Wang, L. L., Hashim, N. H. and McDonald, J. A. (2014) Distinct Enantiomeric Signals of Ibuprofen and Naproxen in Treated Wastewater and Sewer Overflow. *Chirality,* **26**(11), 739-746.

Khwanboonbumpen, S. (2006) Sources of nitrogen and phosphorus in stormwater drainage from established residential areas and optionsfor improved management. Retrieved from https://ro.ecu.edu.au/theses/75

Kyung Hwa Cho, Sung Min Cha, Joo-Hyon Kang, Seung Won Lee, Yongeun Park, Jung-Woo Kim, Joon Ha Kim (2010) Meteorological effects on the levels of fecal indicator bacteria in an urban stream: a modeling approach. *Water Research. 44: 2189–2202*.

Muruleedhara N. Byappanahalli, Meredith B. Nevers, Asja Korajkic, Zachery R. Staley, Valerie J. Harwood (2012) Enterococci in the Environment. *Microbiology and Molecular Biology Reviews* Nov 2012, **76** (4) 685-706; **DOI:** 10.1128/MMBR.00023-12

Napper I. E. and Thompson R. C. (2016) Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions, *Marine Pollution Bulletin*, **112** (1–2), Pages 39-45.

NHMRC (2008) National Health and Medical Research Councils Guidelines for Managing Risks in Recreational Water. https://www.nhmrc.gov.au/about-us/publications/guidelines-managing-risks-recreational-water

OEH (2018) Office of Environment and Heritage. Annual State of the beaches reporting. https://www.environment.nsw.gov.au/topics/water/beaches/reporting-beach-water-quality/state-of-the-beaches

Passerat, J., Ouattara, N. K., Mouchel, J.-M., Vincent, R. and Servais, P. (2011) Impact of an intense combined sewer overflow event on the microbiological water quality of the Seine River. *Water Res.,* **45**(2), 893-903.

Ramonaite, S., Novoslavskij, A., Zakariene, G., Aksomaitiene, J. and Malakauskas, M. (2015) High Prevalence and Genetic Diversity of Campylobacter jejuni in Wild Crows and Pigeons. *Current Microbiology,* **71** (5), 559-565.

Rippy, M. A., Stein, R., Sanders, B. F., Davis, K., McLaughlin, K., Skinner, J. F., Kappeler, J. and Grant, S. B. (2014) Small Drains, Big Problems: The Impact of Dry Weather Runoff on Shoreline Water Quality at Enclosed Beaches. *Environ. Sci. Technol.,* **48** (24), 14168-14177.

Schiff K, Kinney P. (2001) Tracking sources of bacterial contamination in stormwater discharges to Mission Bay, California. Water Environ Res. Sep-Oct;73(5):534-42. PubMed PMID: 11765989.

Schijven, J., Bouwknegt, M., Husman, A. M. D., Rutjes, S., Sudre, B., Suk, J. E. and Semenza, J. C. (2013) A Decision Support Tool to Compare Waterborne and Foodborne Infection and/or Illness Risks Associated with Climate Change. *Risk Anal.,* **33**(12), 2154-2167.

Schijven, J. F. and de Roda Husman, A. M. (2005) Effect of climate changes on waterborne disease in The Netherlands. *Water Sci Technol,* **51**(5), 79-87.

Stewart, J. R., Gast, R. J., Fujioka, R. S., Solo-Gabriele, H. M., Meschke, J. S., Amaral-Zettler, L. A., del Castillo, E., Polz, M. F., Collier, T. K., Strom, M. S., Sinigalliano, C. D., Moeller, P. D. R. and Holland, A. F. (2008) The coastal environment and human health: microbial indicators, pathogens, sentinels and reservoirs. *Environ. Health,* **7** (Suppl 2), S3-S3.

Wetzel, R. G. (2001) Limnology: lake and river ecosystems. Cambridge: Cambridge University Press.

World Health Organization (WHO). (2003) Emerging issues in water and infectious disease. Geneva, World Health Organization, 22pp.

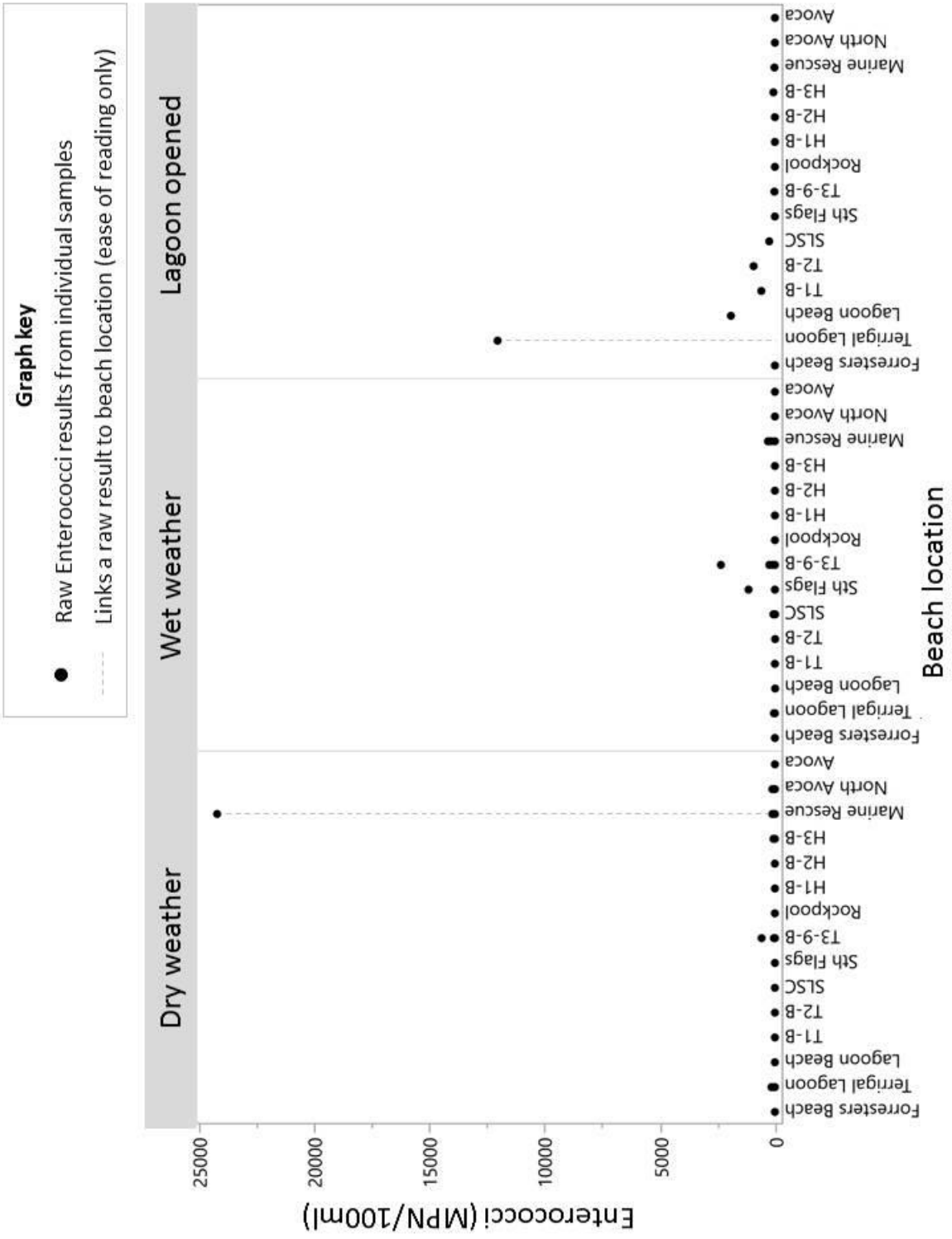
APPENDIX

Appendix 1: List of controls and the possible pollution and environmental conditions (aspect) experienced by control sites.

Location	Pollution potential based on sanitary inspections	Ocean aspect
Foresters Beach	Low	North
Terrigal Beach	Moderate	South
Terrigal Haven	Moderate	South
North Avoca Beach	Low	North
Avoca Beach	Moderate	South

Appendix 2: Photograph of ocean sample location T3-9B which received two days of elevated Enterococci in 23 days of sampling. Photograph shows dry weather flow from drain T8.

Appendix 3: Outliers included. Raw Enterococci data for beach samples from 17 January – 31 May 2019 with outliers included to see data more easily.



Appendix 4: Outliers excluded. Raw Enterococci data for beach samples from 17 January – 31 May 2019 with outliers excluded to see data more easily.