WATER QUALITY IN THE KAVHA CATCHMENT

Report Prepared by

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On behalf of

The Norfolk Island Regional Council

Document History

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Summary

The primary objective of the study was to analyse representative water samples from the Watermill Creek and Upper catchment with a view to identify potential contamination and assess the risk to public health and the environment.

The water quality values most applicable to the project were identified using the Australian and New Zealand Guidelines for Fresh and Marine Waters (ANZECC 2000) and the NSW Water Quality Objectives (NSW WQOs). While Norfolk Island is not specifically recognised in these guidelines, trigger values representative of a South-East Australian lowland river was selected as a proxy for the purpose of this study.

Three water body types are represented in the KAVHA – Emily Bay study area. Surface waters (creek and wetlands), groundwater and marine receiving waters (Emily Bay). The system was rated as a 'slightly disturbed site' under the guidelines due to the unrestricted access by cattle, feral chickens, ducks and geese. Emily Bay, the receiving waters for the catchment, is rated as a 'site of high conservation value' due to the presence of EPBC listed species and habitats, the enclosed nature of the lagoon with restricted flushing and water exchange and the use of the quiet calm waters of the bay by local residents and tourists. The area is particularly frequented by the most vulnerable members of the population, the very young and the very old.

The results show that the water quality in KAVHA is degraded relative to the ANZECC Guidelines for Lowland rivers in South-East Australia. The unacceptably high nutrient load in the creek is indicative of what would be delivered to the enclosed, poorly flushed Emily Bay lagoon following a significant rainfall event. These nutrients accelerate the growth of primary producers, such as seagrass and algae, at the expense of coral.

The water quality analysis carried out across the KAVHA catchment by Norfolk Island Regional Council (Council), over the months of April to September 2017, have identified coliform concentrations that are substantially higher than the recommended 0 E.coli/L levels set by the National Health and Medical Research Council (NHMRC) Australian Drinking Water Guidelines and by ANZECC for primary contact and secondary contact (150 coliforms/100ml and 1000 coliforms/100ml respectively).

The pathogens that have been found to be present at these sites have the potential to cause serious illness and in severe cases death. Council and the Commonwealth of Australia have a duty of care to protect the health of all users of Emily Bay and until a water management strategy is developed, a routine and scientifically sound water monitoring program must be implemented, along with necessary public notification to make the users of Emily Bay aware of the risks they take when using the bay so they can make informed decisions about their recreational activity.

The final recommendations of this study include:

- Divert the Town Creek outlet (and associated stormwater) from entering Emily Bay into settling ponds. This will allow impurities to settle out, reduce the impact to Emily Bay, recharge groundwater supplies and allow the water to be used as a resource.
- Develop a wetland and leaky weir system across the catchment to allow the natural uptake of nutrients and pathogen containment while reducing the volume of water that is released into the Emily Bay and allow the underground aquifers to be replenished.
- Conduct an audit of septic systems within KAVHA and the upper catchment.

- Develop a plans of management for effluent in the KAVHA Site and to connect the houses in Little Cutter's Corn to the Water Assurance Scheme
- Exclude livestock from Watermill Creek by fencing or cattle collars with a 5m buffer zone either side and install water troughs in an area well clear of permanent water bodies.

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1. Introduction

1.1. Background

In 2015 a letter addressed to the former Administrator of Norfolk Island (dated 5 October 2015) prepared by Dr Kellie Pendoley of Pendoley Environmental Pty Ltd, raised the issue of the poor quality of water flowing into Emily Bay from the KAVHA lands. This letter (Appendix 1) was the most recent attempt, in a long line of concerned individuals stretching back ~ 40 years, to bring this issue to the attention of the Norfolk Island regulators. The letter focussed on the detrimental effects the water runoff from the KAVHA lands was having on the water quality of Emily Bay, i.e.;

"*Large fresh water flows together with elevated nutrient levels have killed the coral in Emily Bay along a transect extending from the outlet to Lone Pine and to the reef outlet channel. Personal observations over the past 50 years, together with anecdotal feedback from numerous island residents, indicates that the die-off of coral, increased algae growth, both on the floor of the bay and covering the dead coral habitat, plus the decrease in the number and diversity of small fish, has accelerated in the past 5 years. We have serious concerns that this accelerated rate of decline will wipe out the entire Emily and Slaughter Bay Lagoon within 5-10 years. Recovery of the ecosystem will be delayed by the lack of immigration of coral spawn from external reef systems (eg Lord Howe) due to the isolated nature of Norfolk'*" Pendoley Environment 2015 (Appendix 1)

This letter also addressed the conservation value of the lagoon, recognising that the Emily Bay and Slaughter lagoons provide critical habitat for the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act) listed, Booths pipefish (*Halicampus boothae*) and green turtles (*Chelonia mydas*). Under the EPBC Act regulators are legally obliged to protect endangered and migratory listed species, and their habitat, from significant impact. Both green turtles and Booths pipefish are listed as *matters of national environmental significance* under the EPBC Act.

The quality of the water draining into Emily and Slaughter Bay lagoons is a function of both the source of the water and the exposure to contaminants as the water moves through the two main surface water catchments on the Island, Watermill Creek and Upper Cascade Creek. Studies of island water quality in recent decades have shown the quality of the water to be poor, presenting a potential risk to human and environmental health (Diatloff,2009). As both groundwater and surface water are utilised by the local population, various exposure pathways for contaminated water to impact human health are recognised (AECOM, 2017). The source of the contamination impacting on the water quality in the KAVHA area is thought to be both livestock and human waste.

The grazing of livestock with unrestricted access to waterways can have an adverse effect on the receiving environment from faecal contamination, excess nutrient loads and erosion. The pathogenic content along with the increased nutrient loads can have a lethal impact on marine and freshwater ecosystems, while eutrophic conditions caused by excessive algae growth can starve the ecosystem of oxygen. The unrestricted access by cattle, chickens, ducks and geese to Watermill and Town creeks is recognised as a major source of animal waste, pathogens and nutrient pollution.

In addition, although a sewerage collection and treatment service, the Water Assurance Scheme (WAS), is available in the most populated areas of the Island (Burnt Pine), the majority of households and businesses typically rely on individual septic systems and land-based effluent dispersal fields (soakage trenches) which are likely to present numerous point sources of pathogen and nutrient pollution that is washed into the streams or soak into the groundwater.

This risk is not unique to Norfolk Island and has been recognised in small communities elsewhere, when poorly managed wastewater collection, treatment and disposal negatively impacts on the receiving environment and threatens public health and safety. Failing systems can release poorly treated effluent, reducing the quality of groundwater and streams which are a likely source of water for the community (Diatloff, 2008). This pollution of groundwater has been demonstrated locally through the anecdotal reports of higher incidences of gastroenteritis in times of drought on Norfolk Island, when the primary water source (rainwater) has been depleted and water is extracted from creeks or shallow aquifers (AECOM, 2017).

Finally, concerns in regards to the quality of water used for recreational activities have also been raised following the reports of widespread ear infections in people swimming in Emily Bay. While the pathogens carried into Emily Bay by Town Creek can impact on human health (Dale et al, 2009), the fresh water and the elevated nutrient concentrations in that water is also having an impact on the ecosystem health of the bay. Historical anecdotal and recent observations of the decline of coral habitat in Emily Bay on a transect extending from the Town Creek outfall, suggests adverse water quality and volume is impacting on the bay.

Historically Town Creek did not drain directly into Emily Bay. The creek was described in 1788 by John Hunters (Hunter, 1793) as follows; *A very fine rivulet runs through this vale, sufficiently large to turn any number of mills. As the bank of the sea-shore is considerably above the level of the rivulet, it sinks into the earth; and, after passing under the bank, it forces a passage for itself through a fissure of the rock, on Stony Beach and Turtle Bay, between high and low water marks, where it boils up with great force, and is excellent water. As the whole of this water is not carried off by the passage just mentioned, sufficient to keep the low ground clear, what does not pass under the bank, overflows the lower part of the valley, for the space of half a mile: this swamp might be drained by cutting a channel for the rivulet to empty itself on the sea-shore; but the operation would require time and a number of hands, and, when finished, it is not clear but that the force of the sea would soon fill the channel up again.*

The Turtle Bay referred to by Hunter is the modern day Emily Bay and describes the sub surface seepage of the creek water into the intertidal zone at Emily Bay. Because water could not drain directly into the bay it flooded the low ground behind the behind Emily Bay and across the public land currently occupied by the golf course. It was the later creation of a manmade tunnel through rock behind Emily Bay that allowed the Town Creek water to drain directly into the bay.

In recognition of the historical issues surrounding water quality on Norfolk Island, Council engaged an external consultant, AECOM, to conduct a water quality study of the Emily Bay and upper Cascade Creek catchment in May 2017 (AECOM 2017). The report made a number of recommendations, including Recommendation 6, that the NIRC should;

'*Conduct monitoring of water quality in Emily Bay to assess whether potential risks to recreational users and marine habitats are likely to be realised, and if so, management procedures that can be employed to reduce risks to human health and the environment'*.

In response to this recommendation, the Waste and Environment Section of Council implemented a monitoring program in mid-2017 to assess the water quality in the KAVHA Catchment and source tributaries, with a specific objective of assessing the level of risk to public health and the receiving environment from the water.

This report presents the preliminary findings of that study.

1.2.Objectives and Scope

The primary objective of the study was to analyse representative water samples from the Watermill Creek and Upper catchment with a view to;

- establishing a benchmark to measure existing water quality against,
- assess the risk to human health from swimming in the receiving waters at Emily Bay, and
- assess the risk to the listed species, their habitats and the marine ecosystem in Emily Bay/Slaughter lagoon system.

The scope of the study was restricted to the KAVHA site only and does not address water quality of creeks or groundwater systems outside of this area.

1.3 Related Water Quality Studies

Over the past decade a number of water quality studies have been carried out across the island and within the study area. These studies have been either internal or independent and for both the Administration of Norfolk Island and the Commonwealth of Australia. The reports that have been reviewed during this study are listed below:

- Norfolk Island Water Quality Study: Emily Bay & Upper Cascade Creek Catchments (URS 2013)
- Assessment of Groundwater Contamination in the Built-up Areas of Norfolk Island (Wilson 2010)
- Norfolk Island Hydrology Study (Diatloff, 2007)
- Norfolk Island Water Quality & Sewerage Infrastructure Management Strategy (2014)
- Emily Bay and Upper Cascade Creeks Catchments: Norfolk Island Water Quality Study (AECOM 2017)
- Water Distribution System Integrity Investigation Study: Government House, Norfolk Island (Diatloff, 2011)

The aforementioned studies have consistently identified elevated levels of microbial contamination and excessive nutrient loads in the lower waterways flowing through the Kingston Commons, Town Creek and the Recreation Reserves. *E.coli* levels reported in the waterways which discharge into Emily Bay have been shown in numerous studies to almost always exceed safe levels for primary contact, swimming and fishing. These waters were only considered suitable for restricted uses where human contact was avoided.

The information reported across the various studies appear to identify increases in microbial activity after rainfall and also after significant disturbance of the creeks (i.e. dredging events).

Although the reports are generally ambiguous about the exact source of contamination they generally recommend further investigation into onsite wastewater treatment and collection systems in the upper catchment and the restriction of cattle entering the waterways.

2. Methods

2.1 Water quality indicators and triggers

The water quality values most applicable to the project were identified using the Australian and New Zealand Guidelines for Fresh and Marine Waters (ANZECC 2000) and the NSW Water Quality Objectives (NSW WQOs). The NSW WQOs are consistent with the ANZECC guidelines in providing the environmental values for NSW waters while the ANZECC 2000 Guidelines provide the technical guidance to assess the water quality needed to protect those values. The WQOs provide trigger values for a range of contaminants according to the environmental value selected for the waterway of interest. While Norfolk Island is not specifically recognised in these guidelines, trigger values representative of a South-East Australian lowland river was selected as a proxy for the purpose of this study.

Three water body types are represented in the KAVHA – Emily Bay study area. Surface waters (creek and wetlands), groundwater and marine receiving waters (Emily Bay). The system was rated as 'slightly disturbed site' under the guidelines due to the unrestricted access by cattle, feral chickens, ducks and geese. Emily Bay, the receiving waters for the catchment, is rated as a 'site of high conservation value' due to the presence of EPBC listed species and habitats, the enclosed nature of the lagoon with restricted flushing and water exchange and the use of the quiet calm waters of the bay for recreation. The use of the bay by humans, particularly elderly tourists and very young children requires the receiving waters be assessed for 'primary contact' under 'recreational use'. Finally, the use of the groundwater by local residents for domestic use requires some of the samples be assessed against drinking water guidelines (NHMRC, 2016).

The trigger values representative of slightly disturbed sites are listed in the **Table 2.1** below. Trigger values are used to assess the risk of adverse effects to the environmental value from selected contaminants or water characteristics, e.g. nutrients, biodegradable organic matter and pH (ANZECC 2000). These values have been used as a guide only to assess the current condition of the KAVHA waterways.

Table 2.1: ANZECC guidelines for Lowland Rivers in South-East Australia

Water quality	Trigger value
Total Phosphorus (mg/L)	0.05
Filterable reactive phosphate (mg/L)	0.02
Total Nitrogen (mg/L)	0.5
Oxides of nitrogen NOx (mg/L)	0.04
Ammonium NH_4 (mg/L)	0.02
Dissolved Oxygen (lower limit) %	90%
pH (lower limit)	6.5

Nitrogen and phosphorus are nutrients commonly found in sewage effluent. The elements are mobilized in the system in the form of Nitrate (NO^{-3}) and phosphate (PO_4^{-3}). These nutrients are among the leading pollutants of surface water. In drinking water, NO^{-3} should not exceed 10 mg N/l. Levels greater than this may be toxic to infants and be responsible for increases in stomach cancer for others. Phosphates are typically present in raw wastewaters at concentrations near 10 mg P/l. Effluent limits usually range from 0.1-2 mg P/l.

Ammonium (NH^{+4}) is considered to be harmless; however chemical reactions in the water body produce ammonia and nitrite which can be extremely toxic. The acceptable level of ammonium in natural waterways is 0.02mg/l NH^{+4} (ANZECC 2000).

Recreational water quality values are primarily targeted at the protection of human health. Faecal coliform concentrations are used to assess recreational water quality and E. coli is a specific indicator of faecal contamination from human or animal sources. E. coli are also an indicator of recent or ongoing contamination as the organisms do not have the ability to multiply in the natural environment. Exposure to E. coli can cause diarrhoea, nausea and severe stomach pains and long term exposure can result in severe blood and kidney problems.

The ANZECC/WQO Guidelines provide primary and secondary contact limits for recreational waters. Primary contact includes any activity that requires complete immersion in the water, e.g. swimming, surfing, snorkelling etc. Secondary contact does not involve a significant risk of ingestion of the water, e.g. boating, sailing, fishing etc. Primary and secondary contact limits reflect the difference in risk to swallowing water polluted with pathogens.

The ANZECC guidelines recommend that median bacterial content in samples of fresh or marine waters taken at regular intervals (not exceeding one month) over the bathing season should not exceed;

- primary contact, 150 faecal coliforms/100 mL
- secondary contact, 1000 faecal coliforms/100 mL

The faecal coliform count includes a range of coliform pathogens (including E. coli), while the E. coli count is a count of E. coli only.

The NHMRC water quality standards for drinking water are applicable for sites where there is the potential for human consumption. The standards used here include; ammonia (an indicator of waste contamination), <0.2 mg/L in uncontaminated waters and no E. coli.

2.2 Sample collection timing and site selection – Norfolk Island

Water samples were collected between April 2017 and September 2017. Samples that were collected between the 16th of April and the 22nd of August after an extended period of dry weather, represent the direct contamination of the water system from grazing animals or human effluent.

Samples collected on the 27th of August followed a significant rainfall event when Town Creek broke through a sand plug barrier and flowed into Emily Bay.

Samples were not collected across the sample sites systematically. Samples were collected from different sites on different days (**Table 3.2**).

Sampling site selection was determined by two main factors;

- the likelihood of the public coming into direct contact with the water body, and
- the ability to identify the different sources of contamination.

The location of the six sample sites across the KAVHA Catchment are shown in **Figure 2.1**. The creek running from Site 1 is known locally as Watermill Creek and Site 3 and 4 is known as Town Creek. An aerial view of the site is shown in **Figure 2.2**.

Figure 2.1: Sample Locations in the KAVHA Catchment

Figure 2.2: Aerial Photograph of KAVHA Catchment (Sourced from Google Earth)

The sample site location codes shown on Figure 2.1 represent;

1. Watermill Dam
2. Community Reservoir
3. Main bore (Officers Bath)
4. Surface Water Officers Bath
5. Town Creek Post Wetland
6. Emily Bay Inlet

Details regarding individual sample site selection are summarised below.

Site 1: Watermill Dam

This site was selected because it represents the site that all of the tributaries from the upper Burnt Pine Catchment converge and then enter into Town Creek. These tributaries potentially carry contaminants from the Southern end of the airport runway, Burnt Pine and Queen Elizabeth Avenue.

In addition, this site represents the water quality where the creek system enters the KAVHA Site and is a benchmark for comparing samples further downstream.

Site 2: Community Reservoir

This water source taps into an underground stream and is used by community members to collect water for agricultural and horticultural purposes. The risk of the public coming into direct contact with contaminated water is high.

This site also identifies contamination entering the KAVHA Site from the western side of Middlegate Rd. The reservoir has been dug into an underground stream and is open to surface stormwater runoff. For this reason, the site is considered as a surface water site.

Site 3 Main Bore (Officers Bath)

Site 3 is the only true groundwater sample assessed in the KAVHA Catchment. This bore was monitored because it provides water to the majority of the domestic and office buildings in KAVHA. Some of the buildings have been fitted with water treatment devices for drinking water however the remaining buildings connected to the mains supply (in particular the public toilets) are delivered a raw supply from the bore.

Site 4 Surface Water Officers Bath

Site 4 has been selected because it represents the contamination entering the system from the Eastern Side of Middlegate Road and the Western Side of Rooty Hill Road and is the last tributary to enter into Town Creek before it discharges into Emily Bay.

The sample is taken from the bottom of the stairs inside the Officers Bath and its accessibility makes it a risk for primary contact with public health implications.

Site 5 Town Creek Post Wetland

This site is at the downstream end of the Town Creek wetland system and immediately before the entrance to a manmade tunnel through a rocky mound behind Emily Beach. Water flowing through the tunnel enters directly into Emily Bay however during dry periods, when rainfall levels are low, sand from the bay washes up the creek bed and blocks the free flow of water behind a sand plug.

This site represents the lowest point in the catchment.

Site 6 Emily Bay Inlet

Site 6 is at the mouth of the creek where it enters Emily Bay. Under dry conditions this creek mouth is plugged with sand and there is no surface water movement. Observations of the intertidal zone in front of the creek outlet in Emily Bay indicates the trapped water percolates through the sand and into the bay. This observation is consistent with the historical records of Hunter, 1793. During periods of high rainfall the creek volume increases to a point that sufficient volume washes the sand plug out and allows the water to discharge into the bay.

This site was only sampled after significant rainfall event, when there was fresh water entering Emily Bay. This is to analyse the quality of the stormwater discharging into Emily Bay and assess the potential impacts this may have on the receiving environment and to public health.

2.3 Sample collection and analysis

Water samples were collected and analysed according to the methods and protocols outlined in the ISO:19458: 2006 *Water sampling for Microbiological Analysis (reviewed 2015)* and the ISO/IEC 17025:2005 *General requirements for the competence of testing and calibration laboratories* (reviewed 2010)

The sample collection guidelines employed included;

- Surface water samples were collected by grab sample methodology
- Samples were taken as close to the raw source of water as possible
- Groundwater was run for a length of time to avoid the collection of old water
- Samples were collected in sterilized air tight containers
- All relevant equipment was decontaminated with Decon 90 solution and rinsed with distilled water between sample locations
- Samples were transported in a cooler bag and kept out of the sunlight to avoid denaturing of microorganisms
- Samples were collected using disposable gloves to avoid cross contamination of samples

The water samples were analysed for the following:

- Nitrate
- Phosphate
- Ammonium
- Ammonia
- Total Coliforms
- E. Coli
- pH
- Dissolved oxygen (DO)

For the purpose of quality assurance duplicate samples were collected twice across the study period and sent to the Norfolk Island Health and Residential Aged Care Facility Pathology Unit for microbial analysis. These results were consistent with the water samples analysed in this study. These results are shown in Appendix 3.

3. Results

The results of the physical and chemical analysis of the samples are shown in **Table 3.1**. These samples were collected during a dry period and therefore there was no contribution from stormwater runoff. **Table 3.2** presents the results for the faecal coliforms analysis of samples from the six sites across the KAVHA catchment.

Table 3.1: Physical and Chemical Analytes, red text denotes samples that exceed ANZEEC trigger values for lowland rivers in SE Australia (Table 1). NA = Not Available

Site Location	Date	DO (mg/L)	Phosphate PO_4^{-3} (mg/L)	Ammonia NH_3 (mg/L)	Nitrate NO_3^- (mg/L)	Ammonium NH_4^+ (mg/L)
Site 1	18/08/2017	7.3	2	0.2		
	22/08/2017	7.1	1.9	0.3		
	7/09/2017	NA	NA		0.91	1.4
Site 2	7/09/2017	NA	NA		0.79	1.2
Site 4	7/09/2017	NA	NA		2.43	1.1
	18/08/2017	5	0.4	1.21		
	22/08/2017	5.2	0.6	1.32		
Site 5	7/09/2017	NA	NA		2.73	1.9
	18/08/2017	4.8	1.2	0.09		
	22/08/2017	5.1	1.3	1		

Table 3.2: Water Quality Results for Sites 1-6 * red text denotes sample exceeds ANZECC trigger for both primary (100 coliforms/100ml) and secondary (1000 coliforms/100ml) contact. Note Site 6 (Emily Bay) was only sampled after heavy rainfall in late August.

Site Location	Date	Temp °C	pH	E.coli CFU/100mL*	Coliforms CFU/100mL*
Site 1	26/06/2017	18.9	7.31	1300	22800
Site 1	31/07/2017	18.1	6.91	3300	5594
Site 2	13/06/2017	18.5	6.71	500	12000
Site 2	31/07/2017	17.8	6.7	3300	17600
Site 3	16/04/2017	21.8	6.52	<1	<1
Site 3	18/04/2017	19.7	6.61	<1	<1
Site 3	8/06/2017	18.6	6.8	<1	<1
Site 3	13/06/2017	18.2	6.65	<1	<1
Site 4	13/06/2017	18.9	6.56	16800	30000
Site 4	12/07/2017	16.8	6.83	19200	21600
Site 4	31/07/2017	18.6	6.71	3000	12000
Site 4	31/07/2017	18.6	6.71	3996	14400
Site 4	9/08/2017	18.1	6.31	3900/3300	4200
Site 4	22/08/2017	18.5	6.72	3600	18400
Site 5	13/06/2017	18.7	6.46	5100	11600
Site 5	26/06/2017	19.1	6.75	5800	24800
Site 5	31/07/2017	18.8	6.9	3800	14000
Site 5	9/08/2017	18.7	6.7	333/400	2800
Site 5	27/08/2017	18		4300	90010
Site 6	9/08/2017	18.9	6.72	1800/1500	4400
Site 6	27/08/2017	18.1		4100	86000
Site 6	27/08/2017	18.2		1233	23710

4. Detailed Microbial Analysis and Identification of Pathogens

Table 4.1 provides the results of a detailed microbial analysis from Site 4 and Site 5. The assessment provides a more thorough analysis of the results and has expanded on the variety of pathogens that are present in the water body.

This analysis was carried out through the NIHRACs Pathology unit so detailed methodology is unknown however the water samples were analysed by suitably trained biomedical scientists.

Table 4.1: Detailed Microbial Analysis

Location	Date	Enterbacteriacie (CFU/100mL)	E. coli (CFU/100mL)	Salmonella (CFU/100mL)	Gram Negative Anti-Biotic Resistant (CFU/100mL)	Total Coliforms (CFU/100mL)
Site 4	17/09/2017	18000	4400	3000	3000	40000
Site 5	17/09/2017	6000	4400	2800	590	13000

Pathogen	Location	Date tested	
P. Aeruginosa	Site 4	18/06/2017	Positive
Enterobacter cloacae	Site 4	18/06/2017	Positive

Generally the potential for faecal contamination is assessed based on Faecal Coliforms or nutrient load. This assessment has aimed, however, to analysis a wider range of bacteria to determine the level of risk to public health.

Enterbacteriacie are a family of bacteria which are primarily known for their ability to cause intestinal upset however many of the strains have the ability to cause serious illness. These include urinary tract infections, wound infections, gastroenteritis, meningitis, septicemia, and pneumonia (Rogéria *et al,* 1998). *Enterobacter cloacae* is a member of this family.

The presence of these organism at any level poses a significant public health risk and given that the island's visiting demographic are typically mature age the likelihood of these bacteria causing infection would be increased.

Salmonella can present in the form of gastroenteritis (diarrhoea, abdominal cramps, and fever) to enteric fevers (including typhoid fever) which are life-threatening febrile systemic illnesses requiring prompt antibiotic therapy (Giannella, 1996). The levels found in the water entering at Site 4 and accumulating in Site 5 are extremely concerning. The potential for human illness as a result of coming into contact with this water is considered high.

Gram-negative bacteria also have the ability to cause infections including pneumonia, bloodstream infections, wound or surgical site infections, and meningitis. The particular gram-negative bacteria that were found are resistant to multiple drugs and the number of antibiotics available for treatment is diminishing. The structure of these bacteria have allowed them to find new ways to be resistant and allow them to pass along the drug-resistant genetic material to future generations (Centers for disease Control & Prevention, 2011).

Pseudomonas aeruginosa is a common gram-negative bacterium frequently implicated in healthcare-associated infections (HAIs), particularly in critically ill or immunocompromised patients. Rates of antibiotic resistance in *Pseudomonas aeruginosa* are increasing worldwide with the World Health

Organization now listing it as one of the top ten most antibiotic resistant bacteria. In addition, it is identified as '*Priority 1: Critical'* for priority pathogens that antibiotics need to be developed for (WHO, 2017).

Data from the National Nosocomial Infections Surveillance system from 1986–2003 reported *P. aeruginosa* as the second most common cause of pneumonia (18.1%), the third most common cause of urinary tract infection (16.3%) and the eighth most frequently isolated pathogen from the bloodstream (3.4%) (Hirsch & Tam, 2010).

The presence of gram-negative bacteria is extremely high, particularly at Site 4. The concern with regards to public health is the difficulty in treating a casualty in the event that they are infected.

Not only do these results show that there is a high level of contamination, most likely from raw sewerage, it outlines the severity of the results in relation to public health and safety. It also further highlights the duty of care for government to mitigate these risks and remove the source of contamination.

5. Discussion

5.1.Chemical and physical parameters

The concentration of nutrients in the samples from sites 1, 2 4 and 5 were well in excess of all of the ANZEEC/WQO trigger values for Total Phosphorous (TP) and Total Nitrogen (TN). It is important to note that TP and TN are measures of all nitrogen compounds (i.e. nitrate, nitrite, ammonia, ammonium etc.) and all phosphorous compounds in the water samples and so reporting phosphate or nitrate only is an underestimate of the nutrient contamination levels.

Phosphate is an indicator of detergent contamination (e.g. dishwashing soap, laundry soap) and because the most elevated concentration was recorded in Site 1 it is possible the contamination is entering the system at that site or from further upstream. The lowest concentration of phosphate was recorded at Site 4 (Officers Baths) which drains from the Eastern Side of Middlegate Road and the Western Side of Rooty Hill Road and is the last tributary flowing into the KAVHA site before it reaches Emily Bay.

The decrease in phosphate concentrations between Site 1 and Site 5 suggests that there is some form of nutrient uptake from the limited wetland system. However, given that the phosphate value at Site 5 is 26 times greater than the ANZECC trigger value the water quality at Site 5, and presumably in the water draining into Emily Bay, is at an unacceptably high level.

The presence of ammonia is an indicator for faecal contamination and two of the samples, Site 1 and Site 5 both sampled on the 18/08/2017, returned values < the 0.2mg/L typically found in uncontaminated waterways. (NHMRC, 2011). Site 4 in contrast reported exceptionally high ammonia levels in excess of 1 mg/L, indicating sewage sourced microbial contamination.

Individually the nitrate and ammonium concentration in samples from Sites 1, 2 and 5 (the only sites sampled) exceeded the 0.5 mg/L Total Nitrogen trigger by several orders of magnitude at all sample sites (1, 2, 4 and 5). Analysis of Total Nitrogen in these samples is expected to return even higher exceedances. The consistently high ammonium levels found in samples collected on September 7th in samples from sites 1,2 4 and 5 is likely due to the inflow from the tributaries, unrestricted access by cattle to the creek and pooling of the water at the end of the catchment. Although ammonium is deemed to harmless to humans the elevated levels are a potential risk to the marine and fresh receiving waters and the value recorded at site 5 (immediately before the creek enters Emily Bay) is 95 times higher than the 0.02 mg/L ANZECC trigger.

The Nitrate levels increased significantly across the catchment with a heavily polluted source entering the waterway at Site 4 and mixing with the high concentrations flowing in from Sites 1 and 3 and peaking at Site 5. The ANZECC trigger value of oxides of Nitrogen (NOx) is 0.04 mg/L. The level for Nitrate at Site 5, at the end of the catchment and immediately prior to the water entering Emily Bay is 68 times the recommended trigger. Given that Nitrate is only one portion of the NOx the true value would be expected to be even greater.

The results show that the water quality in KAVHA is degraded relative to the ANZECC Guidelines for Lowland rivers in South-East Australia. The unacceptably high nutrient load in the creek is indicative of what would be delivered to the enclosed, poorly flushed Emily Bay lagoon following a significant rainfall event. These nutrients accelerate the growth of primary producers, such as seagrass and algae, at the expense of coral. The impact of the discharge of Town Creek into Emily Bay is discussed in more detail in section 5.3.

5.2.Pathogens

The water quality analysis carried out across the KAVHA catchment over the months of April to September 2017 have identified coliform concentrations that are substantially higher than the recommended 0 E.coli/L levels set by the NHMRC Australian Drinking Water Guidelines and by ANZECC for primary contact and secondary contact (150 coliforms/100ml and 1000 coliforms/100ml).

The water from Site 2 (community reservoir), which could potentially be consumed by humans, was contaminated by E coli at concentrations 500- 3300 times higher than the 0 E. coli/100ml trigger level for the protection of drinking water. Water from Site 6, where Town Creek discharges into Emily Bay the E. coli concentrations are up to 27 times higher than the acceptable levels for primary contact while total coliforms are 86 times higher than the secondary contact limits. These very high coliform concentrations prove that the Watermill Creek and the Town Creek systems are contaminated by human and/or cattle faeces and exposure to this water puts the health of Norfolk Island community members in jeopardy.

The contamination levels also exceeded the recommended 100 E. coli CFU/100mL limit for livestock drinking water putting the cattle grazing on the commons and drinking from Watermill Creek at risk.

The only sampling location not showing faecal coliform contamination was the water bore at Site 3. This is the only true groundwater sample that was analysed in the catchment. These survey results show that this particular aquifer was not adversely affected by human or cattle faeces up stream and because the samples were collected before significant rainfall events had occurred they represent background levels for dry weather. Results are not available for coliform contamination from stormwater runoff.

The results are generally consistent across the catchment with the exception of Site 4. Although the levels of microbial activity are significant in all other sites the E.coli to coliform ratio found in Site 4 indicates a consistent source of contamination entering the stream presumably from raw effluent. Sources of raw effluent potentially include; poorly maintained septic systems and uncontained cattle grazing in the upper catchment and a cattle yard that is located adjacent to Site 4.

Although further investigation is required to determine an exact source it is assumed that the contamination in the Officer's Bath (Site 4) is caused by failing soakage trenches located too close to the ground water table within the catchment and the high density housing in the upper catchment of which are serviced by individual septic systems.

The samples collected on the 27th of August followed a significant rainfall event when the water ponding in the wetlands at Site 5 broke through the sand barrier and entered into Emily Bay. The extremely high microbial levels in samples from both Site 5 and 6 (as the water entered Emily Bay) pose a significant risk to public health.

Results from a routine water quality sampling program conducted by the Administration of Norfolk Island Health and Quarantine Officer between 2010 – 2012 are presented here for comparison with the 2017 results (Appendix 2), to look at longer term trends in coliform contamination of the KAVHA water catchment. It should be noted that the sample collection and analysis methods for this routine monitoring program are not clearly stated, the expertise of the sample collector has not been assessed and the results have not been subject to any QA/QC, as evidenced by the reports of E.coli levels in excess of Total coliform counts, which is an impossible result since Total coliforms include E.coli as a subset of the total coliform count. Nonetheless the results provide some indication of approximate E. coli/Total coliform concentrations in water samples at the time.

At Site 5, immediately prior to discharge into Emily Bay, E. coli/Total coliform levels were reported at 4 – 2000 E coli/100ml under dry conditions and up to 15,000 total coliforms following heavy rain compared to a peak of 14,000 total coliforms (dry) and 90,000 total coliforms (heavy rain) in 2017. These results suggest the faecal contamination of the Town Creek has increased over the 7 year time frame and extraordinarily high levels of E coli/total coliforms are entering Emily Bay from the system, both through percolation through the sand when in the absence of rain, or as direct flow during heavy rain. It is important to note that the coliforms can only be killed by chlorination or heat (boiling) and are therefore not filtered out of the water as it percolates into the intertidal zone in Emily Bay.

Additional evidence of the decline in water quality in the KAVHA Catchment, since 2010, is shown in the results of a study commissioned by the Norfolk Island Administration in 2010 and carried out by the author (Mr P. Wilson) who had received University training in the water quality sample collection and analysis. Microbial analysis was undertaken using IDEXX's patented Defined Substrate Technology and the results were determined using IDEXX Laboratories Inc methodologies. The results, shown in Table 5.1, are indicative of dry weather conditions and show that both the nutrient load and microbial levels have increased relative to the 2017 study also suggesting that the contamination in the catchment has increased over the past 7 years.

Table 5.1: Water Quality Data 2010 (Wilson, 2010)

	Watermill Dam (Site 1 this study)	Community Bore (Site 2 this study)	Emily Bay Out (Site 6 this study)
Nitrate	0.078 mg/l N	0.264 mg/l N	0.055 mg/l N
Ammonia	0.1 mg/l N	0.98 mg/l N	0.09 mg/l N
Ammonium	N/A	0.76 mg/l P	N/A
Phosphate	0.3 mg/l P	0.18 mg/l P	0.4 mg/l P
Total Coliforms	1413.6 cf/100mL	1011.2 cf/100mL	1011.2 cf/100mL
E.Coli	960.6 cf/100mL	63.8 cf/100mL	691 cf/100mL
Enterococci	343.6 cf/100mL	N/A	N/A

While the extremely poor water quality in the KAVHA Site and its tributaries is of great concern it is the potential for significant human health impacts to people swimming in Emily Bay that is more alarming. Town Creek water trapped in the creek behind Emily Bay together with the water seeping into the bay through the sand contains unacceptably high concentrations of coliforms and other pathogens that can cause gastroenteritis, ear, nose and throat infections in humans.

While water samples are typically sampled for E. coli and total coliforms to assess water quality, these are not the only pathogens that are present in the water. A detailed analysis of water contaminated by human and stock faeces is also expected to contain a range of viruses, including adenovirus, norovirus, Hepatitis A, cryptosporidium etc. which persist in marine water much longer than bacteria. The quiet and sheltered waters of Emily Bay are favoured by young children and elderly residents and tourists. Children are often seen playing in and near the Town Creek discharge point in Emily Bay, exposing them unknowingly to a high risk of illness. This risk increases significantly following major rainfall events when the bay is flooded with contaminated water, increasing pathogen and virus levels throughout the bay for extended periods of time (days) until the natural tidal cycles flush the contaminants from the lagoon.

Council and the Commonwealth Government have a duty of care to protect the health of all users of Emily Bay and until a water management strategy is developed, a routine and scientifically sound water monitoring program must be implemented, along with an education program to make the users of Emily Bay aware of the risks they take when using the bay so they can make informed decisions about their recreational activity.

5.3. Risk to Emily Bay ecosystem and tourism sector

The Emily and Slaughter Bay Lagoon is the corner stone for Norfolk Island's tourism market, being voted in the top ten Australian beaches on Trip Advisor in 2017. Protection and preservation of this ecosystem is vital for the island's economy. The impacts from the discharge of large volumes of nutrient rich, turbid stormwater into the lagoon are becoming increasingly evident.

Anecdotal evidence from long term Norfolk Island residents suggests that there has been significant degradation of the coral reef from the Town Creek outlet and around the shoreline adjacent to the

Salt House. Large areas of sea grass and algae growth are developing on the coral reef and the sea floor. At the same time coral is dying along a transect extending from the creek outlet to Lone Pine (Pendoley, 2015). Recent video footage provided by Mrs Corrine Parsons's shows that the marine ecosystem between the creek discharge point and Middle Beach has been compromised.

Figures 3 and 4 show the coral reef off Salt House point in April 2016. Rich and luxuriant algal growth on and around the dead coral is evident. The introduction of high levels of phosphorous and nitrogen is known to cause bleaching and death in coral and to enhance algal growth (AIMS 2017, Vega Thurber *et al* 2014, D'Angelo and Wiedenmann, 2014).

Figure 5.1: Dense algal growth adjacent the Salt House (source Mrs Corrine Parsons, 2016)

Figure 5.2: Image shows limited coral amongst dense and luxuriant algal and seagrass growth (source Mrs Corrine Parsons, 2016)

The loss of total coral cover and diversity is demonstrated in Figures 5.1 -5.6. Images made in Emily Bay in 1992 show the reef was characterised by a diverse range of vibrant coral and marine species with limited algae growth (Figure 5 and 7). Images from the bay taken in 2016 show a considerable decease in coral cover and diversity and a substantial increase in algal growth relative to 1992.

While no quantitative baseline data is available on the fish and invertebrate fauna of the bay, the absence of small fish that were once abundant, and the absence of a rich invertebrate fauna assemblage that is typical of a pristine coral reef environment is obvious to long term users of the bay.

Figure 5.3: Emily Bay Plate Coral 1992 showing high coral cover and rich diversity in coral species and small fish (Source Mr Jack Marges)

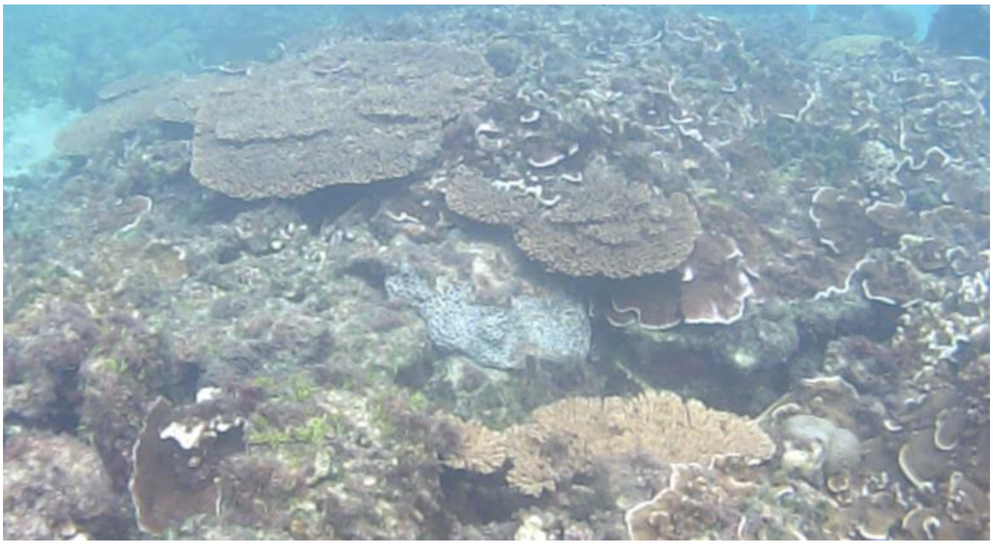

Figure 5.4: Emily Bay plate coral 2016, showing a decline in coral diversity and cover and a complete absence of small fish (source Mrs Corrine Parsons)

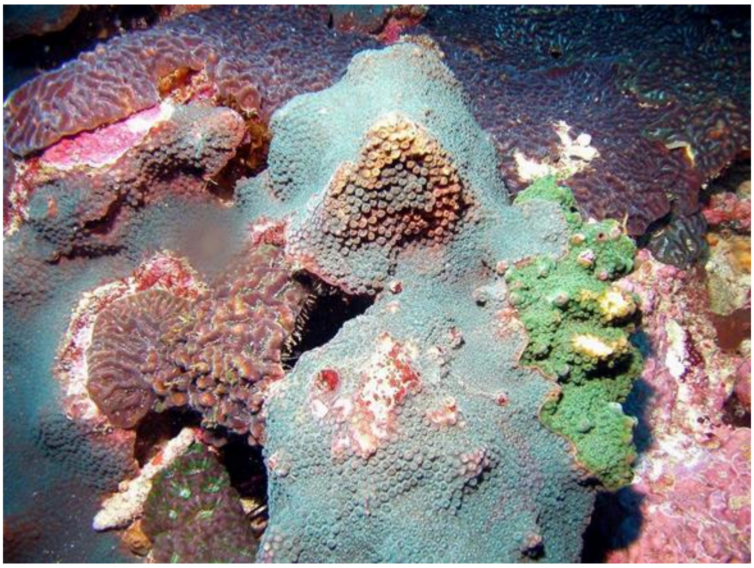

Figure 5.5: Image showing the 100% coral cover with no algal growth (Source Mr Jack Marges, 1992)

Figure 5.6: Image from 2016 showing dead coral being overgrown by algae (Source Corrine Parsons 2016)

The ongoing degradation of the Emily Bay lagoon ecosystem is clearly obvious and based on the rate of coral loss and algal growth in Emily and Slaughter Bay, the entire ecosystem could be lost within 5 – 10 years (Pendoley Environmental, 2015). If 100% of the coral is lost, recovery of the ecosystem will be delayed by the lack of immigration of coral spawn from external reef systems (e.g. Lord Howe) due to the isolated nature of Norfolk Island. However if the discharge of fresh water and nutrients into the bay is stopped soon, the system is expected to show signs of recovery within 1 year (Vega Thurber *et al* 2014).

6. Conclusions and Recommendations

The conclusions from this study are summarized below;

- the water quality in the KAVHA area is highly contaminated by nutrient and coliforms, likely from human and stock sewage,
- the drainage of contaminated water from Town Creek into Emily Bay poses a serious and persistent health risk to recreational users of the Emily Bay lagoon area,
- the drainage of large volumes of turbid, nutrient rich water into the Emily Bay lagoon is
    - killing the dense, rich and diverse coral assemblages in the lagoon, and
    - promoting the growth of algae and seagrass on and around the coral and on the lagoon floor
- a routine and scientifically sound water quality monitoring program should be implemented to assess long term trends in water quality throughout the KAVHA and Emily Bay area
- recreational users of Emily Bay need to be alerted to any dangerously high pathogen levels and the beach closed until the water quality returns to acceptable levels
- A water management plan is urgently needed to protect;
    - human and stock from exposure to contaminated water and
    - the high conservation values of the Emily Bay lagoon, and the EPBC Act listed species and protected ecosystems contained within the bay.

6.1 Recommendations for short term water management

While we recognise that sewage contamination and water quality needs to be managed island-wide, and the difficulties of removing the sources of contamination that is entering the KAVHA system, we believe steps can be taken in the short term to protect human health and the high ecological values of Emily Bay. Options to be considered are listed below.

6.1.1 Divert the Water

The Town Creek water (and particularly stormwater) discharging into Emily Bay needs to be prevented from reaching the bay. This can be achieved by diverting Town Creek (and associated stormwater) to the golf course following the alignment of the original channel as described in 1793 by Hunter.

Settling ponds on the golf course could provide a number of water features to enhance the golfing experience and provide water for irrigation in KAVHA which would reduce the need to draw water from groundwater supplies. The settling ponds would in turn allow the stormwater to seep into the aquifer to recharge the groundwater supply.

Excess water could be pumped to an outfall off Cemetery Bay, into an open high energy location where water is rapidly diluted and dispersed by the open ocean.

An emergency overflow into Emily Bay may be maintained, initially, to ensure that sufficient volume has been allocated for the collection of stormwater. However, every attempt to should be made to ensure that the stormwater is of sufficient quality and that the volume that is released has been significantly reduced.

The volumes of freshwater that is currently released is a waste of a natural resource. This option not only provides a means of protecting Emily Bay from further degradation it will also provide the opportunity for harvesting this water and replenishing the groundwater supply.

6.1.2 Improve the Wetland System

Expanding on and improving the wetland system across the catchment will reduce the nutrient load and contain the pathogenic content. A leaky weir system could be constructed at the Watermill Dam, slowing the water flow and allowing the water to seep into the ground and recharge the underground aquifers.

Development of the wetland will require the free roaming cattle be excluded from the water body with fencing, or cattle collars, with a minimum 5m buffer zone either side of the water body. This buffer zone will prevent erosion in the creek, reduce the nutrient and faecal contamination of the water by cattle and protect the wetland plants. Water troughs should also be installed a significant distance from the waterways to reduce volume of stock adjacent to the cattle free zone.

An effective wetland system will minimise the direct flows into Emily Bay while providing opportunities for biological and physical removal of nutrients and pathogens by conserving and managing the freshwater to maximise water quality and wetland habitat.

A wetland maintenance strategy should be developed with the aim of:

- maintaining freshwater marsh habitats
- maximising water quality and;
- protecting heritage structures

Drainage channel work, such as dredging by excavator, should not be carried out annually, routinely, or as a matter of course. Periodic harvesting and removal of sediment deposited in the wetland should only be undertaken in a planned and progressive sequence and with the assurance that such activities will not adversely affect the appropriate wetland flora and wetland birds. Such work may be needed urgently to protect heritage structures however the integrity of the system must be taken into account.

6.1.3 Manage Effluent

An audit of wastewater systems in the KAVHA Catchment should be conducted and any unsanitary facilities closed and upgraded. This audit should extend to the area of Little Cutter's Corn given the high density of houses that could potentially impact Town Creek.

The Commonwealth Government, in consultation with Council, need to development a wastewater management plan within the KAVHA Site to ensure that effluent from the buildings is not presenting an immediate risk to the receiving water bodies and the environment.

Council need to develop a plan to incorporate residential properties currently serviced by septic systems in unsuitable locations onto the Water Assurance Scheme. The focus would be on housing developments on small building blocks with septic systems that are not appropriate for the location. Underperforming septic tanks are likely to be a major source of contamination in the lower catchment. This can be achieved by installing pumps in the existing septic tanks that feed into the mainline that discharges into the sewer at the Norfolk Island Central School.

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Appendix 1: Pendoley Environmental Pty Ltd letter, 2015

PENDOLEY
ENVIRONMENTAL

MARINE CONSERVATION
ENVIRONMENTAL SERVICES

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5 October 2015

The Hon Gary Hardgrave
Administrator Norfolk Island
Commonwealth of Australia

RE: WATER QUALITY IN EMILY BAY

Dear Sir

Following my recent visit to Norfolk Island, Dr Martin Goldsmith and I would like to bring to your attention our concerns regarding the quantity and quality of water entering Emily Bay. Primary risks are;

- Death of coral and increased algal growth, short term loss of all corals and associated habitats it the bay (5-10 years)
- Population level impact on the EPBC listed Booths pipefish and green turtles and their habitats
- The health and safety of people swimming in Emily Bay
- Management of the groundwater in the KAHVA catchment

Additional detail is provided below;

1. Large fresh water flows together with elevated nutrient levels have killed the coral in Emily Bay along a transect extending from the outfall, across the bay to Lone Pine and to the reef outlet channel. Personal observations over the past 50 years, together with anecdotal feedback from numerous island residents, indicate that the die-off of coral, increased algal growth, both on the floor of the bay and covering the dead coral habitat, plus the decrease in the number and diversity of small fish, has accelerated the past 5 years. We have serious concerns that this accelerated rate of decline will wipe out the entire Emily and Slaughter Bay lagoon within 5 – 10 years. Recovery of the ecosystem will be delayed by the lack of immigration of coral spawn from external reef systems (e.g. Lord Howe) due to the isolated nature of Norfolk Island.

2. The Emily and Slaughter Bay lagoon supports the EPBC listed *Halicampus boothae* (Booths pipefish) and *Chelonia mydas* (green turtle). These species are at risk of disease, reduced health and habitat loss due to the

water entering the bay and under the EPBC Act the responsible Governing Authority is obliged to protect these species and the ecosystems that support them.

3. While the existing sand plug in the creek has temporarily stopped water flowing from the creek into the bay, water continues to percolate through the sand and enter they bay in the intertidal zone near the mouth of the creek mouth in Emily Bay. The filtration action of the sand will remove solids but it will not remove the dissolved nutrients and pathogens which can cause a range of illnesses in people swimming in the bay. The pathogens found in sewage contaminated water waste can cause very serious illness and death include viruses (gastroenteritis, Hepatitis A, cystitis, skin rashes etc.) bacteria (e. coli., salmonella, diarrhoea, Staphylococcus aureus, (golden staph), Pseudomonas aeruginosa. (ear, nose and throat infections) Legionella (as in legionella disease) Streptococcus pneumoniae, cholera etc.), fungus (Candida albicans). Dr Pendoley's 83 year old father swims in Emily Bay daily and he, together with other local resident we have discussed this with, have experienced persistent ear infections, indicative of bacterial infection.

4. The pathogens' in the Emily Bay outfall were measured by Dr Goldsmith between 2014 and 2015 are beyond the safe limits for human activity such as swimming, based on DoE Water Quality Guidelines. This is especially true after heavy rain washes human and animal waste from the catchment into the Kingston area. Commonwealth NHMRC Water quality standards for primary contact (e.g. swimming) require the water to contain little or no e.coli (<40 e. coli pre 100ml) however sampling carried out in in June 2015 reported E. Coli levels in excess of 670 per 100 ml and Coliform counts in excess of 1860 per 100ml. The water entering Emily Bay is contaminated and a risk to human health. I am attaching the Commonwealth NHMRC Guidelines for Water Quality for your information.

   We have serious concerns over the welfare of residents and tourists using Emily Bay, particularly the age groups most vulnerable, i.e. the elderly and the very young. There is a Duty of Care on the regulatory bodies governing Norfolk Island to protect the public health, and given the lack of medical facilities on the island at the moment this could have serious implications for the survival of an at risk infected patient.

We recommend the following actions be considered as a matter of urgency

Short Term recommendations

1. Stop the flow/seepage of water into Emily Bay immediately.
2. Sample the water quality in Emily Bay daily and close the beach when standards for primary contact are exceeded (links to guidelines are attached).
3. Install signage to make people aware of the risk of swimming in Emily Bay due to potential water contamination so they can make an informed decision as to their usage of the bay.

Long Term recommendations

1. Investigate other options for directing water containment and flow, i.e. to pond in situ on the Commons behind Slaughter Bay and/or allow the water to flow and pond in the public open space that is currently occupied by the Golf Course.
2. Pipe the water offshore from Cemetery Beach where the high energy will ensure rapid dilution and mixing.
3. Clean up the water quality in the catchment.

Thank you for your attention and if there is anything we can do to assist with resolving this problem please do not hesitate to contact Dr Goldsmith or myself.

Yours Faithfully

Kellie Pendoley BSc MSc PhD MRACI

Martin Goldsmith BSc (Hons) PhD

Attachment 1

Reference Standards

Commonwealth Drinking Water quality Guidelines, 2011
https://www.nhmrc.gov.au/guidelines-publications/eh52

Commonwealth Govt, NHMRC 2008 Water quality guidelines
https://www.nhmrc.gov.au/guidelines-publications/eh38

Commonwealth Govt Geosciences Australia.
http://www.ozcoasts.gov.au/indicators/marine_pathogens.jsp

Appendix 2: Water Quality Data from the Administration of Norfolk Island

Date	Time	Comments	Rain (mm)	Outlet		EB Out		EB Chinamans		Pier St		Officers Bath		Gov.Hs Ck		Gov. Lodge		Golf Bore		WMV Dam		Pipe (Comm. Water)	
				Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms	Ecoli	Total Coliforms
22/01/2013	2:30pm					0		0								0	0	1	2			40	
3/01/2013	12:30pm			590		10		0		770						88		88	110			690	
31/12/2012	9:45am	Heavy Rain	40+	6600		3060		180				2200										2000	
19/11/2012	8:00am	Rain	9			90		0		6600		3800				4	42	2	37			300	
19/11/2012	3:00pm	Heavy Rain	check on BoM	9900		230				9900		11000											
				7700																			
22/10/2012	11:30am			240		30		0		250		420				7	10			10		0	
4/09/2012	10:00am			320		10		0		180		390				11	3					190	
22/08/2012	12:30pm															1	3						
18/07/2012	11:30am															0	3						
3/07/2012	1:00pm			160		10		0		210		420						40				260	
3/05/2012	12:00pm	II stage ck dredge		650		220		0		480		500										880	
26/04/2012	?	I stage ck dredge		120		0		0		170		510				0							
18/04/2012	?			860		30		0		780		910										90	
14/03/2012	1:00pm															1						89	
20/02/2012	11:30am			4		0		0		690		400										0	
8/02/2012				70		10		0		770		90										30	
24/01/2012	1:30pm			90		0		0		420		410						23				9	
11/01/2012	2:00pm			140		0		0				30 or 1130						8				20	
15/12/2011				240		10		10		960		440										430	
5/12/2011																0	4						
28/11/2011	2:00pm			230	52					270	100	130	40					0	6			0	17
22/11/2011	12:00pm															1	1						
8/11/2011	12:00pm			110	56	0	2	0	2	170	43	60	44			12	1			60	7	7	29
19/09/2011				160	330	0	4	0	2			120	51										
6/09/2011				650	93	40	10	10	0			440	115			16	4	11	26				
25/08/2011	12:30pm	Heavy Rain >24hrs		13200	15000					13200	11000	6600	7000										
18/08/2011																4	5	17	12				
29/07/2011	1:30pm	Heavy rain, high flow		3600	600					7000	840	6000	600					30	31				
8/07/2011	1:30pm			350	66					550	130	560	40									35	30
7/06/2011	1:00pm	Heavy rain immed. Prior		800	140					210	228	500	182									60	20
13/05/2011	1:30pm			880	210					1100	180	880	170	600	300								
										1320 Pond	770												
28/04/2011	12:00pm			334	180					528 Ck	196	660	88	100	660			24	19			98	83
24/03/2011	1:00pm			520	270					520	550	180	360	252	650							90	100
										Pool 22000	Pool 1000												
3/03/2011	1:30pm			>400	>500	80	30									3	1		100	8	30	3	13
13/01/2011				424	150							358	140					1	1	186	80	96	40
5/01/2011	2:30pm			720	480					916	284	400	180							256	80	24	32
21/12/2010	1:00pm			936	480					1200	360	440	130			0	0	9	7			54	43
8/12/2010	12:30pm			912	320					3600	256											68	35
11/11/2010																4	0						
14/10/2010	12:30pm			440	55					236	81	72	97	6	186	2	1					46	31
28/09/2010	12:00pm																						
25/08/2010	1:00pm			776	274					520	126	360	188					0	3	500	40	3	4
13/08/2010	12:00pm			>2000	300							600	300	2200	360								

Appendix 3: Norfolk Island Health and Residential Aged Care Facility Pathology Unit water quality results

The following tables show the results that were carried out by the NIHRACs Pathology Unit for the purpose of QC/QA

Duplicate Samples sent to NIHRACs Pathology Unit 13/06/2017

Location	E. coli (CFU/100Ml)	Coliforms (CFU/100Ml)
Community Bore	500	12000
Kingston Bore	<1	<1
Officer's Bath	16 800	30 000
Emily Bay Outlet	5 100	11 600

Duplicate Sample sent to NIHRACs Pathology Unit 12/7/2017

Location	E. coli (CFU/100Ml)	Coliforms (CFU/100Ml)
Officer's Bath	19 200	21 600