Owhiro Stream and its catchment

Summary of existing water quality and freshwater ecology information,

Recommendations for future monitoring

1 Background

1.1 Scope of this report

This work was commissioned by Greater Wellington Regional Council. The aim was to collate existing water quality and freshwater ecology information on the Owhiro Stream and its catchment, create a searchable catalogue of reports and data sources and produce a high-level summary of the water quality and freshwater ecology information available for the Owhiro Stream and its catchment, and recommendations for future monitoring and investigations (this report).

1.2 The Owhiro Stream and its catchment

The Owhiro Stream takes its source within the Wellington suburb of Brooklyn, and flows in a southerly direction along Ohiro Road and Happy Valley Road to its mouth in Owhiro Bay, on Wellington's South Coast. Owhiro Bay forms part of the Taputeranga Marine Reserve.

The Owhiro Stream catchment covers approximately 953 hectares, bounded by Hawkins Hill to the West, Polhill Reserve and Todman Street to the North, and The Ridgeway, Frobisher and Severn Streets to the East.

The Owhiro Stream has two main tributaries, draining Kowhai Park Gully (where the T&T landfill is located) and Carey's Gully (where the Southern Landfill and the C&D landfill are located).

The Owhiro Stream has an estimated dry weather flow rate of approximately 0.1 cubic metres per second (m^3/s) or 100 litres per second (L/s). Flood flows are much higher, in the order of 20 to 32 m^3/s[1].

The majority of landcover in the catchment (85%) is in gorse scrubland, with 7% urban, 4% pastoral and 4% bareground/landfills[1].

A map of the Owhiro Stream catchment is shown in Figure 1 below.

[1] Wellington Water (2017)

1.3 Human induced pressures on the Owhiro Stream catchment

The northern and eastern parts of the catchment are dominated by urban (mostly residential but with some commercial) properties. Stormwater generated from these areas is discharged into the stream, with stormwater treatment currently absent or limited to grit traps. Typically, water quality of urban streams is under pressure from stormwater borne contaminants such as metals and hydrocarbons from buildings and vehicles, sediment from earthworks, and a variety of smaller, miscellaneous discharges to the stormwater network from individual properties (such as car washing on driveways). Urban streams can also contain discarded or wind-driven rubbish and plastics. Cross-contamination between the sewerage and stormwater reticulation networks can lead to faecal contamination of stormwater, and thus to urban streams. The natural flow regime of urban streams is also affected by impervious surfaces such as roads and roofs, which cause rainwater to runoff more quickly, and limit water infiltration through soil into groundwater. Typically, an urban stream responds more quickly to rainfall, with larger peak flows, and has reduced base flows during dry periods.

Three active landfill operations are present in the Owhiro Stream catchment. The Southern landfill is operated by Wellington City Council. It accepts general and green waste and includes a recycling centre. The T&T landfill and the C&D landfill are privately owned and operated and it is our understanding that both operate as “cleanfill” operations. The Southern Landfill and T&T landfill occupy a significant area of individual gullies/valley floors and have resulted in the loss of stream habitat and barriers to fish migration. The T&T landfill operations have historically and recently resulted in significant degradation in water quality and effects on aquatic life, at times along the whole downstream course of the Owhiro Stream[2]. Mitigation works are currently underway to divert stormwater around the landfill to reduce the site’s effects on water quality.

Only a small area of the catchment is currently farmed, with farming activities limited to low intensity sheep farming and forestry. The predominance of gorse on the majority of the catchment is of interest to water quality. Gorse has been shown to be a measurable source of nitrate-nitrogen in otherwise undeveloped catchments, and may constitute a diffuse source of nitrogen to the Owhiro Stream.

Stormwater discharges and landfills require resource consents, which typically require some form of water quality and/ or ecological monitoring. Consent monitoring data form a significant proportion of the water quality and ecological data available for the Owhiro Stream, as detailed in the following sections.

[2] Aquanet (2017)

Figure 1: Map of the Owhiro Stream catchment.

1.4 Values

The Owhiro Stream is the only urban stream flowing to the Wellington South coast that retains an open channel for most of its course, albeit with some modifications of its original course and culverting of a number of its tributaries. The other south coast streams (e.g. Island Bay, Houghton Bay) are fully or near-fully culverted or piped.

Community interest and involvement in the Owhiro Stream is strong. The Owhiro Stream is too small for swimming or kayaking, however it is widely used for a range of activities involving direct contact with water. For example, the Owhiro Bay Primary School has a number of curricular and extra-curricular activities involving the Owhiro Stream and its margins. Community groups, such as Friends of the Owhiro Stream undertake regular stream care days. The Owhiro Bay community gardens use stream water for irrigation of fruit and vegetable.

Being a coastal stream, with year-round sustained flow, the Owhiro Stream is expected to naturally have diverse and abundant fish communities. Large longfin eels are a known feature of the stream.

The Owhiro Stream flows into the Owhiro Bay, itself part of the Taputeranga Marine Reserve. Owhiro Bay is used for swimming and various water activities (paddle boarding, kayaking) and has a two-lane concrete boat ramp forming the main trailer boat launching point on the Wellington South Coast.

2 Stream Monitoring – what do we monitor and why?

Monitoring of water quality and freshwater ecology includes a mix of visual observations, field measurements of variables such as water temperature, and the taking of samples for analysis in a laboratory, for example to know what nutrients or metals they contain. Each variable tells us a different thing on the state of water quality and living communities, or on the risks of detrimental effects (such as toxicity effects) on aquatic life. This section provides a simple guide to the various indicators typically measured in an urban stream.

The various water quality and ecological indicators were compared with environmental guidelines and trigger values to provide an indication of the state of water quality. The various guidelines we have used are detailed in Appendix A.

2.1 Ecological variables

2.1.1 Habitat

Habitat characteristics such as vegetation along the stream banks (riparian cover), the nature and size of the material forming the stream bed (substrate), such as cobbles, sand and silt, stream width, depth, and current velocity of each site are often measured at the time of sample collection. They are all important variables to understand the ecology and water quality of a stream. For example, riparian vegetation stabilises banks, keeps water cool via shading, but also provides cover and food for fish and insects.

2.1.2 Stream flow

Stream flow is a critical component of stream ecology. Low flows in summer can act as a bottleneck for fish populations.

Understanding stream flow is critical to interpreting water quality data. For example, poor water clarity is expected naturally during a flood, but poor water clarity during stable or low stream flows can indicate a possible discharge or disturbance in the catchment.

2.1.3 Aquatic macroinvertebrates

Benthic macroinvertebrates refer to a wide range of aquatic insects, worms and snails living on the bottom of streams. They are known to respond differently to ambient water quality or habitat conditions, and the mix of species found at a site is a widely used indicator of overall "stream health" at a site.

Snails (Gastropoda) and worms (Chironomidae) are generally considered to be tolerant of poor quality water, whilst others such as mayflies (Ephemeroptera) or stoneflies (Plecoptera) prefer good water quality. Mayflies and stoneflies and other pollution-sensitive bugs tend to disappear or be less abundant in response to pollution, whilst worms and snails tend to more abundant and dominate the makeup of the community.

Biological indices are calculated to provide simple indicators of water quality and stream health.

The Macroinvertebrate Community Index (**MCI**) is calculated on the basis to a score assigned to each macroinvertebrate species present in the samples, dependent on their tolerance to pollution. MCI is a good indicator of overall health of the macroinvertebrate community. A score of 80 is considered poor, whilst a score of 120 or more is excellent. The recent National Policy Statement for Freshwater Management (NPSFM) 2017 sets a new requirement for every regional council to establish methods to improve on an MCI score if it is below 80.

The Quantitative Macroinvertebrate Community Index (**QMCI**) is similar to the MCI, but also takes into account the number of individuals of each species collected. Changes in QMCI are often used to assess the effects of a discharge on stream health.

Guidelines and interpretation of MCI and QMCI scores are provided in Appendix A.

2.1.4 Periphyton

Periphyton is the brown or green slime coating stones, wood or any other stable surfaces in streams and rivers. In some situations, it can proliferate to form thick masses of green or brown filaments on the river bed degrading the aesthetic and recreational qualities of the river. Periphyton growth is generally controlled by a number of physical (e.g. river flow, sunlight, temperature) chemical (e.g. bioavailable nutrients, such as phosphorus and nitrogen) and biological (e.g. grazing by stream insects) phenomena.

The Ministry for the Environment guidelines for periphyton biomass (chlorophyll *a*) and cover (diatoms, cyanobacteria and filamentous algae) in streams are presented in Appendix A.

2.1.5 Fish

New Zealand has a unique, although sparse, freshwater fish fauna, with 35 native species, 31 of which are only found in New Zealand. Most of the native species belong to just four families of fish, and include twenty galaxiids, seven bullies, two eels, and two smelts. In addition, fifteen species of introduced fish are known to have established breeding populations in more than one location.

A high proportion of the native fish are diadromous (i.e. they have a marine phase in their lifecycle). Some grow to adulthood in freshwater then migrate downriver to breed in the sea (e.g., eels, freshwater flounder), but most breed in freshwater with their juveniles travelling downriver to develop at sea (e.g., galaxiids, smelt and bullies). Only the lamprey breeds and develops in freshwater streams and spends its entire adult life at sea.

Because these diadromous species all need to migrate upriver from the sea at some stage, they are vulnerable to barriers created by falls, chutes, dams, weirs, and culverts. They also vary widely in their ability to move upriver. Some species (eels and certain galaxiids) can climb vertical wet rock faces and they penetrate far upriver to high altitudes. Others cannot climb and are restricted to lowland, coastal streams. As a consequence, the geographical distributions of the species vary widely within rivers and are greatly affected by both altitude and distance from the sea[3].

Lowland coastal streams such as the Owhiro Stream are expected to naturally have very diverse fish communities.

Fish populations are monitored using a range of techniques, including electric fishing, trapping and spotlighting at night. Monitoring data is often restricted to records of presence of fish species, although more intensive monitoring methods provide an indication of abundance and population structure.

NIWA maintain a national database of freshwater fish records in New Zealand, to which a range of public and private organisations contribute fish data[4].

2.2 Water Quality

2.2.1 Visual appearance of water

Water clarity is measured as the proportion of light transmitted through water. It has two important aspects: (1) visual clarity (sighting range for humans and aquatic animals), and (2) light penetration for growth of aquatic plants.

Water clarity is of considerable importance for the protection of the recreational and aesthetic values of a stream, because it directly affects the aesthetic quality of the water.

Changes (generally reductions) of water clarity can also affect the foraging ability of fish, such as trout, by reducing their ability to see food drifting in the water column. Scientific studies have

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[3] Paragraphs adapted from NIWA: https://www.niwa.co.nz/freshwater-and-estuaries/nz-freshwater-fish-database/niwa-atlas-of-nz-freshwater-fishes/an-overview-of-new-zealands-freshwater-fish (accessed July 2017)

[4] https://www.niwa.co.nz/our-services/online-services/freshwater-fish-database

concluded that native fish are also sensitive to poor water clarity / high suspended sediment, the most sensitive being the banded kokopu (*Galaxias fasciatus*). Maximum turbidity thresholds of 15 to 20 NTU are required to be met most of the time to avoid effects on native fish feeding and migratory behaviour.

Visual clarity is measured using a black disc. The measurement consists of measuring the horizontal distance that a black disc of standard size can be seen under water. Suspended sediment concentration provides a measure of the amount of sediment suspended in the water column. Turbidity is an indirect measure of water clarity and suspended sediment.

2.2.2 Iron / manganese deposits

Anoxic (low or no oxygen) conditions can lead to the dissolution of metals such as manganese and iron, which can then form an orange-coloured floc when oxic (oxygenated) conditions are reinstated. The floc can deposit on the stream bed, colouring and smothering the bed substrate, with potential consequential effects on both visual/aesthetic and ecological values of the stream. Although not a common issue in streams, the presence of large quantities of iron/manganese deposits has been documented in the Owhiro Stream[5]

A guideline of 1 mg/l for the sum of iron + manganese concentrations to prevent bed smothering by iron/manganese floc is used in this report, based on the recommendations of a 2012 report by NIWA.

2.2.3 Recreational use and swimmability: microbiological water quality

Microbiological water quality indicators, such *as Escherichia coli* (*E. coli*) in freshwater and *enterococci* in coastal waters, are used to provide an indication of the level of health risk to recreational users of the water.

The most recent National Policy Statement for Freshwater Management (NPSFM, 2017 changes) defines five "bands" in relation to the suitability of freshwaters for activities such as swimming (primary contact). The top two bands (A/blue and B/green) are considered suitable for primary contact; whilst the other three bands (C/yellow, D/orange and E/red) correspond to increasingly high risk of infection to recreational users of water (Appendix A).

Similarly, the 2003 microbiological water quality guidelines (MfE/MoH, 2003) define a three-mode risk management system for recreational coastal waters: Acceptable/Green (*enterococci* < 140 /100 ml); Alert/Amber (*enterococci* 140 /100 ml to 280 /100 ml) and Action/Red (*enterococci* > 280 /100 ml).

2.2.4 Nutrients

Nitrogen (N) and phosphorus (P) are key 'growth limiting' nutrients that influence the growth rate and biomass of algae (or periphyton) and aquatic plants. Low availability of these two nutrients often limits plant biomass development.

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[5] NIWA (2012), Aquanet (2017)

Eutrophication is the term used to describe the enrichment of water bodies by inorganic plant nutrients such as nitrate or phosphate. Eutrophication may occur naturally, but is often increased as a result of human activity, such as direct discharges, farming and urban development.

Where stream bed is dominated by hard substrate (gravel, cobbles), too much nutrients can result in excessive periphyton growth, with consequential effects on ecological, aesthetic and recreational values. In the coastal environment, excessive nutrients can result in accumulation of macroalgae (e.g. *Ulva spp*., or sea lettuce) and/or phytoplankton blooms.

2.2.5 Toxicants

Ammonia: In sufficient concentrations, ammonia can cause both chronic (as a result of long-term exposure) and acute (short term exposure) toxic effects on aquatic life. The toxicity of ammonia increases with water pH and temperature. In streams and rivers, ammoniacal-nitrogen is rapidly removed from the water column through a number of chemical (e.g. oxidation, volatilisation) and biological (e.g. absorption) processes, and it is generally expected to be in low concentrations in most streams and rivers, unless there is a point-source discharge (e.g. wastewater, landfills) nearby.

Nitrate: In elevated concentrations, nitrate can be toxic to aquatic life, its effects being primarily associated with slowing the growth rates of sensitive fish species.

Metals: Various metals (zinc, copper, lead, cadmium, etc.) or metalloids (arsenic) can also cause both chronic and acute toxic effects on aquatic life. Most metals and metalloids are generally present in low concentrations in water or sediment as a result of natural sources, but their presence can be increased by sources associated with human activity. For example. zinc and copper are typically present in stormwater discharges. Other metals and metalloids can originate from a number of sources, including road runoff, landfill leachate.

Organic microcontaminants: A huge range of organic contaminants can be present in the stream environment. Some will be present in the water columns, but a majority of persistent organic contaminants (e.g. Polycyclic Aromatic Hydrocarbons (PAHs), Organichlorine pesticides, Polychlorobyphenyls (PCBs)) tend to have a stronger affinity to sediment and living tissue.

Environmental guidelines for ammonia, nitrate and metals are provided in Appendix A.

2.2.6 Physical and chemical variables

A number of physical and chemical characteristics of the water, such as water temperature, pH (acidity), hardness, dissolved oxygen, etc. are often measured.

They are important both in themselves (e.g. fish need dissolved oxygen to breathe) and to aid in the interpretation of other water quality variables. For example, ammonia toxicity varies significantly with water pH and temperature, so monitoring water temperature and pH is essential to being able to assess whether a given concentration of ammoniacal nitrogen is putting aquatic life at risk of toxic effects.

3 Data and information available

Data and information on water quality and ecology of the Owhiro Stream are available from multiple sources. Some of the data have been gathered under regular monitoring programmes, and other during as part of specific investigations.

Key regular monitoring programmes include:

- GWRC's State of the Environment water quality monitoring programme included a site on the lower Owhiro Stream where water quality was sampled monthly between 1988 and 2003, and samples analysed for a suite of water quality variables. This dataset provides a robust understanding of historical water quality in the catchment. This dataset was analysed in detail in a 2005 technical report published by GWRC (Milne and Perrie, 2006). We have mostly relied on the analysis and conclusions of this report;
- Wellington Water sampling programme, undertaken as part of the stormwater discharge consent held by Wellington City Council. Six sites are sampled approximately weekly, four along the Owhiro Stream, one on the Lower Carey's Gully Tributary and one in Owhiro Bay. Samples are analysed for faecal coliforms and *E.coli* (stream) or Enterococci (bay). We could not source a report where these data had been assessed in detail, and have analysed the data against the provisions of the NPSFM (2017) for freshwater results and the Ministry of Health Guidelines (2003) for coastal results;
- As part of their resource consent compliance monitoring, T&T landfill undertake quarterly water quality and annual macroinvertebrate sampling at 5 sites upstream and downstream of the landfill. Results are summarised in quarterly reports prepared by MWH/Stantec and provided to the Regional Council;
- Similarly, Wellington City Council undertake regular monitoring of Carey's Gully tributary upstream and downstream of the Southern Landfill. Monitoring includes monthly water quality monitoring and six-monthly macroinvertebrate monitoring, spanning the period from 2008 to 2016. Results are summarised in annual reports prepared by URS and AECOM;
- C&D landfill also undertake quarterly water quality at three sites on Burrell's Gully Stream, a tributary of the Carey's Gully Tributary. Results are summarised in quarterly reports prepared by Pattle Delamore Partners (pdp).

Water quality and/or ecology data have also been collected as part of a range of one-off, targeted or region-wide investigations, including:

- A region wide investigation of stormwater contaminants in sediments and water of urban streams in the Wellington region undertaken in 2005-2006 by GWRC (Milne and Watts, 2008). The lower Owhiro Stream was one of 42 sites sampled as part of this study;
- An ecological assessment of the Owhiro Stream was prepared in 2002 by MWH (Cameron, 2002). This report provides an overview of the state of water quality and ecology of the Owhiro Stream and its tributaries, with a particular focus on restoration potential and priorities;

- The resource consents held by T&T landfill require some "response" monitoring when water quality triggers are exceeded, including additional water quality and macroinvertebrate monitoring. Macroinvertebrates were sampled at sites upstream and downstream of T&T landfill in 2010 and 2016, the results being summarised in reports produced by MWH (Cameron, 2017);
- Water quality and ecological monitoring at various sites along the Owhiro Stream were undertaken in the period November 2016 to February 2017 by GWRC and Aquanet, in response to a pollution event from the T&T landfill. The results of this monitoring, along with an assessment of the long-term and event-related effects of the T&T landfill on water quality and ecology are summarised in a 2017 report prepared by Aquanet (2017).

Table 1 provides further details on the data available.

Table 1: Summary of water quality and ecological data available for the Owhiro catchment.

Site	Type	Parameters	Frequency	Period	Source/programme
Upper Owhiro Stream (Kingston/ upstream of T&T landfill)	Water quality	pH, Alkalinity, Conductivity, COD, Ammoniacal-N, Total Metals (Arsenic, Chromium, Lead, Zinc, Iron, Manganese, Copper), Calcium, TSS, Total Hardness	Quarterly	2008 - 2016	T&T /MWH (Quarterly reports)
	Microbiological water quality	E. coli	Weekly	2001 - 2016	Wellington Water data
	Biological indicators	Macroinvertebrates (MCI, QMCI)		2010 Dec. 2016	MWH Aquanet
		%Periphyton cover	One off	Dec. 2016	Aquanet
Kowhai Park Gully Tributaries (upstream and downstream of T&T landfill)	Water Quality	pH, Alkalinity, Conductivity, COD, Ammoniacal-N, Total Metals (Arsenic, Chromium, Lead, Zinc, Iron, Manganese, Copper), Calcium, TSS, Total Hardness	Quarterly + "response" sampling	2008 - 2016	T&T /MWH (Quarterly reports)
	Biological indicators	Macroinvertebrates (MCI, QMCI)	"response" sampling	2010 Dec. 2016	MWH Aquanet
Middle Owhiro Stream	Biological indicators	Macroinvertebrates (MCI, QMCI)	"response" sampling	Dec. 2016	Aquanet
Carey's Gully Tributary (upstream and downstream of Southern Landfill)	Water quality	pH, Ammoniacal-N, BOD_5, conductivity, faecal coliforms Iron, manganese	monthly	1994 - 2016	Wellington Water URS/AECOM Annual reports
	Water quality	chloride, nitrate-N, dissolved reactive phosphorus aluminium, arsenic, boron, cadmium, chromium, copper, lead, nickel, zinc	Six monthly		
	Biological indicators	Macroinvertebrates (MCI)	Six monthly		
Lower Carey's Gully Stream	Microbiological water quality	E. coli	Weekly	2001 - 2016	Wellington Water data
Burrell's Gully Tributary (upstream and downstream of C&D Landfill)	Water quality	Alkalinity, Ammoniacal-N, COD, hardness, Total and dissolved arsenic, boron, cadmium, chromium, copper, iron, lead, manganese, nickel, zinc,	quarterly	2016-2017	pdp Quarterly reports
	Water quality	Total and dissolved mercury, Total petroleum hydrocarbons, SVOCs, VOC	annually		
Owhiro Stream at Mouth	Sediment quality Water quality	Stormwater Contaminants (metals, PAHs, Organochlorine pesticides, PCBs)	One-off	June 2002 May 2005	WCC (Cameron 2002) GWRC (Milne and Watts, 2008)
	Water Quality	Water temperature, conductivity, Dissolved Oxygen, pH, black disc, Periphyton, faecal coliforms, turbidity, ammoniacal nitrogen, BOD_5	Monthly	1988 - 2003	GWRC (State of the Environment Monitoring data, 1988 to 2003)
		Nitrate nitrogen, Dissolved reactive phosphorus	Monthly	1990 to 2003	
		Total organic Carbon, Total Nitrogen Total phosphorus	Monthly	2001 - 2003	
	Ecological indicators	Macro invertebrates (MCI)	Annually	1994 1999 - 2003	GWRC
				Dec. 2016	Aquanet

Site	Type	Parameters	Frequency	Period	Source/programme
	Microbiological water quality	Faecal coliforms	Weekly	2000-2016	Wellington Water (stormwater consent monitoring
		E. coli	Weekly	2001 - 2016	
Owhiro Bay	Microbiological water quality	Enterococci (n/100ml)	Weekly	2001 to 2017	GWRC (recreational beaches monitoring)

4 State of the Owhiro Stream: what do the data tell us?

4.1 Physical Habitat

The Owhiro Stream bed substrate is dominated by hard substrate, being a mix of boulders, cobbles and gravels, with some sand and silt in the slower parts. Habitat quality is generally good, with near-continuous riparian vegetation, largely replanted and maintained by community groups such as Friends of the Owhiro Stream over the last 15 years.

4.2 Macroinvertebrate communities

Macroinvertebrate communities indicates generally poor ecological health in the main Owhiro Stream with MCI scores consistently near or below the "national bottom line" score of 80.

Milne and Perrie (2006) reported an average MCI score of 69 in the lower Owhiro Stream, based on annual sampling in 1999 to 2003. This site was the second worst out of 51 monitoring sites regionally. Other indicators were equally indicative of poor water quality: QMCI score of 2.5 and %EPT taxa of 7.5%. The most recent results for this site (December 2016) indicate a slightly better MCI score (84), but still very poor QMCI (2.1) and EPT taxa (2.7%) scores.

The upper Owhiro Stream is also characterised by macroinvertebrate communities in relatively poor health (average MCI score of 82), with the notable low numbers of sensitive insects such as stoneflies, mayflies and caddisflies, presumably due to the influence of stormwater discharges and stormwater-borne contaminants from the suburb of Brooklyn.

The best macroinvertebrate communities in the Owhiro catchment are found in the side tributaries upstream of the T&T and Southern Landfills: Kowhai Park tributary (average MCI score of 109) and Carey's Gully tributary (average MCI score of 120).

Investigations have shown that the discharge from the T&T landfill resulted in a major degradation of macroinvertebrate communities in the Kowhai Park Tributary (average MCI score of 74) and further degradation in the Owhiro Stream itself (average MCI score of 70). As mentioned previously, remediation work is underway, and it would be interesting to assess whether it is successful in reducing the effects of the landfill on aquatic life.

Annual reports prepared on behalf of Wellington Water indicate that MCI scores in Carey's gully tributary are similar upstream and downstream of the Southern landfill; however, no information is provided on other macroinvertebrate indicators such as QMCI (which is more commonly used to assess the effects of specific activities).

4.3 Periphyton

Little data exist for periphyton in the Owhiro Stream. Limited data collected in December 2016 showed low levels of periphyton cover, although this survey was undertaken following a relatively wet period and does not reflect summer low flow conditions when nuisance periphyton growths typically occur. Visual observations indicate that periphyton growth can be abundant at times, with full cover of slimy brown filamentous growths establishing relatively quickly during periods of stable flow. Relatively elevated nutrient concentrations (in particular nitrogen) indicate a relatively high risk of excessive periphyton growth in unshaded reaches of the stream. It is thus suggested that periphyton cover and abundance be further monitored.

We are not aware of any formal surveys of macroalgae abundance in Owhiro Bay, although anecdotal observations indicate patches of sea lettuce (*ulva spp.*) on the eastern part of the Bay during periods of settled weather.

4.4 Fish

Records from the NZ Freshwater Fish database show that 9 freshwater fish species, plus koura, the native freshwater crayfish have been recorded in the Owhiro catchment. The conservation status of these species is as follows:

- One species, the shortjaw kokopu is classified as "threatened, nationally vulnerable"
- Five species, the longfin eel, giant kokopu, inanga, koaro and redfin bully are classified "At risk/ Declining";
- The shortfin eel, banded kokopu and common bully are classified as "not threatened

The location of the fish records is shown on Figure 2. To our knowledge, most of the records relate to presence/absence of fish species, and no formal assessment of fish population densities has been undertaken.

It should be noted that some of the above records are relatively old, and additional surveys would be required to robustly establish the current state of fish communities in the Owhiro Stream.

Rainbow trout have also been observed in the Owhiro Stream, although they are probably escapees from the trout hatchery located in Carey's gully rather than an established self-sustaining population.

4.5 Iron/manganese precipitate

Surveys undertaken in late 2016 in response to a pollution event from the T&T landfill showed the presence of abundant orange-coloured iron/manganese precipitate in the Kowhai Park Tributary downstream of the T&T landfill and in the Owhiro Stream downstream of that point, although in progressively reduced abundance moving downstream to the stream mouth. These deposits are thought to be a likely cause of, or contributing factor to, the significant adverse effects on macroinvertebrate communities measured during these surveys[6]. Iron and manganese concentrations consistently exceeded the 1 mg/L guideline during that period.

[6] Aquanet 2017

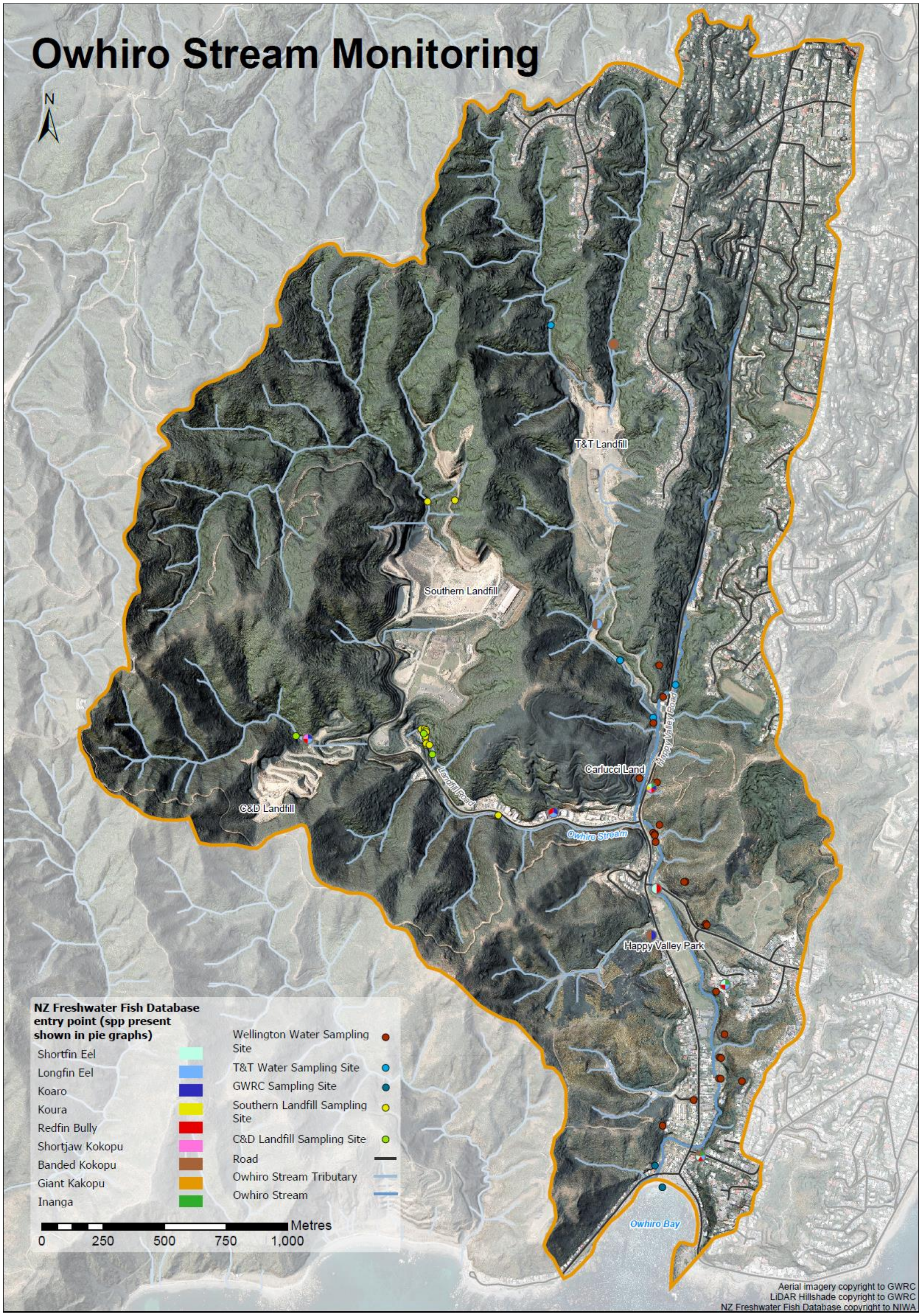

Figure 2: Freshwater fish and koura records in the Owhiro Stream catchment (map provided by Greater Wellington Regional Council).

4.6 Microbiological water quality: is the Owhiro Stream safe to swim or play in?

The regular monitoring undertaken by WCC and GWRC since 2001 includes a large number (467 samples taken between 2001 and 2016) of samples taken in a range of weather, season and stream conditions, and as such provides a very robust dataset on which to base an assessment of the state of microbiological water quality in the Owhiro Stream, and therefore of health risks to recreational users of the stream. Samples are collected at 4 sites on the Owhiro Stream itself (from upstream to downstream: at Kingston, upstream of Carey's Gully, downstream of Carey's Gully, and above the stream mouth at Owhiro Bay), as well as on the lower Carey's Gully Stream.

When assessed against the 2017 provisions of the NPSFM, the data shows that:

- There is a general degradation in microbiological water quality from upstream (Kingston) to downstream (Mouth) along the Owhiro Stream
- When considering the whole monitoring period (2001-2016), all sites fall either in the Orange (Band D) or Red (Band E) bands, meaning that none of the sites are suitable for primary contact;
- All sites fall in the Red category (Band D) in relation to the 95th percentile concentrations, indicating that high levels of faecal contamination occurs at least 5% of the time at all sites.
- Some degree of improvement over time is apparent at most sites (Kingston, upstream and downstream of Carey's Gully, and Carey's Gully Stream itself), although we have not undertaken any formal statistical temporal trend analysis;
- The lower Owhiro Stream site is by far the worst of the four stream sites and has fallen within Band E/Red in each 5-year period since 2001 for all numeric attribute states, indicating a high risk of infection to recreational users of the Owhiro Stream at most times. There also appears to be a worsening of all indicators over the last few years, although we have not undertaken any formal statistical temporal trend analysis.
- There is a clear increase in *E. coli* concentrations between downstream of the Carey's Gully confluence and the lower stream site (at Mouth), pointing to sources of contamination in that reach of the stream. The Southern landfill/Carey's Gully Stream do not appear to be the main source of contamination.

A more detailed analysis of the data available at each site against the NPSFM band system is provided in Appendix B.

Historically, Owhiro Bay has presented relatively poor microbiological water quality, and was one of the few sites in the Wellington harbour/ south coast area graded "poor" in GWRC's 2013 State of the Environment report. Recent data suggests some improvement in the last few years, and Owhiro Bay was classed in the "C-fair" class in 2016-2017, up from "D – poor" the previous year[7].

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[7]Refer to GWRC's website for annual monitoring reports, e.g. http://www.gw.govt.nz/assets/Our-Environment/Environmental-monitoring/Environmental-Reporting/Recreational-Water-Quality-Annual-Report-2016-web.pdf

4.7 Visual clarity

GWRC reported moderate visual clarity in the lower Owhiro Stream based on 1997-2003 data, with a median visual clarity of 1.6m. The maximum recorded clarity was 4.3 m.

Visual clarity was reported as being majorly affected in November-December 2016 and April 2016 as a result of discharges from the T&T landfill[8].

Anecdotal evidence also suggests that visual clarity in the Owhiro Stream is regularly affected by a number of un-identified sources/activities in the catchment.

4.8 Stormwater-borne contaminants (metals and organic microcontaminants)

Routine quarterly water quality monitoring in the upper Owhiro Stream (downstream of the Brooklyn urban area, upstream of the T&T landfill) shows the presence of copper and zinc consistently exceeding ANZECC trigger values for the protection of aquatic life.

Copper and zinc in excess of ANZECC trigger values were also reported in the lower Owhiro Stream during storm flows[9], and copper under base flow conditions. Copper and Zinc also exceeded ANZECC trigger values in Carey's Gully Tributary downstream of the Southern Landfill[10].

Polycyclic Aromatic Hydrocarbons (PAHs), organochlorine pesticides (including DDT) and PolyChloroBiphenyls (PCBs) were detected in the particulate fraction of Owhiro Stream water samples taken during a moderate rainfall event in 2002[5].

Stream sediment in the lower Owhiro Stream sampled in 2005 and 2006 were found to contain zinc, lead, DDT and dieldrin in excess of ANZECC trigger values on at least one occasion. Polycyclic Aromatic Hydrocarbons (PAHs) were also detected in Owhiro Stream sediments, although not in excess of ANZECC trigger values.

4.9 Ammonia

GWRC state of the Environment monitoring data indicates that ammoniacal-nitrogen concentrations were generally low in the lower Owhiro Stream during the period 1997-2003, with a median concentration of 0.005 mg/L and a maximum concentration of 0.250 mg/L. Such concentrations are unlikely to cause any more than minor toxic effects on aquatic life.

Routine quarterly monitoring upstream and downstream of the T&T landfill indicates that ammoniacal nitrogen concentrations consistently increase in both the Kowhai Park Tributary and the Owhiro Stream itself downstream of the T&T landfill, with a number of significant concentration peaks measured in January 2012, August 2012, June 2013 and October 2016. Further concentration peaks were measured in November-December 2016 and April 2017[11]. Ammoniacal nitrogen concentrations measured along the whole course of the Owhiro Stream

[8] Aquanet (2017)

[9] Milne and Watts (2008); KLM (2005); Cameron (2002)

[10] Cameron (2002)

[11] Aquanet (2017)

during November-December 2016 were elevated and likely to have caused both chronic and acute toxic effects on aquatic life.

The Southern landfill does not appear to be causing elevated ammoniacal nitrogen concentrations in the Carey's Gully Tributary.

4.10 Nutrients

Dissolved Inorganic Nitrogen (DIN) concentrations are generally elevated in the lower Owhiro Stream. For example, the median DIN concentration during the 1997-2003 was over 1.3 mg/L, although some improvement was apparent during that period [12]. Dissolved Reactive Phosphorus (DRP) concentrations were relatively low during that period (median concentration of 0.005 mg/L). Based on these concentrations, DIN is well in excess of plant/periphyton requirements, and any nutrient limitation of periphyton growth in the Owhiro Stream is likely to be associated with the relatively low DRP concentrations.

Unfortunately, there does not appear to be any recent data on which to base an assessment of the current nutrient status of the Owhiro Stream, although visual observations of abundant periphyton growth indicate that nutrient concentrations are possibly excessive in the Owhiro Stream.

Water quality monitoring in the Carey's Gully Tributary show a significant increase in nitrate-nitrogen concentrations in this tributary downstream of the Southern landfill, indicating that the Southern Landfill is one of the sources of the elevated DIN concentrations in the lower Owhiro Stream. The nature and location of any other sources of DIN (nitrate and/or ammoniacal-nitrogen) in the catchment are unknown, but may include stormwater, sewage cross-contamination of stormwater, other landfills, and land use (including gorse).

To our knowledge, there are no data available on nutrient concentrations in Owhiro Bay.

5 Conclusions and Recommendations for future monitoring

There is a relative abundance of water quality and ecological data available on the Owhiro Stream, reflecting its semi-urban location, the interest of the community and the multiple pressures it is facing.

Available monitoring data indicates multiple pressures and issues on water quality and aquatic health, but also to significant existing recreational and ecological values. The Owhiro Stream is home to a relatively diverse native fish community, including 6 "Threatened / At Risk" fish species. It is also the focal point of significant restoration and education effort, and a water source for the Owhiro Community Gardens.

Some aspects of water quality and aquatic health are degraded, and the most recent National Policy Statement for Freshwater Management requires at least improvement of its macroinvertebrate communities and suitability for recreation.

Water quality and stream ecological health management requires robust data, both to follow any improvement or degradation over time, to identify sources and causes of issues, and to develop

[12] Milne and Perrie (2006)

appropriate management solutions. We have identified a number of knowledge gaps, which could be addressed by further monitoring and/or further data analysis. These form the basis for our recommendations below.

Recommendation 1: Re-establish State of the Environment monitoring site(s)

The most comprehensive body of water quality monitoring data was collected by GWRC as part of their SoE monitoring between 1988 and 2003. Whilst this dataset provides a robust understanding of water quality and macroinvertebrate communities during that period, it is now relatively old (15 years for the most recent data), and of limited relevance to the current situation.

With regards to number and location of sites, we suggest that the highest priority is to re-establish a regular monitoring site on the lower Owhiro Stream, at or close to its historical location. Ideally, another 2 sites should be added, one in the on the upper reaches of the stream (downstream of the Brooklyn urban area, but upstream of the Kowhai Park/T&T Tributary), and one in the middle reaches of the stream, possibly near the Murchison Street Bridge.

Monitoring should include:

- monthly water quality sampling and field measurements and
- monthly periphyton monitoring: visual observations (cover) and/or sampling (biomass)
- annual macroinvertebrate sampling during summer low flows

This regular monitoring is considered essential to establish an updated analysis of the state of water quality and aquatic ecology and follow any improving or declining trends over time.

Recommendation 2: Further analysis of *E.coli* data (temporal trends)

Our analysis suggests that *E.coli* concentrations in the lower Owhiro Stream have increased over the last 5 years, whilst they may have decreased at other sites across the catchment. We recommend that a formal statistical analysis of temporal trends in *E.coli* concentrations be conducted to confirm whether any trends are indeed material and/or significant. Data for all six monitoring sites should be analysed.

Recommendation 3: Targeted investigations of the source(s) of faecal contamination

Monitoring data show relatively poor microbiological water quality (*E. coli* concentrations) and elevated risk of infection at all Owhiro Stream sites, but with a clear pattern of degradation from upstream to downstream along the Stream. The data points to a significant source of contamination somewhere between downstream of the Carey’s Gully Tributary confluence and the stream mouth. *E.coli* concentrations in the Carey’s Gully Stream are generally comparable to, or better than, those measured in the Owhiro Stream itself, indicating that the Southern Landfill or C&D landfill are unlikely to be the main cause.

The lower Owhiro Stream falls into the “red” category for all indicators under the recent NPSFM provisions, indicating sustained sources of faecal contamination under both dry and wet-weather conditions. This is of public health concern, given that most use of the Owhiro Stream (recreation and community garden irrigation) occurs within this reach.

We recommend that further investigations be undertaken to identify the nature and location of the contamination source(s). Investigations could include longitudinal surveys (i.e. taking measurements and/or samples at regular intervals along the stream) and/or faecal source tracking analysis (to determine whether the faecal contamination is from humans, birds, dogs or livestock).

Recommendation 4: Regular reporting to community as to health risks

Given the above conclusions regarding infection risks to water users in the lower Owhiro Stream, it may be advisable to directly communicate monitoring results to the community, including the primary school and the community garden.

Recommendation 5: Targeted investigations of the source(s) of nitrate nitrogen

As indicated in this report, dissolved nitrogen concentrations are elevated in the Owhiro Stream (or at least were elevated in the period leading to 2003). Whilst the Southern landfill appears to be a source of nitrate-nitrogen, data available does not allow us to establish whether it is the main, or even a significant, source of nitrate-nitrogen in the catchment. We suggest that some targeted investigations be carried out to locate and quantify the various sources of dissolved nitrogen into the Owhiro Stream. These investigations should be undertaken if/when the presence of high dissolved nitrogen concentrations in the lower Stream are confirmed (refer to recommendation 1).

Recommendation 6: Macroalgae surveys in Owhiro Bay

As indicated in this report, dissolved nitrogen concentrations elevated in the Owhiro Stream. This nitrogen is eventually discharged into Owhiro Bay. Nitrogen is generally seen as the limiting nutrient in coastal environments, meaning that an addition in nitrogen is likely to boost algae growth locally. Whether this leads to an actual effect such as an accumulation of macroalgae depends to a large extent on the local conditions, particularly how well flushed is the receiving environment.

To our knowledge, little is known about the nutrient status of Owhiro Bay, and although patches of sea lettuce are observed in summer in parts of the bay, there does not appear to have been any formal macroalgae surveys or assessments. We note however that we are not coastal water specialists, and we suggest that the risk of actual effects and the need to undertake actual monitoring should be assessed by a coastal specialist.

Recommendation 7: Continuous monitoring of turbidity and dissolved oxygen

Visual observations indicate frequent changes in visual clarity in the lower Owhiro Stream, including during dry weather, indicating an influence from activities within the catchment. Continuous turbidity monitoring would allow to determine the frequency and severity of these influences, as well as (if telemetered) real-time data allowing rapid response to contamination events.

To our knowledge, the only dissolved oxygen (DO) data available was collected during daytime. Dissolved oxygen concentrations in a stream varies diurnally, from peak concentrations in late afternoon to lowest concentrations just before dawn. As a result, "spot" DO data collected during daytime only provides a very limited indication of the diurnal DO patterns at a given site, in particular night-time minima which are particularly critical to aquatic life.

Recommendation 8: Explore options for cost/time efficiency in monitoring and reporting

A number of organisations undertake or commission water quality and/or ecological monitoring in the Owhiro catchment, and options may be available to minimise costs and optimise data collection. For example, Wellington Water currently take water samples weekly at four sites on the Owhiro Stream. These samples are currently only analysed for faecal indicators, but additional laboratory analyses could be carried out on these samples, at limited additional costs.

Recommendation 9: Community engagement and education

Citizen Science is a concept within which scientific research is conducted, in whole or in part, by members of the community. Citizen Science is strongly developing both in New Zealand and around the world; it has been shown to lead to multiple benefits, including increased data gathering power, reduced monitoring costs and increased understanding of science.

There is a strong interest in the Owhiro Stream within the local community, associated with significant water quality issues and a real need for additional monitoring data; this combination forms an ideal candidate for a citizen science programme, ideally with the support of local government (regional and city councils) and science providers (e.g. NIWA, universities).

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Appendices

Appendix A: Environmental Guidelines used in this report

Table A-1: ANZECC (2000) trigger values 90% protection level (95% protection level in brackets).

Parameter	ANZECC (2000) Trigger values Ecosystem protection 95% protection level	Recent revisions (NIWA 2017) of ANZECC Trigger values for Ecosystem protection 95% protection level
Total Lead (g/m^3)	0.0034	
Total Copper (g/m^3)	0.0014	0.0012
Total Zinc (g/m^3)	0.008	0.003
Total Arsenic (g/m^3)	0.013 (AsV)	
Total Chromium (g/m^3)	0.001 (CrVI)	

Table 3: Attribute states for Ammonia (Toxicity) taken from Appendix 2 of the National Policy Statement for Freshwater management (2017).

Attribute State	Numeric Attribute State		Narrative Attribute State
	Annual Median*	**Annual 95th Percentile***	
A	≤ 0.03	≤ 0.05	99% species protection level. No observed effect on any species.
B	>0.03 and ≤ 0.24	>0.05 and ≤ 0.40	95% species protection level. Starts impacting occasionally on the 5% most sensitive species.
C	>0.24 and ≤ 1.30	>0.40 and ≤ 2.020	80% species protection level. Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species).
National Bottom Line	**1.30**	**2.20**	
D	>1.30	>2.20	Starts approaching acute impact level (i.e. risk of death) for sensitive species.

*Based on pH 8 and temperature of 20°C
Compliance with the numeric attribute states should be undertaken after pH adjustment.

Table 4: Provisional biomass and cover guidelines for periphyton growing in gravel/cobble bed streams for three main instream values. Reproduced from Table 14 Ministry for the Environment guidelines (Biggs and Kilroy 2000).

Instream value/variable	Diatoms/cyanobacteria	Filamentous algae
Aesthetics/recreation (1 November – 30 April)		
Maximum cover of visible stream bed	60 % > 0.3 cm thick	30% > 2 cm long
Maximum chlorophyll a (mg/m^2)	N/A	120
Benthic biodiversity		
Mean monthly chlorophyll a (mg/m^2)	15	15
Maximum chlorophyll a (mg/m^2)	50	50
Trout habitat and angling		
Maximum cover of whole stream bed	N/A	30% > 2 cm long
Maximum chlorophyll a (mg/m^2)	200	120

Table 5: Interpretation of MCI and QMCI values after Stark & Maxted (2007) for stony streams.

Interpretation	MCI	QMCI
Excellent / Clean water	> 119	> 5.9
Good / Possible Mild pollution	100 -119	5 – 5.9
Fair / Probable Moderate pollution	80 - 99	4 – 4.9
Poor / Probable Severe pollution	<80	< 4

NPSFM *E. coli* Attribute

Value	**Human health for recreation**				
Freshwater Body Type	Lakes and rivers				
Attribute	*Escherichia coli (E. coli)*				
Attribute unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)				
Attribute state[1,2]	**Numeric Attribute state**				**Narrative Attribute State**
	% exceedances over 540 cfu/100ml	**% exceedances over 260 cfu/100ml**	**Median concentration (cfu/100ml)**	**95^{th} percentile of *E. coli*/100 mL**	**Description of risk of *Campylobacter* infection (based on *E. coli* indicator)**
A (Blue)	<5%	<20%	≤130	≤540	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 1%*
B (Green)	5-10%	20-30%	≤130	≤1000	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 2%*
C (Yellow)	10-20%	20-34%	≤130	≤1200	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 3%*
D (Orange)	20-30%	>34%	>130	>1200	20-30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >3%*
E (Red)	>30%	>50%	>260	>1200	For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >7%*

Appendix B: Assessment against NPSFM (2017) Human Health for Recreation *E. coli* Attribute, based on Wellington Water weekly monitoring data. Colour coding as per NPSFM (2017) bands.

Owhiro Stream at Kingston, *E. coli* concentrations.

Analysis period (5 year, 1 July - 30 June)		% samples Exceeding 540/100 mL	% samples Exceeding 260/100mL	Median (/100mL)	95th Percentile (/100mL)	Number of samples
2001	2006	34%	43%	200	3800	162
2002	2007	32%	40%	190	4040	138
2003	2008	30%	43%	200	3650	136
2004	2009	28%	43%	200	3360	127
2005	2010	27%	43%	210	3740	127
2006	2011	23%	44%	230	3390	128
2007	2012	18%	44%	230	2210	130
2008	2013	23%	46%	235	3270	134
2009	2014	22%	41%	185	3270	134
2010	2015	20%	38%	150	2360	133
2011	2016	19%	36%	130	2800	132
	All data	**26%**	**41%**	**190**	**3580**	**463**

Owhiro Stream at Happy Valley Tip Bridge (upstream of Carey's Gully confluence). *E. coli* concentrations.

Analysis period (5 year, 1 July - 30 June)		% samples Exceeding 540/100 mL	% samples Exceeding 260/100mL	Median (/100mL)	95th Percentile (/100mL)	Number of samples
2001	2006	37%	48%	250	4200	164
2002	2007	34%	49%	250	3695	142
2003	2008	35%	55%	310	3620	137
2004	2009	34%	55%	315	2995	128
2005	2010	33%	56%	310	3940	129
2006	2011	23%	50%	265	3925	128
2007	2012	24%	47%	240	3515	130
2008	2013	27%	44%	220	7535	134
2009	2014	27%	43%	220	7535	134
2010	2015	24%	42%	220	7680	133
2011	2016	22%	43%	220	7000	133
	All data	**29%**	**49%**	**250**	**5000**	**467**

Lower Carey's Gully Stream, E. coli concentrations

Analysis period (5 year, 1 July - 30 June)		% samples Exceeding 540/100 mL	% samples Exceeding 260/100mL	Median (/100mL)	95th Percentile (/100mL)	Number of samples
2001	2006	29%	40%	160	2740	164
2002	2007	24%	35%	160	2400	140
2003	2008	24%	37%	155	2175	136
2004	2009	24%	39%	180	2490	128
2005	2010	26%	39%	180	3095	128
2006	2011	25%	36%	180	3320	129
2007	2012	23%	35%	170	3065	130
2008	2013	22%	29%	140	6185	134
2009	2014	21%	26%	120	3270	134
2010	2015	17%	22%	100	2140	133
2011	2016	14%	20%	110	1445	132
	All data	**24%**	**34%**	**160**	**2900**	**466**

Owhiro Stream below Happy Valley Tip Bridge (downstream of Carey's Gully confluence). *E. coli* concentrations.

Analysis period (5 year, 1 July - 30 June)		% samples Exceeding 540/100 mL	% samples Exceeding 260/100mL	Median (/100mL)	95th Percentile (/100mL)	Number of samples
2001	2006	40%	60%	320	4300	158
2002	2007	34%	55%	280	3140	137
2003	2008	29%	50%	260	2325	136
2004	2009	29%	46%	225	2525	128
2005	2010	29%	45%	230	3125	128
2006	2011	25%	41%	210	3100	129
2007	2012	26%	42%	220	2530	130
2008	2013	30%	46%	240	3505	134
2009	2014	29%	46%	240	3440	134
2010	2015	23%	47%	250	3250	159
2011	2016	23%	48%	260	3900	133
	All data	**30%**	**51%**	**270**	**3600**	**461**

Owhiro Stream at Mouth *E. coli* concentrations.

Analysis period (5 year, 1july - 30 June)		% samples Exceeding 540/100 mL	% samples Exceeding 260/100mL	Median (/100mL)	95th Percentile (/100mL)	Number of samples
2001	2006	39%	68%	500	4050	171
2002	2007	47%	66%	500	4055	150
2003	2008	50%	71%	550	3280	137
2004	2009	51%	71%	550	3020	129
2005	2010	56%	76%	600	3100	129
2006	2011	50%	71%	520	2920	129
2007	2012	49%	74%	530	2800	130
2008	2013	54%	75%	620	3135	134
2009	2014	57%	78%	640	6010	134
2010	2015	59%	79%	660	6680	133
2011	2016	64%	84%	810	6720	133
	All data	53%	75%	600	4370	467