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Whangamata Harbour water quality investigations, 1999-2000

Prepared by:
Bill Vant

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

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Summary

Surveys of the water quality of Whangamata Harbour and certain of its inflowing streams were conducted during June 1999 to February 2000. The investigations included:

(1) surveys of the levels of faecal bacteria at three popular bathing beaches (two on the open coast, and one inside the harbour) at weekly intervals during the summer,
(2) surveys of salinity, dissolved oxygen, water clarity, plant nutrients and faecal bacteria at 13 widely-distributed sites throughout the harbour on five occasions during June to February,
(3) surveys of these constituents at approximately hourly intervals throughout the tidal cycle at a site in the Moanaanuanu Estuary on the same five sampling days,
(4) surveys of nutrients and faecal bacteria in the lower Wentworth River—the main source of freshwater to the Moanaanuanu Estuary (and to the harbour as a whole),
(5) surveys of these constituents at several sites further up the river, and in the lower part of the Waikiekie Stream (which drains the area of exotic forest where the treated Whangamata sewage effluent is spray-irrigated), and
(6) occasional observations and analyses of surface foams and scums.

The bathing beaches were found to be suitable for swimming. In particular, the median level of enterococci at the harbour bathing beach site was <2 cfu/100 mL, or more than ten times lower than the national guideline level for safe bathing waters. This was despite the fact that substantially-higher levels of bacteria were found in the freshwaters which enter the harbour upstream of this site. Dilution with clean seawater was apparently sufficient to ensure that the water at this site was safe for bathing. However, the guidelines for safe shellfish-gathering waters require a lower level of contamination with faecal bacteria, and these and other results indicate that shellfish gathered from the southern half of the harbour should probably not be eaten.

At the time of sampling, the harbour waters were mostly (clean) seawater, and were generally in good condition: dissolved oxygen levels were generally high (>90% of saturation), and levels of nutrients and faecal bacteria were generally low. However, none of the surveys were undertaken during periods of high freshwater flow, and it is likely that levels of some contaminants may increase during and after flood events. Furthermore, although water quality was generally good over large areas of the harbour, it was found to be poorer in areas where moderately-contaminated river or stream water mixed with harbour water. As a result, contaminant levels were moderately-high at times in the Moanaanuanu Estuary, and near the mouth of the Waikiekie Stream.

In these areas, contaminant levels were generally highest when salinities were low, and vice versa. Most of the contaminants therefore entered the harbour from the land, rather than from the sea (although there may have been an exception to this at the time of the [very windy] December survey). The contaminants found in the Moanaanuanu Estuary appeared to have entered the Wentworth River from the catchment upstream of the Whangamata golf course. There was no evidence of any substantial leak of contaminants from the Whangamata wastewater treatment pond (which is located adjacent to a small stream which enters the Moanaanuanu Estuary downstream of the golf course).

Longitudinal surveys of the Wentworth River suggested that most of the contaminant load at the golf course entered the river from the largely pastoral area in the lower part of the catchment. Inspection of this area showed that livestock had unrestricted access to the river at places, and that contaminated runoff from the adjacent land was likely to enter the river. The moderate degree of contamination observed in the stream was broadly consistent with this type of land use.

Comparison of the levels of faecal bacteria in the Waikiekie Stream with those found in other small streams in the Waikato Region suggests that the bacterial load is partly due

to the small amount of pastoral farming in the catchment, and partly to leakage from the spray irrigation area. The overall loads of faecal bacteria to the harbour from the Wentworth River and the Waikiekie Stream appear to be of similar magnitude.

Levels of nitrogen in the lower Waikiekie Stream were 30–100 times higher than in the Wentworth River. Together with the conclusions of a previous assessment, this fact suggests that leakage from the spray irrigation area is contributing a major load of nitrogen to the stream (and thus to the harbour). This load may have increased over the past decade. The potential for the nitrogen load to support nuisance plant growth in the harbour should be thoroughly assessed.

At times, small areas of foam or scum were seen floating on the water in sheltered parts of the Moanaanuanu Estuary. These appeared to be natural features of this (modified) estuarine area.

Contents

Acknowledgments

Harry Wilson, Mark Davenport and Nath Pritchard helped define the aims of the investigation. Brent Fletcher, Mark Henry, Ralph Ostertag, Perry Empson and Michael Thompson did most of the field work, in surveys co-ordinated by Ian Buchanan. Clean Water Whangamata made available information from its harbour studies, and Jason Rendle helped interpret it. Burns Macaskill (NIWA) and Alice Wilson (Waitawheta) reviewed a draft of this report, and made helpful suggestions for improving it.

1 Introduction

Whangamata Harbour (37.2°S, 175.9°E) is one of several small-to-moderate-sized estuarine embayments on the east coast of the Coromandel Peninsula (Fig. 1). The harbour area is about 4.4 km^2, and the volume of the tidal prism is about 4×10^6 m^3 (Hume & Herdendorf 1993). About 12% of the harbour is occupied by sub-tidal channels, with the remainder being intertidal zone.

The catchment area is about 50 km^2, and can be conveniently divided into two parts (Fig. 1): (1) the 24 km^2 catchment of the Wentworth River—the largest of several streams flowing into the harbour, and (2) the 26 km^2 combined catchment of the other streams (described here as the "Northern" sub-catchment). The average freshwater inflow from the whole catchment is estimated to be about 9×10^4 m^3 per tidal cycle,[1] or about 2% of the volume of the tidal prism. Apart from during floods, the water in the harbour is therefore mostly seawater.

The catchment is largely forested, with 46% of the area being in exotic forest and 35% in native forest or scrub.[2] About 15% of the catchment is in pasture, and is used for sheep and beef farming. The remaining 4% is urban land.

The Hauraki Catchment Board undertook several surveys of harbour water quality during 1974–82 (HCB, unpublished results). Levels of faecal bacteria at sites throughout the harbour were mostly low-to-moderate, although higher levels were found at times in the Moanaanuanu Estuary, the southern side-arm where the Wentworth River drains into the harbour.[3] Other results showed the water was suitable for aquatic life: the water was well-oxygenated with mostly low levels of biochemical oxygen demand, levels of plant nutrients were mostly low and pH levels were acceptable.[4]

Since then, surveys of the water quality of the coastal waters of the Peninsula have focused on conditions at popular bathing beaches during the summer. During the 1990s, Environment Waikato undertook bathing beach water quality surveys at three Whangamata beaches on several occasions, most recently during 1998–99 (Vant 1999).[5] Two of the beaches are open coast sites, while the third is located about 0.5 km inside the harbour (Fig. 1, site 14). All three beaches were found to be suitable for bathing, with levels of faecal bacteria being low (e.g. the enterococci levels at the harbour beach site in 1998–99 were all $\leq$ 10 cfu/100 mL, n = 12).[6]

Concern has recently been expressed that "the harbour water is polluted", with discharges or leaks from the Whangamata sewage system being responsible for this (e.g. Environment Waikato 1999a). During June 1999 to February 2000 Environment Waikato undertook several water quality surveys of the harbour to determine the state of the water, and to identify possible sources of contamination within the catchment. This report describes those surveys, outlines the results obtained, and provides an assessment of the current condition of the harbour water and the likely sources of contaminants.

[1] Based on the average water yield of 41 L/s/km^2 measured at the nearby Wharekawa River catchment (average flow = 1.92 m^3/s, area = 47 km^2: Buchanan 1999, table 10).

[2] Based on information from the Land Cover Database, Terralink NZ Ltd.

[3] Levels of faecal coliforms in the range 10–400 cfu/100 mL were recorded at the Moananuanu Causeway (Fig. 1, site C), with levels being highest when salinities were low (and vice versa).

[4] By contrast, coastal embayments into which sewage wastewaters are discharged can have substantially-higher levels of nutrients and faecal bacteria (e.g. Vant 1995).

[5] Survey results were assessed using the national water quality guidelines for marine bathing waters which were in use at the time of each survey. Note that new guidelines were published in 1998 (MfE/MoH 1998), superseding those published in 1992.

[6] The national guidelines require that the bathing season median enterococci level not exceed 35 cfu/100 mL, and that no single sample exceed 136 ("Alert")/277 ("Action") cfu/100 mL: MfE/MoH (1998).

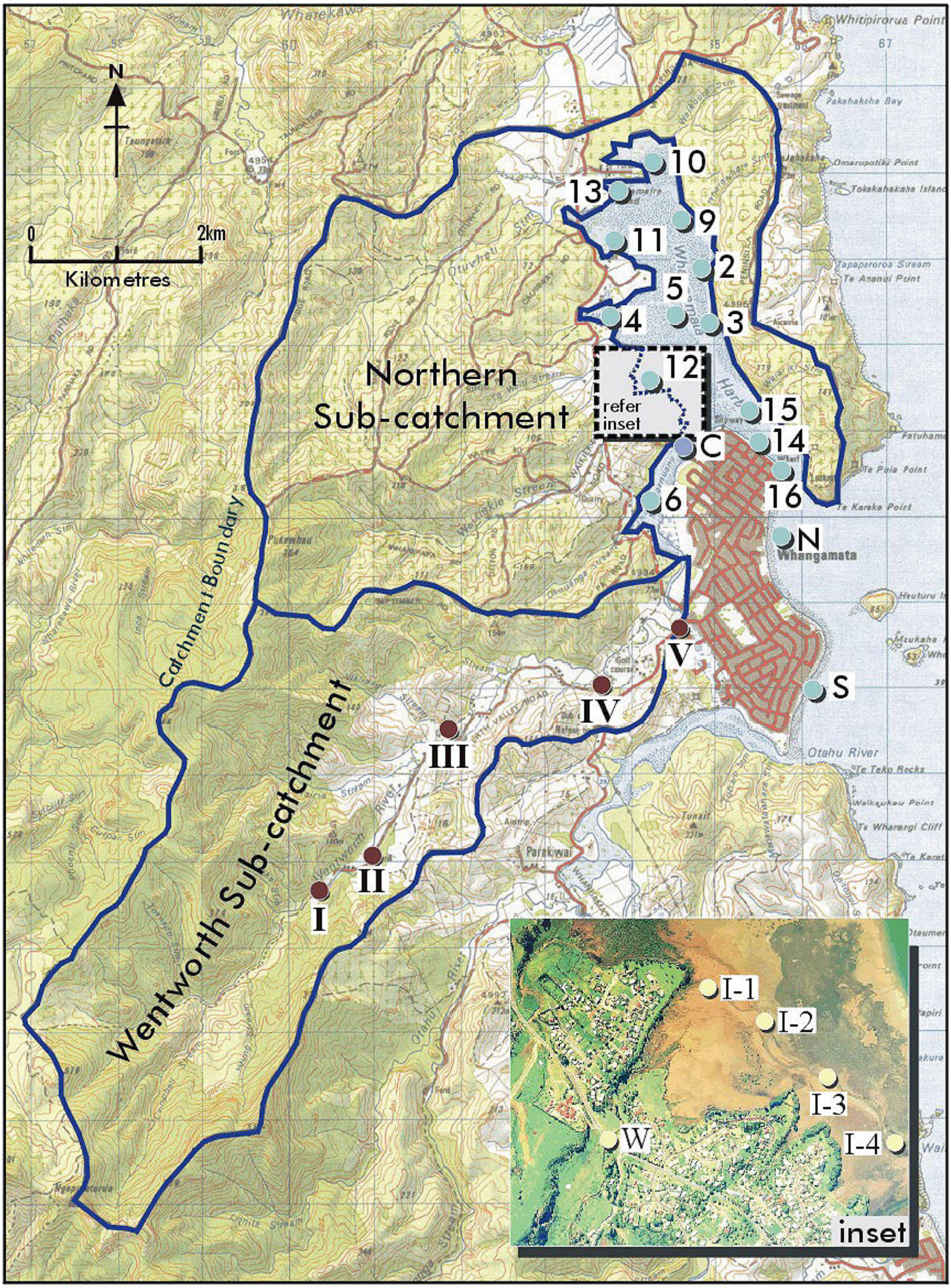

Figure 1: Whangamata Harbour and its catchment. Harbour and stream sites sampled during 1999–2000 are shown: see Table 1 for details. The aerial photo was taken during autumn 1995.

2 Methods

Five water quality surveys were undertaken during June 1999 to February 2000 (Table 2). Samples were collected from a variety of harbour and stream sites, as shown in Figure 1 (see also Table 1). Samples were collected, stored and analysed in accordance with Environment Waikato's standard procedures (e.g. Wilson 1999). In particular, samples were generally collected from approximately 0.1–0.2 m below the water surface, with care being taken to avoid contaminating the sample with any material which may have been concentrated within the surface microlayer (e.g. Blanchard 1989).[7] Table 3 summarises the field and laboratory methods used to determine the various water quality variables.

Table 1: Location of main sampling sites (see Figure 1 also). Map references are all for NZMS 260, sheet T12.

Site		Map reference
Bathing beaches		
14	Whangamata Harbour	655 407
N	Whangamata Beach North	657 397
S	Whangamata Beach South	660 381
Harbour sites		
2	East channel	648 429
3	East mid harbour	649 423
4	Kaupeka Stm mouth	638 423
5	Mid harbour	646 424
6	Moanaanuanu Estuary	642 402
9	North-east channel	647 435
10	North harbour	644 441
11	North of hotel	638 434
12	Waikiekie Stm/Moana Pt	642 416
13	Otuwheti Stm North	638 439
14	Off Rutherford Rd	655 407
15	South mid channel	654 412
16	Wharf	657 406
Causeway site		
C	Causeway (Moanaanuanu)	645 408
Wentworth River		
I	Above camp	603 357
II	Ford	610 360
III	Near quarry	620 375
IV	Above golf course	637 381
V	Lower river	645 387
Waikiekie Stream		
W	SH25 footbridge	638 414
Waikiekie-Moana Pt intertidal		
I-1	Mouth of Waikiekie Stm	642 418
I-2	Mid bay	644 416
I-3	Off Moana Pt	646 414
I-4	Near Moanaanuanu channel	648 412

[7] Contaminant levels can be much higher in surface films, and in foam and bubbles than in the underlying water. For example, levels of bacteria in films, foams and bubbles can be several hundred times higher than in the underlying water. This occurs because various mechanisms, including the formation and movement of bubbles, tend to concentrate the bacteria in these surface features (Blanchard 1989).

In recognition of this, the national guidelines for bacteriological water quality (MfE/MoH 1998) specify that "Samples should be taken … below the surface of the water" (p. 11; the now-superseded 1992 guidelines also specified this). The "Supporting Manual (latest draft, July 1999)" to the guidelines further observes that "In general the sample will be taken at approximately 15–20 cm below the surface" (p. 19). The guidelines were derived using samples collected this way, and it is important that the same technique be used when collecting samples which are to be assessed using the guidelines (G McBride, NIWA, pers. comm., Nov 1999).

Note also that the ASTM (1982) standard for "sampling water from … rivers, streams, lakes, oceans … for chemical, physical, bacteriological or radiological analyses" explicitly states: "Avoid surface scum" (s 12.1.1).

Table 2: Dates of Whangamata Harbour water quality surveys. The time of high water at Whangamata is shown. The average rainfall and stream flow rates at sites* in the nearby Wharekawa catchment during the five days prior to each survey are also shown (minimum and maximum values in brackets).

Date	High water (NZST)	Rainfall (mm/d)	Flow (m^3/s)
24 June 1999	16:05	0.2	0.86
4 October 1999	14:35	0	0.65
14 December 1999	11:38	1.9	–
12 January 2000	11:10	6.9	0.81
10 February 2000	10:41	0	0.35
whole period		5.9 (0, 44.4)	1.25 (0.35, 6.91)

*rainfall from Wharekawa @ Tairua Forest (NZMS 260, sheet T12, 554 377), flow from Wharekawa @ Adams Farm Bridge (T12, 623 468), catchment area = 47 km^2: information from Environment Waikato databases

Table 3: Field and laboratory methods used to measure water quality variables in harbour and stream surveys.

Variable	Method
Field measurements	
Maximum depth (m)	Lead line
Salinity	June/Oct: laboratory conductivity*; Dec-Feb: WTW meter (LF 340)
Temperature (°C)	WTW meter (Oxi 197-S)
Dissolved oxygen (% saturation)	WTW meter (Oxi 197-S)
Secchi depth (m)	20 cm black and white disc
Laboratory measurements (g/m^3 unless stated otherwise)	
Ammoniacal-nitrogen	Phenol/hypochlorite colorimetry, APHA 4500-NH3 G
Nitrate and nitrite nitrogen§	Automated cadmium reduction, APHA 4500-NO_3^- F
Total Kjeldahl nitrogen	Kjeldahl digestion, ammoniacal-N (see above)
Dissolved reactive phosphorus	Molybdenum blue colorimetry, APHA 4500-P F
Total phosphorus	Persulphate digestion, colorimetry. NWASCO method 8
Reactive silica	Molybdenum blue complex, APHA 4500-Si E
Faecal coliforms (cfu/100 mL)	Membrane filtration, mFC Agar @ 44.5°C, 24 h, APHA 9222
Enterococci (cfu/100 mL)	Membrane filtration, mE/EIA Agars, 41.5°C, 48 h, APHA (Water) 9230

*calculated as salinity = 35 × conductivity/5275, with conductivity (millisiemens/m) measured @ 25°C, APHA 2510 B
§hereafter referred to as “nitrate-N”

3 Results and Discussion

The complete results of the surveys are included in Appendices 1–7.

3.1 Bathing beach surveys—suitability for swimming

Figure 2A shows the enterococci levels in samples collected during December 1999-February 2000 at the Whangamata Harbour bathing beach site (Fig. 1, site 14). Results are expressed as the number of colony forming units (cfu) per 100 mL of sample. Values ranged from <1 cfu/100 mL (on six occasions) to 29 cfu/100 mL (20 February). The median enterococci level was <2 cfu/100 mL. Similar results were obtained at the two Whangamata open coast beach sites.

Table 4 summarizes the enterococci results obtained at the three bathing beach sites. The median enterococci levels were <2, 2 and 3 cfu/100 mL at the Whangamata Harbour, Whangamata Beach North, and Whangamata Beach South sites, respectively. The national guidelines for safe bathing beach water quality require that the median enterococci level during the bathing season not exceed 35 cfu/100 mL (MfE/MoH 1998). The median enterococci levels at all three beaches were well below this guideline value. Indeed, they were about ten times lower than the guideline.

The guidelines also identify upper limits to enterococci levels at bathing beaches as follows:

- any single sample between 137 and 277 cfu/100 mL: “Alert” mode

- any single sample greater than 277 cfu/100 mL: "Action" mode

The highest enterococci levels recorded at the three beaches during December 1999 to February 2000 were 29, 15 and 8 cfu/100 mL (at the Harbour, the North Beach and the South Beach sites, respectively: see Table 4). This means that none of the enterococci levels exceeded the "Action" level. Furthermore, none of the samples exceeded the (lower) "Alert" level.

All three beaches therefore met the national guideline requirements for safe swimming, namely that the seasonal median enterococci level be less than 35 cfu/100 mL, and that no single sample exceed 136/277 cfu/100 mL. As shown in Table 4, all three beaches were therefore suitable for bathing according to the national guidelines.

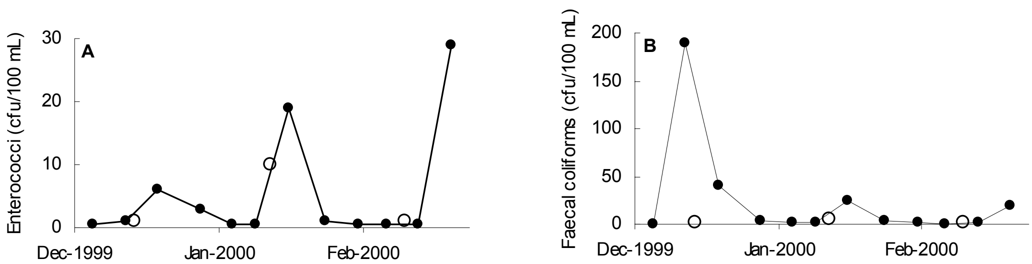

Figure 2: **A**, enterococci, and **B**, faecal coliform levels at weekly intervals at the Whangamata Harbour bathing beach site during December 1999 to February 2000. Results from three harbour surveys during this period are also shown (○).

Table 4: Suitability of water quality for swimming and shellfish-gathering at three bathing beaches during December 1999-February 2000. Samples were collected at approximately weekly intervals (*n* =12, see Appendix 1).

Site	Range	Median	Upper limit*	Suitability
Swimming	***enterococci (cfu/100 mL)***			
Whangamata Harbour	<1 to 29	<2	0	Safe
Whangamata Beach North	<1 to 15	2	0	Safe
Whangamata Beach South	<1 to 8	3	0	Safe
Shellfish-gathering	***faecal coliforms (cfu/100 mL)***			
Whangamata Harbour	<1 to 190	3	8%	Marginal
Whangamata Beach North	<1 to 30	2	0%	Safe
Whangamata Beach South	<1 to 18	4	0%	Safe

*swimming: upper limit is based on *number* of samples > 136/277 cfu/100 mL (see text); shellfish-gathering: upper limit is based on *percent* of samples > 43 MPN/100 mL

3.2 Bathing beach surveys—suitability for shellfish-gathering

Figure 2B shows the faecal coliform levels at the Whangamata Harbour bathing beach site. These ranged from <1 cfu/100 mL to 190 cfu/100 mL (on 12 December). The median faecal coliform level was 3 cfu/100 mL. Similar results were obtained at the two nearby open coast sites (Table 4).

The national guidelines for the suitability of waters used for shellfish-gathering are based on faecal coliform levels as determined using the most probable number (MPN) technique (MfE/MoH 1998). In this survey, however, the membrane filtration technique was used. In highly turbid waters such as wastewaters, the results obtained using the two methods may differ. But in many natural waters—including those described here—the results from the two methods can be expected to be at least broadly similar. The survey results can therefore be regarded as providing *a reasonable indication* of the likely suitability of the harbour and coastal water for shellfish-gathering.

The national guidelines for shellfish-gathering waters require that:

- the seasonal median faecal coliform level not exceed 14 MPN/100 mL, and
- not more than 10% of samples exceed 43 MPN/100 mL

Table 4 summarizes the faecal coliform results for the three bathing beaches. In each case the median faecal coliform level was in the range 2–4 cfu/100 mL. Furthermore, at the two open coast sites no sample contained more than 31 cfu/100 mL. At these two sites the water quality was therefore probably safe for shellfish-gathering. However, at the harbour site one of the twelve weekly samples (i.e. 8% of the samples) contained more than 43 cfu/100 mL (Fig. 2B). Although the median faecal coliform level at this site (3 cfu/100 mL) was well below the shellfish-gathering guideline (14 MPN/100 mL), the fact that levels >43 cfu/100 mL are not uncommon means that the waters are probably no better than marginally suitable for shellfish-gathering (Table 4).

On 12 January 2000, shellfish were collected at about the time of low water from a popular shellfish-gathering area located within 100 m of the harbour bathing beach site. The shellfish flesh was analysed, and the faecal coliform level was found to be 68 MPN/100 g. According to the Ministry of Health Food Administration Manual (1995), shellfish flesh which contains faecal coliform levels lower than 230 MPN/100 g is acceptable for human consumption. The shellfish collected from the harbour on this occasion were therefore safe to eat.[8]

3.3 Harbour surveys

Harbour water quality was determined on five occasions (Table 2). The survey of 14 December 1999 was curtailed due to high winds. On this occasion only four of the 13 harbour sites were able to be visited. Furthermore, water temperatures were not measured during the surveys of June and October 1999, while dissolved oxygen levels were not measured during the June survey. The most comprehensive records were therefore obtained for the surveys in January and February 2000 (Appendix 2).

Measurements of salinity and temperature in the surface and bottom waters at each site during January and February showed little sign of vertical stratification of the water column. On average, the salinity of the bottom water was just 0.2 salinity units greater than that of the surface water, while temperatures were the same. The water column throughout the harbour was therefore reasonably well-mixed vertically. Note, however, that freshwater inflows were below average at the time of these surveys (Table 2). It is likely that some degree of vertical stratification will occur at times of higher freshwater inflow (particularly during flood events).[9] Provided such stratification events are reasonably short-lived, it is unlikely that they would result in adverse ecological effects. In particular, the fact that most of the water in the harbour is exchanged with each tide means that extensive or prolonged depletion of bottom water dissolved oxygen in the harbour waters is unlikely to occur.

The harbour-median values for the key water quality variables at the time of each survey are shown in Table 5. These results show that:

- salinities were typically high (>31), with the value in February (35.4) being close to that of seawater (35–36); therefore most (>90%) of the water present in the harbour at the time of the surveys was seawater
- dissolved oxygen levels were generally high (>90% of saturation), although somewhat lower values were recorded during December[10]; in each case conditions were therefore at least satisfactory for sensitive aquatic animals and fish (and they were generally excellent)
- nitrate-N levels were generally low, except for the (windy) survey of 14 December when levels in the seawater were higher than those in the inflowing freshwater (possibly due either to [1] resuspension and oxidation of nitrogenous compounds from the harbour bottom sediments, or [2] upwelling of nitrate-rich oceanic bottom waters in the nearshore zone)

[8] Note, however, that levels of faecal coliforms which markedly exceeded the standards for safe consumption have been measured in other shellfish samples collected from various parts of the harbour: Clean Water Whangamata, unpublished results.

[9] Marked vertical stratification has been observed during summer floods in estuaries elsewhere on the Coromandel Peninsula (Tairua and Whitianga Harbours: Vant 1990)

[10] Note, however, that on this occasion oxygen levels were only able to be measured at two sites before the meter malfunctioned, so that the reliability of the results for those sites is uncertain.

- phosphorus levels were relatively low, and
- levels of faecal coliform and enterococci bacteria were low (harbour-median levels of both were always <10 cfu/100 mL, and were often <2 cfu/100 mL): on each occasion, conditions throughout the harbour were suitable for swimming, and were probably suitable for shellfish-gathering as well

These results indicate that the water quality over much of the area of the harbour was generally good, and was often excellent. This reflects the fact that the harbour largely empties during each tidal cycle, so that most of the water present in the harbour was (clean) seawater. That is, any freshwater-borne contaminants entering the harbour (see later) were markedly diluted by the large volume of seawater present. Note, however, that freshwater flows were below average at the time of all five surveys described here (Table 2). More freshwater would undoubtedly be present in the harbour when flows were higher, but it is unclear whether contaminant levels would necessarily be much higher as a result of this.[11]

At times, the harbour survey results obtained at site 12 (Fig. 1)—near the mouth of the Waikiekie Stream—were noticeably higher than those obtained elsewhere in the harbour, as follows (see Appendix 2 for details):

- the faecal coliform level at site 12 on 12 January was 20 cfu/100 mL, compared to a harbour-wide median of <10 cfu/100 mL; the enterococci level was 10 cfu/100 mL (harbour-median <10 cfu/100 mL)
- the faecal coliform level at site 12 on 10 February was 24 cfu/100 mL (harbour-median 2 cfu/100 mL), while the enterococci level was 20 cfu/100 mL (harbour-median 1 cfu/100 mL)
- the nitrate-N level at site 12 on 10 February was 0.025 g/m^3, whereas the highest value at the other 12 harbour sites was 3–4 times lower than this (namely 0.007 g/m^3)

Further evidence of elevated levels of contaminants in this part of the harbour is described in the following section.

Table 5: Whangamata Harbour water quality on survey dates during 1999–2000. Values are medians of surface water samples collected from 4–13 sites (see Appendix 2 for complete results). "*n*" = number of samples, "S" = salinity, "DO" = dissolved oxygen (% of saturation), "NNN" = nitrate and nitrite nitrogen (g/m^3), "TP" = total phosphorus (g/m^3), "FC" = faecal coliforms (cfu/100 mL), "ent" = enterococci (cfu/100 mL).

Date	*n*	S	DO	NNN	TP	FC	ent
24 Jun 1999	13	31.8	–	0.012	0.021	<1	<10
4 Oct 1999	13	34.6	102	0.003	0.022	<2	<2
14 Dec 1999	4	35.2	78	0.087	0.027	<2	<2
12 Jan 2000	13	34.4	102	<0.002	0.030	<10	<10
10 Feb 2000	13	35.4	98	0.004	0.020	2	1

3.4 Waikiekie-Moana Pt surveys

On 10 February, samples were collected from four sites along a transect across the Waikiekie Stream-Moana Point intertidal area (Fig. 1, inset). Sites were sampled at about the time of high water (10:41 NZST), as the tide ebbed (12:12 to 12:30), and towards the time of low water (16:48). The results are shown in Appendix 3. Water depths over much of this intertidal area were about 1 m near the time of high water. At low water, however, large areas of intertidal sandflat were exposed, but a narrow, shallow channel continued to drain the sandflats (Fig. 1, inset). The third set of samples was collected from within this channel.

At the time of the first transect, salinities at all four sites were high (34.6–35.6), indicating that most of the water present was seawater. Because of this, contaminant levels across the intertidal zone were mostly low. The exceptions, however, were at

[11] This is because concentrations of some freshwater-borne contaminants tend to increase as flows increase (e.g. total phosphorus), while concentrations of others tend to decrease (e.g. ammoniacal-nitrogen).

site I-1 at the mouth of the Waikiekie Stream. At this site, levels of nitrate-N and faecal bacteria were moderately high.

As the tide ebbed, salinities decreased and the size of the contaminated area increased. By the time of the second transect, levels of faecal bacteria and nitrate-N at site I-1 had increased many-fold. In addition, the zone of contamination had increased to encompass site I-2. By the time of the third transect, bacterial and nitrate-N levels were elevated at all four interidal sites, with values being particularly high at and near the mouth of the Waikiekie Stream (i.e. sites I-1 and I-2). These changes are illustrated in Figure 3 which shows how contaminant levels varied with time at sites I-1 and I-3.

These results indicate that the water in the intertidal zone near the mouth of the Waikiekie Stream contained high levels of certain contaminants, and that both (1) the degree of contamination and (2) the size of the area affected increased as the tide ebbed. Section 3.8 provides further information on contaminant levels in the Waikiekie Stream itself, and of the likely sources of these.

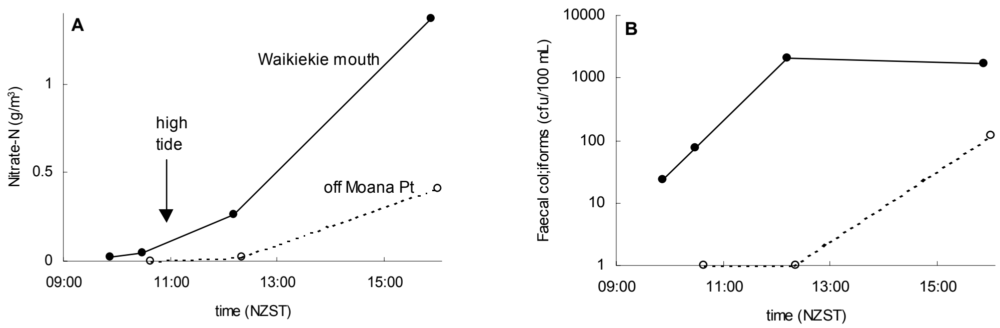

Figure 3: **A**, nitrate, and **B**, faecal coliforms at sites I-1 (●) and I-3 (○) on the Waikiekie-Moana Pt intertidal area (Fig. 1, inset) on 10 February. Note logarithmic axis in **B**. The sample from I-1 at 09:52 was collected as part of the harbour survey (i.e. it is the result for nearby site 12).

3.5 Causeway surveys

Water quality throughout the tidal cycle was determined at the Moananuanu Causeway (Fig. 1, site C) on five occasions (Table 2). As with the harbour surveys, the surveys of 12 January and 10 February were the most comprehensive (see Appendix 4).

The surface and bottom water salinities (December, January and February surveys) showed that a “salt wedge” was present in the Moanaanuanu Estuary. Towards the time of high water, surface and bottom salinities were both similar to that of seawater. But during the outgoing or incoming tide the salinity of the bottom water was often several salinity units higher than that of the surface water (the maximum difference observed was 11.4 salinity units, recorded at 18:00 on 12 January: Appendix 4). In these circumstances less dense water of lower salinity tended to “float” downstream over the more dense, higher salinity water.

Table 6 shows the minimum and maximum values of several key water quality variables observed during each of the surveys at the causeway. In contrast to the harbour-wide surveys (Appendix 2), it is clear that water quality at the causeway was highly variable. During each tidal cycle the relative quantities of freshwater and seawater at the causeway varied markedly. As a result, the levels of freshwater-borne contaminants also varied. When salinity was high (30–35), contaminant levels were usually low, and vice versa. Figure 4 shows several examples of this.

Figure 4A shows a strong inverse correlation between reactive silica levels and salinity at the causeway (correlation coefficient, r = 0.99, p «0.01%). Reactive silica levels are typically much higher in freshwater than in the sea, and a linear relationship like that in

Figure 4A is evidence of "conservative" mixing behaviour within the estuary.[12] The reactive silica concentrations at the pure freshwater (S = 0) and pure seawater (S $\approx$ 36) ends of the plot are termed the "freshwater end-member" and "ocean end-member" concentrations, respectively. In this case, the estimated freshwater end-member reactive silica level was about 20 g SiO_2/m^3 (see Fig. 4A).

The average value of reactive silica measured in the main freshwater inflow to the Moanaanuanu Estuary on the same day was 20.1 g SiO_2/m^3 (n = 8, see Appendix 5). Reactive silica levels in the fresh component of the estuarine water sampled at the causeway and in the main freshwater inflow to the estuary were thus very similar. This means that any other sources of freshwater to the estuary which may have contained markedly-different levels of reactive silica from those in the main inflow were likely to be minor. That is, comparison of the estimated freshwater end-member level of constituent "*C*" with the measured level in the main freshwater inflow provides a way of determining whether other sources of freshwater which may contain markedly-different levels of constituent *C* are likely to be important. This is discussed further in section 3.6.

Although the other freshwater constituents did not show the same degree of strictly conservative mixing behaviour as did reactive silica, Figures 4B–4D indicate that nitrate-N (Fig. 4B), faecal coliforms (Fig. 4C) and enterococci (Fig. 4D) all showed some degree of "quasi-conservative" behaviour at times. The freshwater end-member concentrations of these variables were typically much higher than the ocean end-member concentrations. That is, contaminants typically entered the harbour in the freshwater (i.e. from the land), rather than from the sea. Further information is provided on the source(s) of these in the next sections.

Although contaminant levels generally tended to decrease as salinity increased (Fig. 4), there was a notable exception to this. Nitrate-N levels on 14 December were substantially higher in the seawater (0.090 g/m^3) present at the causeway than in the low salinity water present near the time of low water (<0.002 g/m^3). The reasons for this are not clear. As noted in section 3.3, nitrate-N levels in the seawater present at the harbour sites were unusually high at the time of this (windy weather) survey. However, it is not clear why levels were so low in the predominantly fresh estuarine water which was present towards the time of low water.

The January and February dissolved oxygen results at the causeway were also noteworthy (Figure 5A). In these cases, levels appeared to vary with time of day (i.e. "diurnally"), rather than with salinity. Oxygen levels were lowest in the early morning,[13] and highest towards the end of the afternoon. The observed levels are probably the net result of ecological and other processes which (1) produce, or (2) consume dissolved oxygen.[14] For example, plants and animals living in the estuary's intertidal sandflats require oxygen for respiration. During the night there is no oxygen production, so respiration tends to remove dissolved oxygen from the overlying water. By contrast, during the day various aquatic plants produce oxygen via photosynthesis, thereby adding oxygen to the surrounding water.

Both 12 January and 10 February were bright, sunny days at Whangamata, so photosynthetic rates were probably high on those occasions. Furthermore, on 12 January a slight green sheen was apparent on the subtidal and intertidal sandflats upstream of the causeway, indicating that benthic microalgae were probably abundant. These microscopic, bottom-dwelling plants are normally present in healthy estuaries,

[12] Note that this information is included here not because levels of reactive silica in Whangamata Harbour are cause for concern, but because silica is a constituent which is known to often exhibit markedly conservative mixing behaviour in estuaries, including at nearby Tairua Harbour (Bell 1994). That is, reactive silica should not be regarded as being a "contaminant" in this context, but as a robust tracer of freshwater.

[13] This was also the case on 14 December (see Appendix 4). However, on that occasion the oxygen meter malfunctioned later in the day, so a complete tidal cycle record was not obtained. Oxygen levels were not measured during the June and October surveys.

[14] Exchange with the atmosphere also affects dissolved oxygen levels in the water.

and are often responsible for much of the plant production which occurs there (e.g. Vant et al. 1998).

Increased production as the day proceeds may also account for the somewhat non-conservative behaviour of nitrate-N at the causeway on these occasions. Figure 5B shows that in both cases levels were moderately high in the (low salinity) water present in the early morning (incoming tide), but were substantially lower in the (low salinity) water present in the late afternoon (outgoing tide). This suggests that the benthic microalgae were stripping the nitrate-N from the water more rapidly during the latter part of the day—following their long exposure to bright, sunny conditions.[15]

Table 6: Moanaanuanu Causeway water quality on survey dates during 1999–2000. Values are the minima and maxima of 9–12 samples of near-surface water collected at about hourly intervals throughout a full tidal cycle (see Appendix 4 for complete results). Abbreviations as in Table 5.

Date	*n*	S	DO	NNN	TP	FC	ent
24 Jun 1999	11	5.3, 32.5	–	0.013, 0.126	0.004, 0.024	1, 300	<1, 38
4 Oct 1999	11	7.9, 34.5	–	<0.002, 0.091	0.018, 0.039	<2, 200	<2, 76
14 Dec 1999	12	3.9, 35.5	79, 95	<0.002, 0.090	0.019, 0.059	<2, 400	<2, 98
12 Jan 2000	12	5.7, 34.7	76, 123	<0.002, 0.042	0.020, 0.063	<10, 410	<10, 240
10 Feb 2000	9	10.2, 35.5	72, 128	<0.002, 0.045	0.018, 0.046	<1, 360	<1, 160

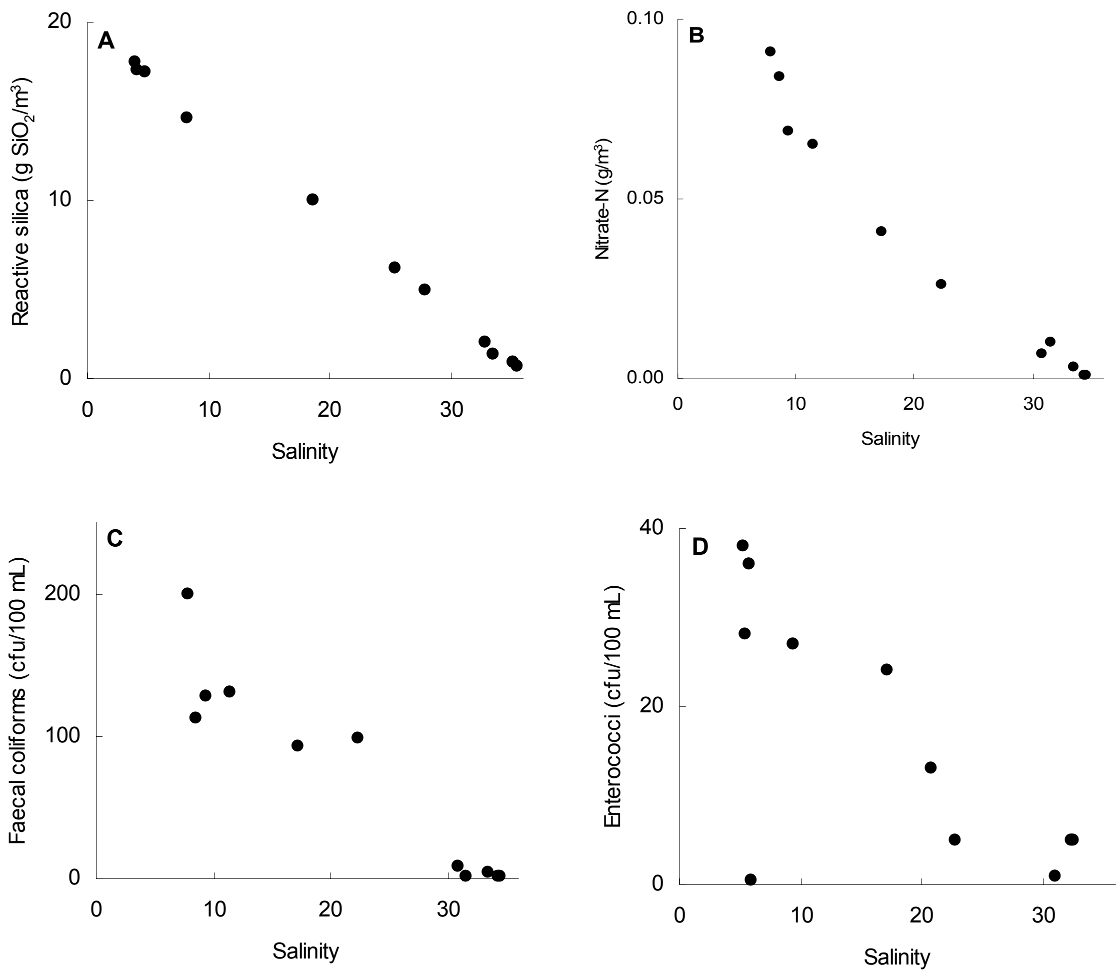

Figure 4: Water quality and salinity at the Moanaanuanu Causeway during surveys in 1999. **A**, reactive silica (14 Dec); **B**, nitrate-N (4 October); **C**, faecal coliforms (4 October); and **D**, enterococci (24 June).

[15] Note also that water temperatures were higher during the afternoon (Appendix 4), which may also have contributed to higher uptake rates then.

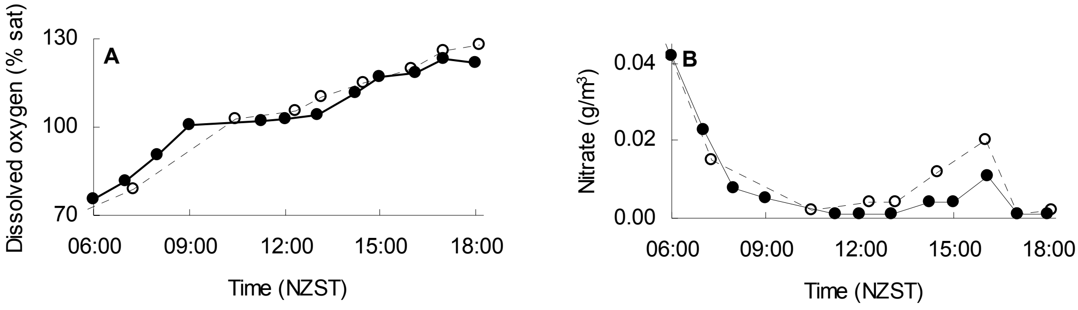

Figure 5: **A**, dissolved oxygen, and **B**, nitrate-N during tidal cycles at the Moanaanuanu Causeway on 12 January (●) and 10 February (○). High water occurred at 11:10 and 10:41 NZST, respectively.

3.6 Lower Wentworth River surveys

The June and November causeway surveys both showed that moderate levels of freshwater-borne contaminants were entering the harbour via the Moanaanuanu Estuary. As a result of this, additional surveys were arranged to identify the likely contaminant source(s). These surveys were undertaken on the same days as the December, January and February harbour and causeway surveys. A preliminary reconnaissance (by kayak, 12 December) identified a convenient sampling site in the lower reach of the Wentworth River, just upstream of the Moanaanuanu estuarine mixing zone. This site was located near the downstream or seaward end of the Whangamata golf course (Fig. 1, site V).

The Okauanga Stream flows into the Moanaanuanu Estuary between site V on the Wentworth River and the Moanaanuanu Causeway. The Whangamata wastewater treatment pond is adjacent to this stream (map reference T12, 638 397). It was considered that any substantial leak of contaminants from this system would cause contaminant levels in the freshwater flowing past the causeway to be appreciably higher than those flowing past site V. The aim of the additional surveys was therefore to use the “freshwater end-member” technique described in section 3.5 to determine whether there was any evidence of additional source(s) of contamination between the lower end of the Wentworth River (at site V) and the Moanaanuanu Causeway.

Table 7 shows the daily median levels of nitrate-N, faecal coliforms and enterococci in the lower Wentworth River (site V). The complete results are given in Appendix 5. Daily median nitrate-N levels on the three occasions were similar, being in the range 0.020–0.033 g/m^3. Daily median faecal coliform levels were 365–650 cfu/100 mL, while daily median enterococci levels were 100–275 cfu/100 mL. These values were typical of those found in small streams draining developed areas elsewhere in the Waikato region (e.g. Wilson 1999). They represent a “moderate” degree of contamination by these constituents.

Table 7 also shows the freshwater end-member levels of these contaminants, as estimated from the salinity-based mixing plots from the causeway surveys (see Fig. 4). In most cases the freshwater end-member contaminant level at the causeway was similar to—or lower than—the corresponding daily median level of the contaminant in the lower Wentworth river. For example, on 10 February the median faecal coliform level in the lower Wentworth River was 650 cfu/100 mL, slightly higher than the freshwater end-member level of 200–500 cfu/100 mL at the causeway. The enterococci levels were 275 cfu/100 mL (Wentworth) and 100–200 cfu/100 mL (causeway). There was therefore no evidence from these surveys of any major additional sources of contamination between the lower Wentworth River and the Moanaanuanu Causeway. In particular, there was no evidence of any substantial leak of contaminants from the wastewater treatment pond adjacent to the Okauanga Stream (which flows into the Moanaanuanu Estuary upstream of the causeway). Broadly-speaking, the contamination observed at the causeway was consistent with that found in the lower Wentworth River.

Table 7: Median water quality in the lower Wentworth River on survey dates during 1999–2000 (see Appendix 5 for complete results), and approximate freshwater end-member values further downstream—estimated from surface water samples collected throughout the tidal cycle at the Moanaanuanu Causeway (results in Appendix 4). Abbreviations as in Table 5.

	Lower Wentworth River				Causeway freshwater end-member		
Date	***n***	**NNN**	**FC**	**ent**	**NNN**	**FC**	**ent**
24 Jun 1999	–	–	–	–	0.140–0.160	200–400	30–50
4 Oct 1999	–	–	–	–	0.080–0.120	150–250	40–60
14 Dec 1999	8	0.026	365	100	0	100–500	50–120
12 Jan 2000	4	0.020	450	160	0.020–0.050	300–500	100–300
10 Feb 2000	6	0.033	650	275	0.030–0.060	200–500	100–200

3.7 Wentworth River longitudinal surveys

These surveys were designed to provide a preliminary indication of the way in which contamination levels varied down the length of the Wentworth River (Fig. 1, sites I to V).[16] Table 8 shows some of the water quality results for the two surveys (12 January and 10 February: complete results are given in Appendix 6). In each case contaminant levels progressively increased down the length of the river (see Figure 6 also).

On both dates surveyed, levels of nitrate-N increased by about 2–4 fold down the river (Table 8, Fig. 6). Levels of faecal coliforms increased by 3–5 fold, and levels of enterococci increased by 4–10 fold. The results indicated that the river flowing out of the largely-forested area upstream of site I ("Above camp") was slightly contaminated with faecal bacteria, but that nutrient levels were relatively low. In the lower reaches of the river, particularly at sites IV and V, levels of faecal bacteria were moderately high. The results suggest that much of the contaminant load observed at site V entered the river from the largely pastoral area of the catchment downstream of site I.

On 12 January a visual survey of the river was made between sites III and V (by kayak). At several places it was apparent that stock had unrestricted access to the river channel. At one point (map reference T12, 627 384), a simple ford connected paddocks on either side of the river. Cattle were observed in the river at this point, and cow pats (i.e. faeces) were visible at the edge of the river. Areas such as these are likely to be major sources of the contaminants found further downstream at sites IV and V on this date (Table 8).

Table 8: Water quality at sites on the Wentworth River (site locations as in Figure 1 and Table 1). See Appendix 6 for complete results. "Dist" = distance from head of catchment (km), other abbreviations as in Table 5.

		12 January 2000			10 February 2000		
Site	**Dist**	**NNN**	**FC**	**ent**	**NNN**	**FC**	**ent**
I	5	0.005	70	30	0.012	92	24
II	6	<0.002	180	50	0.009	210	49
III	8	0.004	310	70	0.007	150	48
IV	10	0.016	380	60	0.025	210	69
V	12	0.019	370	130	0.025	270	240

[16] Note that the most upstream site—just above the Department of Conservation camping area, and at the downstream end of the large forested part of the catchment—was still several kilometres from the head of the catchment. In this preliminary investigation no attempt was made to collect samples from within the forested area further upstream.

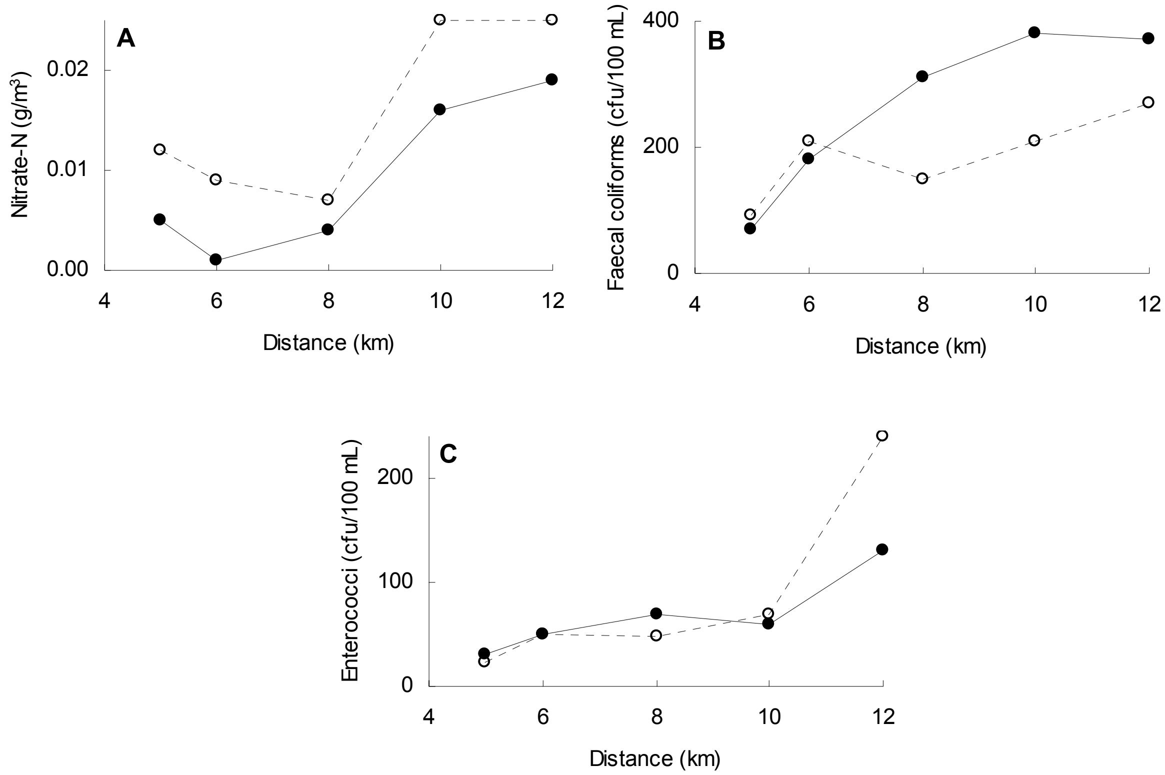

Figure 6: Water quality in the Wentworth River at increasing distances from the head of the catchment on 12 January (●) and 10 February (○). **A**, nitrate-N; **B**, faecal coliforms; and **C**, enterococci.

3.8 Lower Waikiekie Stream surveys

Samples were collected from the lower Waikiekie Stream (Fig. 1, inset, site W) on the days of the December, January and February harbour and causeway surveys (Table 2). The complete set of results is shown in Appendix 7.

The most striking feature of the water quality at this site was the particularly high nitrate-N levels, with daily medians ranging from 0.78 g/m^3 (14 December) to 2.08 g/m^3 (12 January). Levels of faecal bacteria were also high: (1) median faecal coliform levels ranged from 1300 to 1550 cfu/100 mL, while (2) enterococci levels ranged from 225 to 360 cfu/100 mL.

It is interesting to compare the results for the lower Waikiekie Stream with those for the lower Wentworth River. Table 9 shows the daily median results for nitrate-N, faecal coliforms and enterococci on three sampling occasions. Nitrate-N levels in the Waikiekie were 30 to 100 times higher than those in the Wentworth, while levels of faecal bacteria were about two or more times higher.

Treated sewage wastewater from Whangamata is spray-irrigated to an area of exotic forest part way up the catchment of the Waikiekie Stream (in the vicinity of map reference T12, 623 394). It has previously been shown that a portion of the wastewater-derived nitrogen bypasses the forest wetland and reaches the stream. In 1990, DSIR estimated that the overall nitrogen removal rate of the Whangamata forest irrigation system was about 77%, with the remaining 23% leaching to the stream (DSIR 1990). It is therefore likely that most of the nitrate-N observed at site W in these surveys came from the wastewater irrigation area.

On 10 February, a single sample was also collected from a site about 1 km upstream of site W (see Appendix 7 for details). This site was downstream of the spray irrigation area, but upstream of a small area of pastoral farming in the lower part of the Waikiekie catchment. While the nitrate-N levels at this site were similar to those observed at site W, the faecal bacteria levels were several times lower (Appendix 7).[17] Although further information on this would be desirable, these preliminary results do suggest that while the spray irrigation system is the main source of the nitrogen observed in the Waikiekie Stream at site W, the faecal bacteria in the stream come from both the spray irrigation system and from the area of pastoral farming.

On the same day, a sample was also collected from a site about 0.2 km downstream of site W (at the "Lions' footbridge", map reference T12, 639 417). The stream was sampled at 11:01 NZST, near the time of high water. There was evidence of some salt water intrusion this far up the stream, with surface water salinity being 3.6 (i.e. about 10% seawater). The contaminant levels were high (e.g. nitrate-N = 1.71 g/m^3, and faecal coliform and enterococci levels of 1300 and 400 cfu/100 mL, respectively). These levels were similar to those obtained at about the same time (10:50 NZST) at site W (see Appendix 7).

Table 9: Median water quality in the lower reaches of the Wentworth River (site V) and the Waikiekie Stream (SH25) on three sampling days in 1999–2000 (complete results in Appendices 5 and 7). "Wen" = Wentworth River, "Wai" = Waikiekie Stream, other abbreviations as in Table 5.

	NNN		FC		ent	
Date	**Wen**	**Wai**	**Wen**	**Wai**	**Wen**	**Wai**
14 Dec 1999	0.026	0.78	365	1550	100	225
12 Jan 2000	0.020	2.08	450	1400	160	240
10 Feb 2000	0.033	1.86	650	1300	275	360

3.9 Foams and scums

Concern has been expressed about the nature and possible origin of conspicuous foams and scums observed floating on the surface of the harbour waters, particularly in the Moanaanuanu Estuary. During the June 1999 survey, five samples of foam were collected from the Moanaanuanu Estuary. At the time of collection the foam appeared yellow-brown in colour, and was no more than one centimetre thick. The samples were sent to the Industrial Research Ltd laboratory for carbohydrate analysis.

The abstract from the analyst's report (IRL 1999) is reproduced in Appendix 8. The main findings of the report were as follows:

- samples were dried by rotary evaporation and analysed by gas chromatography
- several different carbohydrates were identified in all the samples
- all samples contained relatively high levels of the carbohydrates rhamnose and fucose
- it is unclear whether these carbohydrates were present only in the foam or whether they may have come from the underlying water (which was also present in the samples collected)
- the levels and type of carbohydrates which would be expected to be found in foams and water from around the New Zealand coast are not known, so the significance of the results of these analyses is unclear

A brown surface scum was observed at the Whangamata slipway (map reference T12, 651 411) on 4 October at 22:00 NZST (about an hour after low water). The water was ankle-deep. The scum was sampled, and found to contain faecal coliform and enterococci levels of 5900 cfu/100 mL and 700 cfu/100 mL, respectively. These levels were much higher than those found in the near-surface water samples collected on the same day (see Appendices 2 and 4). The faecal coliform level in the near-surface sample collected from the causeway at 22:25 was 200 cfu/100 mL, or about 30 times

[17] Note that although no samples were collected upstream of the Watts Rd gate, we may infer that stream water quality in the forested region upstream of the spray-irrigation area would be likely to be similar to that at site I on the Wentworth River—see Table 8. That is, contaminant levels in the Waikiekie Stream upstream of the spray-irrigation area are likely to be much lower than those observed downstream of this area at SH25 (see table 9).

lower than the level in the scum. The enterococci level in the causeway sample (44 cfu/100 mL) was about 16 times lower than that in the scum.[18] These results are consistent with the general observation in section 2 that levels of bacteria in surface films can be many times higher than those in the underlying water.

As noted above (section 3.6), on 12 December a reconnaissance was made of the Moanaanuanu estuarine mixing zone between the causeway and the golf course (Fig. 1, sites C and V). Conspicuous surface features were observed at two locations near the time of high water (colour photographs were taken of these, and copies are available on request). The first was a patch of yellow-brown foam, about 2 m × 1 m in size which was observed in shallow water (c. 0.2 m deep) near the edge of the channel in an area of salt-marsh vegetation (map reference T12, 646 389). It appeared to be typical of the type of foam which is often observed in such areas. I consider it was likely to have been a naturally-occurring estuarine foam, resulting from wind and wave action on polysaccharide surfactants which had been released by coastal plants (e.g. microalgae).

The second was a similar-sized patch of brown, fibrous-looking material at the edge of the channel in deeper water, just upstream of the Old Tairua Bridge (map reference T12, 644 391). At first it appeared as though this was an accumulation of plant fibres. However, when the surface of the water was agitated (by hand), the material broke-up and dispersed. When I rubbed the remnants between my fingers, they felt gritty—like fine sediment (silt-to-sand-sized). I concluded this material was fine silt which had washed down the river and was floating in a patch on the water surface. Presumably a combination of currents and the wind had caused the particles to line-up into an apparently-structured feature.[19] In both cases the surface features had disappeared when the area was re-visited about an hour later. It's likely that they had broken-up and dispersed as the tide began to ebb.

Surface foams have also been observed on other Coromandel estuaries. A visual and microbiological assessment is available for samples of foam which were collected from Tairua Harbour on 30 September 1999.[20] The samples "showed a high level of marine material including living and dead pennate diatom skeletons, aggregates of organic matter and inorganic particles. Bacteria were numerous and active".[21]

It was concluded that the foam "was most likely derived from a natural bloom of photosynthetic algae … probably pennate diatoms". It was observed that "these organisms coat their silica cell in mucilage and excrete further mucilage as a slime layer on which they move", and that the mucilage "may give rise to a stable foam when suspended from tidal flats on the incoming tide and worked by the wind". It was further concluded that "the foam itself is not indicative of, or resulting from, waste containing high levels of faecal bacteria".

These various observations suggest that the foams and scums observed in and near the Moanaanuanu Estuary, while being visually conspicuous—and having the potential to be aesthetically unpleasant, are likely to have been natural phenomena.[22] There was no evidence from these observations that the features were directly associated with sewage.

[18] The levels of faecal bacteria in the (near-surface) water samples collected from the causeway at other times on 4 October were all lower than those in the sample collected at 22:25—see Appendix 4.

[19] Regular features like this which are caused by various physical processes are often observed on the surfaces of waterbodies (e.g. Langmuir cells).

[20] Letter of 22 October 1999 to Environment Waikato from Woodward-Clyde Consultants, Auckland (I Fraser and G Lewis). Samples were analysed for faecal coliforms, *Escherichia coli*, and enterococci, and microscopic observations were made (at 100× and 400× magnification).

[21] The highest faecal coliform and enterococci levels in the foam samples were 1700 cfu/100 mL and 170 cfu/100 mL, respectively.

[22] Note that while the processes directly responsible for these phenomena may be described as "natural", the rates at which the processes occur may have increased as a result of catchment and urban development (e.g. higher nutrient levels supporting higher algal biomass, increased bank erosion producing higher loads of fine sediments).

4 Conclusions

4.1 Bathing beaches

All three of the popular bathing beaches in the Whangamata area which have been routinely monitored by Environment Waikato were found to meet the national guidelines for marine bathing waters, and thus were suitable for bathing (Table 4). This includes the harbour beach (Fig. 1, site 14), located about 0.5 km landward of the harbour entrance. Despite the fact that moderately-contaminated freshwater does enter the harbour upstream of this beach, levels of faecal bacteria at the beach were generally low. This suggests that dilution with clean seawater generally ensures that the water at this beach is safe for bathing.

Although the water at this beach was also found to be generally suitable for shellfish-gathering, elevated bacterial levels were occasionally recorded. Because many shellfish are filter-feeders, and thus can concentrate contaminants within their flesh, these occasionally elevated bacterial levels in the water mean shellfish from this area may not be safe to eat. Even so, shellfish gathered from near this site during January 2000 did meet Ministry of Health guidelines, and were thus considered safe to eat. However, shellfish previously collected from the harbour by others have exceeded the guidelines and were not safe to eat (Clean Water Whangamata, unpublished results).

The fact that levels of faecal bacteria are moderately-high in certain of the rivers and streams which flow into the harbour, and are likely to be high in the urban stormwater which enters the harbour, means that shellfish gathered from parts of the southern half of the harbour should probably not be eaten. This is not unexpected: the *Waikato State of the Environment Report* concluded that the water quality of enclosed harbour or estuarine waters in the Waikato Region was generally not suitable for shellfish-gathering (Environment Waikato 1999b, p. 207, fig. 65).

4.2 Harbour water quality

Apart from extreme flood events, most of the water in Whangamata Harbour is seawater. And contaminant levels are usually low in seawater. This means that any contaminants which enter the harbour in the inflowing freshwaters are usually substantially diluted by the clean seawater. As a result, contaminant levels were usually found to be low over a wide area of the harbour (Table 5). In particular, levels of faecal bacteria were low over most of the harbour so that the water was suitable for swimming. Although the water generally met the guidelines for shellfish-gathering as well, the occasionally-elevated bacterial levels, particularly in the more-urbanized area in the southern part of the harbour, means shellfish taken from this area should probably not be eaten (see above).

Furthermore, levels of the plant nutrients (dissolved) nitrogen and (total) phosphorus were also generally low over a large area of the harbour. As a result, the nutrient levels would probably be unlikely to support severe nuisance plant growths (e.g. major algal blooms, sea lettuce infestations). Levels of dissolved oxygen were also generally good (and were often excellent), so that fish and aquatic animals living in the harbour were unlikely to be stressed by severe oxygen depletion.

There are two important caveats to these broad conclusions, however. Firstly, as it happened, all five harbour surveys were undertaken following periods of lower than average freshwater inflow. It is unclear what effect higher flows would have on harbour water quality. While high flows are typically turbid, and contain higher phosphorus levels for example, levels of other contaminants often fall as flows increase (e.g. ammoniacal nitrogen). Higher than average flows will therefore not necessarily mean poorer harbour water quality than that found in these surveys. Even if contaminant levels do increase, the increased flows should rapidly-flush these from the harbour, so any effect should be relatively short-lived.

Secondly, while water quality was generally good over large areas of the harbour, it was found to be poorer in areas where moderately-contaminated river or stream water mixed with harbour water. In particular, contaminant levels were moderately-high at times in the Moanaanuanu Estuary where the Wentworth River enters the harbour, and in the vicinity of the mouth of the Waikiekie Stream.

As the tide ebbed at both these locations it was found (1) that contaminant levels increased, and (2) that the area of harbour affected also increased. The tidal cycle surveys at the Moanaanuanu Causeway clearly showed that the contaminants generally entered the harbour in freshwater. This was also apparent from the more limited sampling in the vicinity of the mouth of the Waikiekie Stream.

As noted above, areas such as these are probably not suitable for shellfish-gathering for human consumption. Furthermore, it is probably not safe to swim within perhaps 0.2–0.5 km of the mouth of the Waikiekie Stream,[23] particularly at times other than near high tide. It is not clear, however, whether the elevated nitrogen levels observed in these areas—particularly in the immediate vicinity of the mouth of the Waikiekie Stream (see Fig. 3A)—are cause for concern. While no nuisance plant growths were observed in these areas, the fact that the current nitrogen loads to the harbour in general are considerably higher than the pre-development loads means that aquatic plant growth rates within the harbour are probably higher now than in the past.[24] This does mean that the *potential* for nuisance plant growths in the harbour is likely to be higher now than it was prior to the development of the area. It would be desirable to give further consideration to this issue, in particular to determine whether nitrogen levels—especially those in the Waikiekie Stream—should be reduced, and if so, to what extent.

4.3 Sources of contaminants

As noted above, it is clear that most of the faecal bacteria and nitrate-N observed in the harbour entered in the inflowing rivers and streams (i.e. from the land rather than from the sea). The results from the causeway demonstrated that contaminant levels were generally highest when salinities were low, and vice versa (Fig. 4).

Comparison of the contaminant levels observed in the lower Wentworth River with the "freshwater end-member" values estimated from the measurements made at the causeway (Table 7) indicated that there was no evidence of any major additional sources of contamination between these sites. In particular, there was no evidence of any substantial leak of contaminants from the Whangamata wastewater treatment pond to the Moanaanuanu Estuary. This suggests that the moderate degree of contamination observed in the harbour at the causeway came from the catchment of the Wentworth River. Furthermore, the results of the longitudinal surveys (Table 8) suggested that much of the contaminant load entered the river from the largely pastoral area in the lower part of the catchment (i.e. between sites I and V, Fig. 1). Inspection of this area showed that livestock had unrestricted access to the river in places (and indeed were observed in and near the river channel).

Levels of faecal bacteria in the lower Waikiekie Stream were somewhat higher than those in the Wentworth River, while nitrate-N levels were 30–100 times higher (Table 9). The results of this study are consistent with the conclusions of an earlier assessment that leakage from the wastewater spray irrigation system in the catchment of the Waikiekie Stream is the main cause of the markedly elevated nitrate-N levels observed in the stream (DSIR 1990). By contrast, it appears that both the spray irrigation system and an area of pastoral farming probably contribute to the levels of faecal bacteria observed in the stream (although it is noted that there is very little information currently available on this).

[23] Nor is it likely to be safe to swim in the stream itself, given the high levels of faecal bacteria reported in section 3.8.

[24] DSIR (1990) estimated that leakage from the spray irrigation system contributed 30% of the nitrate load to the harbour in 1990, and considered that the spray irrigation load could more than triple by 2010. (The native forest, exotic forest, pastoral and urban areas were also estimated to contribute 28%, 18%, 20% and 5% of the 1990 nitrate load, respectively.)

During 1987–90 the highest nitrate level observed in the Waikiekie Stream below the spray irrigation area during summer months was about 0.5 g/m^3 (DSIR 1990, fig. 1). In this survey, daily-median nitrate-N levels during December-February were rather higher than this, ranging from 0.78 to 2.08 g/m^3 (Table 9).[25] This suggests either (1) that the spray irrigation system has become less effective in removing nitrogen from the wastewater during the past decade, or (2) that the nitrogen load to the system has increased. As noted above, it would be desirable for the likely effects on the harbour of this large—and apparently increasing—load of wastewater nitrogen to be thoroughly assessed.

As noted in section 3.6, the levels of faecal bacteria in the lower Wentworth River were typical of those found in many small streams in developed parts of the Waikato Region. Figure 7 shows how enterococci levels in 67 rivers and streams throughout the region vary with the extent to which their catchments have been developed for pasture or cropping.[26] Broadly speaking, the more developed a catchment is, the higher the enterococci levels are likely to be (r = 0.62 for log-linear data, p <0.01%).

Figure 7 also shows the results for the lower Wentworth River and lower Waikiekie Stream (sites V and W, respectively).[27] It is apparent that in both cases—but particularly for the Waikiekie Stream (site W)—the observed median enterococci levels are considerably higher than would be expected for “typical” Waikato rivers/streams of the same degree of catchment development. So while there are other streams in the region which contain higher levels of faecal bacteria, they tend to be located in catchments which are considerably more-developed. This suggests that for the Waikiekie Stream in particular, some part of the total load of faecal bacteria to the stream is due to factors other than catchment development. This is consistent with the conclusion noted above that part of the load results from leakage from the wastewater spray irrigation area.

The area of the catchment of the Waikiekie Stream is about 5 km^2, or about five times smaller than that of the Wentworth River. The average flow in the Wentworth is therefore likely to be about five times greater than that in the Waikiekie. By contrast, levels of faecal bacteria in the Waikiekie were about two or more times higher than those in the Wentworth (Table 9, Fig. 7). This indicates that the loads of faecal bacteria to the harbour from the Wentworth River and the Waikiekie Stream are probably of the same order of magnitude.

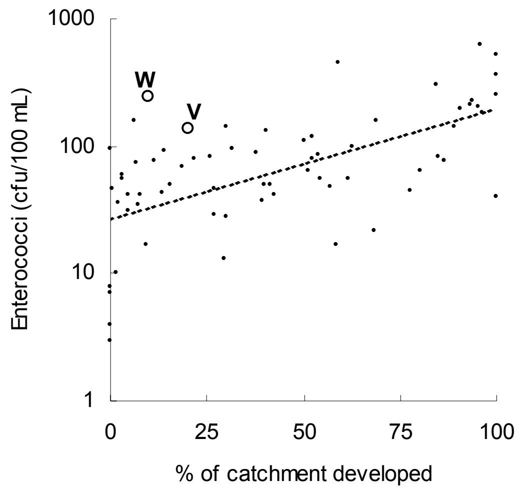

Figure 7: Median enterococci level during 1994–98 and percent of catchment developed at 67 sites in the Waikato Region (from Vant et al. 2000; note logarithmic axis). Results for the Wentworth River (“V”) and the Waikiekie Stream (“W”) during December 1999 to February 2000 are also shown.

[25] By way of comparison, the median nitrate-N level at 80% of river and stream sites elsewhere in the Waikato Region is less than 1 g/m^3; it exceeds 2 g/m^3 only at the 5% of sites which are markedly-affected by point source discharges or intensive land use (Wilson 1999).

[26] Note that this definition of “developed land” does not include land used for exotic forestry. In general the loads of faecal bacteria (and plant nutrients) from areas of exotic forest are low, similar to those from native forest.

[27] Enterococci levels are the medians of all the results in Appendices 5 and 7, respectively. Percent of catchment developed for sites V and W was estimated from the land uses shown on the NZMS 260 map (sheet T12).

References

ASTM 1982: *Standard Practices for Sampling Water*. D 3370 – 82. American Society of Testing and Materials, Philadelphia.

Bell, R.G. 1994: Behaviour of Dissolved Silica, and Estuarine/coastal Mixing and Exchange Processes at Tairua Harbour, New Zealand. *New Zealand Journal of Marine and Freshwater Research 28:* 55–68.

Blanchard, D.C. 1989: The Ejection of Drops from the Sea and Their Enrichment with Bacteria and Other Materials: A Review. *Estuaries 12:* 127–137.

Buchanan, I. (ed.) 1999: *Environmental Monitoring—Data Report 1998*. Environment Waikato Technical Report 1999/05. Environment Waikato, Hamilton.

DSIR 1990: *Environmental Impacts of the Whangamata Sewage Land Treatment System*. Water Quality Centre Consultancy Report 6029. Department of Scientific and Industrial Research, Hamilton.

Environment Waikato 1999a: *The Future of the Whangamata Catchment and Harbour—Results of a Community Consultation, Labour Weekend, October 1999.* Environment Waikato, Hamilton.

Environment Waikato 1999b: *Waikato State of the Environment Report 1998*. Environment Waikato, Hamilton.

Hume, T.M.; Herdendorf, C.E. 1993: On the Use of Empirical Stability Relationships for Characterising Estuaries. *Journal of Coastal Research 9:* 413–422.

IRL 1999: *Carbohydrate Analysis of Estuarine and Pond Water Samples from Whangamata*. IRL Report 56634.01. Industrial Research Limited, Lower Hutt.

MfE/MoH 1998: *Bacteriological Water Quality Guidelines for Marine and Fresh Water: Guidelines for the Management of Recreational and Marine Shellfish-gathering Waters.* Ministry for the Environment and Ministry of Health, Wellington.

Vant, W.N. 1990: Causes of Light Attenuation in Nine New Zealand Estuaries. *Estuarine, Coastal and Shelf Science 31:* 125–137.

Vant, W.N. 1995: *Water Quality Survey of Manukau Harbour: Seventh Annual Report.* ARC Environment Technical Publication 56. Auckland Regional Council, Auckland.

Vant, B. 1999: *Coromandel Peninsula Bathing Beach Survey 1998/99*. Environment Waikato Technical Report 1999/04. Environment Waikato, Hamilton.

Vant, W.N.; Gibbs, M.M.; Safi, K.A.; Thrush, S.F. 1998: Fluxes of Organic Carbon in Manukau Harbour, New Zealand. *Estuaries 21:* 560–570.

Vant, B.; Taylor, A.; Wilson, B. 2000: Land use and river condition in the Waikato Region. In: *Proceeding of Water 2000 Conference*. New Zealand Water and Wastes Association, Auckland.

Wilson, B. 1999: *Regional Rivers Water Quality Monitoring Programme—Data Report 1998*. Environment Waikato Technical Report 1999/01. Environment Waikato, Hamilton.

Appendix 1: Bathing beach surveys

Whangamata Harbour

Date	NZST	T_s	S_s	ent	FC	Bathers	Others
5-Dec-99	15:05	19.4	35.2	<1	<1	0	7
12-Dec-99	14:45	22.1	33.3	<2	190	0	10
19-Dec-99	09:30	18.8	31.2	6	40	0	10
28-Dec-99	09:05	18.9	35.1	3	3	5	12
4-Jan-00	14:45	18.7	35.0	<1	2	0	2
9-Jan-00	14:45	22.7	33.0	<1	1	5	30
16-Jan-00	09:05	20.5	33.0	19	25	0	5
24-Jan-00	09:20	20.5	35.5	<2	4	0	0
31-Jan-00	13:10	20.6	35.7	<1	1	3	12
6-Feb-00	13:50	23.4	34.4	<1	<1	0	6
13-Feb-00	09:55	20.7	35.4	<1	2	0	8
20-Feb-00	10:05	–	35.2	29	19	5	12

Whangamata Beach North

Date	NZST	T_s	S_s	ent	FC	Bathers	Others
5-Dec-99	15:25	18.9	35.3	6	5	50	65
12-Dec-99	15:00	19.0	35.4	<2	30	27	65
19-Dec-99	09:05	17.2	35.5	<2	<2	3	26
28-Dec-99	08:55	19.0	35.1	15	4	75	100
4-Jan-00	14:55	18.7	35.2	<1	<1	50	100
9-Jan-00	15:00	21.2	35.1	<1	<1	>400	>500
16-Jan-00	08:55	20.2	35.1	2	1	20	50
24-Jan-00	09:05	20.8	35.5	2	2	50	50
31-Jan-00	13:20	21.3	35.6	3	3	60	150
6-Feb-00	13:55	21.4	35.7	<1	2	50	140
13-Feb-00	09:45	20.6	35.3	<1	1	20	60
20-Feb-00	09:55	–	35.2	5	1	60	200

Whangamata Beach South

Date	NZST	T_s	S_s	ent	FC	Bathers	Others
5-Dec-99	15:35	20.8	35.2	6	<1	5	20
12-Dec-99	15:15	19.8	35.3	<2	2	10	15
19-Dec-99	09:15	17.7	34.1	2	18	2	14
28-Dec-99	08:45	19.3	34.8	4	6	5	70
4-Jan-00	15:05	19.1	35.1	6	4	11	60
9-Jan-00	15:15	23.0	31.8	<1	3	>200	>200
16-Jan-00	08:45	19.6	32.8	2	18	15	50
24-Jan-00	09:00	21.4	35.3	4	4	5	12
31-Jan-00	13:35	21.8	35.5	4	2	9	25
6-Feb-00	14:10	22.4	35.5	<1	<1	12	35
13-Feb-00	09:35	20.4	34.9	2	2	2	40
20-Feb-00	09:45	–	35.3	8	10	10	55

Abbreviations used in appendices

amm-N	ammoniacal-nitrogen, g/m^3
Bathers	number of people swimming at bathing beach site
bot	Secchi disc visible on bottom (i.e. $z_{SD} > z_{max}$)
DO_b	dissolved oxygen near the bottom, % of saturation concentration
DO_s	dissolved oxygen near the surface, % of saturation concentration
DRP	dissolved reactive phosphorus, g/m^3
DSi	dissolved reactive silica, g SiO_2/m^3
ent	enterococci bacteria, colony forming units/100 mL
FC	faecal coliform bacteria, colony forming units/100 mL
NNN	total oxidized nitrogen (nitrate and nitrite), g/m^3
NZST	NZ Standard Time, hh:mm
Others	number of people on beach at bathing beach site
S_b	salinity near the bottom, no units
S_s	salinity near the surface, no units
T_b	water temperature near the bottom, °C
T_s	water temperature near the surface, °C
TKN	total Kjeldahl nitrogen, g/m^3
TP	total phosphorus, g/m^3
z_{max}	maximum depth at sampling site, m
z_{SD}	Secchi disc depth, m

Appendix 2: Harbour surveys. Abbreviations as in Appendix 1.

24 Jun 1999; HW @ 16:05 NZST

site	NZST	z_{max}	S_s	S_b	T_s	T_b	DO_s	DO_b	z_{SD}	amm-N	NNN	DRP	TP	FC	ent
2	13:45	–	31.4	–	–	–	–	–	–	0.02	0.014	<0.004	0.021	<1	<10
3	13:35	–	31.5	–	–	–	–	–	–	<0.01	0.012	<0.004	0.021	<1	<1
4	14:30	–	32.9	–	–	–	–	–	–	<0.01	<0.002	<0.004	0.018	<1	<1
5	14:35	–	33.1	–	–	–	–	–	–	<0.01	<0.002	<0.004	0.021	<1	<1
6	15:00	–	31.3	–	–	–	–	–	–	<0.01	0.015	<0.004	0.021	1	<10
9	13:55	–	31.8	–	–	–	–	–	–	0.01	0.016	<0.004	0.023	2	<10
10	14:00	–	31.5	–	–	–	–	–	–	0.02	0.011	<0.004	0.025	<1	<10
11	14:25	–	31.6	–	–	–	–	–	–	0.03	0.012	0.004	0.021	<1	<10
12	14:50	–	31.9	–	–	–	–	–	–	0.03	0.025	<0.004	0.021	<1	<1
13	14:10	–	30.4	–	–	–	–	–	–	0.02	0.010	<0.004	0.029	<1	<1
14	15:10	–	32.9	–	–	–	–	–	–	<0.01	0.027	<0.004	0.019	<1	<10
15	13:20	–	32.6	–	–	–	–	–	–	<0.01	0.017	<0.004	0.018	<1	<10
16	13:00	–	32.6	–	–	–	–	–	–	<0.01	0.010	<0.004	0.019	<1	<10

4 Oct 1999; HW @ 14:35 NZST

site	NZST	z_{max}	S_s	S_b	T_s	T_b	DO_s	DO_b	z_{SD}	amm-N	NNN	DRP	TP	FC	ent
2	13:45	4.0	34.8	–	–	–	102.3	103.1	4.0	0.02	<0.002	<0.004	0.022	<2	2
3	13:34	–	35.0	–	–	–	105.0	105.7	3.8	<0.01	<0.002	<0.004	0.022	<2	4
4	14:35	0.4	35.0	–	–	–	101.3	–	bot	0.02	0.003	<0.004	0.020	2	<2
5	14:45	1.3	35.0	–	–	–	100.8	100.4	bot	0.01	0.004	<0.004	0.024	<2	<2
6	15:10	0.5	34.5	–	–	–	104.4	–	bot	0.02	0.006	<0.004	0.020	2	<2
9	13:55	5.5	34.2	–	–	–	101.3	102.1	3.5	0.02	0.004	<0.004	0.020	4	<2
10	14:00	1.0	33.6	–	–	–	96.4	–	bot	0.03	0.009	<0.004	0.065	<2	<2
11	14:15	1.1	34.6	–	–	–	100.7	100.7	bot	0.02	0.003	<0.004	0.018	<2	<2
12	14:55	0.4	34.6	–	–	–	106.3	–	bot	0.02	0.004	<0.004	0.022	2	<2
13	14:10	1.0	33.3	–	–	–	98.0	–	bot	0.03	0.007	<0.004	0.032	2	<2
14	12:50	0.4	34.6	–	–	–	109.1	–	bot	<0.01	<0.002	<0.004	0.020	<2	<2
15	13:00	2.9	35.0	–	–	–	106.4	106.2	bot	0.01	<0.002	<0.004	0.020	<2	<2
16	12:30	–	34.8	–	–	–	108.2	107.4	3.5	<0.01	<0.002	<0.004	0.022	<2	2

14 Dec 1999; HW @ 11:38 NZST

site	NZST	z_{max}	S_s	S_b	T_s	T_b	DO_s	DO_b	z_{SD}	amm-N	NNN	DRP	TP	FC	ent
6	10:40	1.1	33.9	34.5	18.0	17.7	–	–	bot	0.03	0.063	0.009	0.025	<2	<2
12	11:25	0.8	34.8	34.8	18.7	18.7	–	–	bot	0.03	0.067	0.008	0.027	4	<2
14	10:05	1.6	35.6	35.6	16.2	16.2	78.3	77.8	bot	0.02	0.107	0.011	0.027	<2	<2
16	10:00	3.7	35.6	35.6	16.2	16.1	77.8	75.8	3.7	0.01	0.106	0.011	0.028	<2	<2

12 Jan 2000; HW @ 11:10 NZST

site	NZST	z_{max}	S_s	S_b	T_s	T_b	DO_s	DO_b	z_{SD}	amm-N	NNN	DRP	TP	FC	ent
2	10:20	3.8	34.0	34.8	19.4	19.4	101.2	100.7	2.2	<0.01	<0.002	<0.004	0.028	<10	<10
3	10:10	3.2	34.9	34.9	19.3	19.4	106.0	104.0	2.2	<0.01	0.003	<0.004	0.026	<10	<10
4	10:50	0.5	35.0	35.0	19.1	19.1	105.9	106.3	bot	<0.01	<0.002	<0.004	0.043	<10	<10
5	10:58	1.6	34.6	34.6	19.3	19.3	102.3	101.2	1.5	<0.01	<0.002	<0.004	0.028	<10	<10
6	11:07	1.1	34.3	34.4	19.3	19.3	102.7	102.5	bot	<0.01	<0.002	<0.004	0.026	<10	<10
9	10:20	1.7	34.4	34.6	19.3	19.3	99.9	99.9	bot	<0.01	0.003	<0.004	0.032	<10	<10
10	10:30	1.3	33.2	33.3	19.2	19.2	95.3	94.7	bot	0.01	0.004	<0.004	0.034	<10	<10
11	10:45	0.8	34.8	34.8	19.3	19.3	105.1	104.3	bot	<0.01	<0.002	<0.004	0.032	<10	<10
12	11:01	0.7	34.3	34.4	19.2	19.3	102.7	99.3	bot	<0.01	0.003	0.005	0.030	20	10
13	10:35	1.0	34.3	34.5	19.3	19.3	102.7	102.2	bot	<0.01	0.005	<0.004	0.039	<10	<10
14	09:05	1.0	34.6	34.6	19.1	19.1	100.4	100.4	bot	<0.01	<0.002	<0.004	0.030	<10	10
15	11:30	3.3	34.1	34.8	19.5	19.5	104.1	103.0	2.2	<0.01	<0.002	<0.004	0.028	<10	10
16	09:15	2.6	34.6	34.6	19.2	19.2	101.6	99.1	1.8	<0.01	<0.002	<0.004	0.034	<10	<10

10 Feb 2000; HW @ 10:41 NZST

site	NZST	z_{max}	S_s	S_b	T_s	T_b	DO_s	DO_b	z_{SD}	amm-N	NNN	DRP	TP	FC	ent
2	08:28	3.9	33.6	35.6	19.5	19.5	97.5	96.9	2.7	<0.01	0.005	0.010	0.022	3	1
3	08:22	2.8	35.5	35.5	19.5	19.5	96.6	95.0	2.8	<0.01	0.005	0.008	0.020	2	<1
4	09:15	0.7	35.6	35.6	20.0	20.0	102.3	103.3	bot	<0.01	0.003	0.007	0.018	<1	1
5	09:03	1.2	35.6	35.6	19.5	19.5	101.3	100.3	bot	<0.01	0.002	0.005	0.016	1	<1
6	10:08	1.3	34.8	35.2	21.0	21.0	99.8	100.9	bot	<0.01	0.004	0.006	0.020	10	2
9	08:34	2.3	35.2	35.0	19.7	19.8	90.9	90.1	1.7	0.01	0.006	0.008	0.030	2	1
10	08:40	0.9	34.3	34.3	20.3	20.3	87.7	87.5	bot	0.04	0.007	0.007	0.038	10	2
11	08:52	0.8	34.5	34.5	20.4	20.5	89.6	89.3	bot	0.03	0.007	0.008	0.032	1	1
12	09:52	0.8	35.4	35.5	21.0	20.6	105.5	106.9	bot	0.02	0.025	0.005	0.016	24	20
13	08:46	0.6	34.9	34.9	20.5	20.6	87.1	87.1	bot	0.01	0.004	<0.004	0.074	4	5
14	07:55	1.5	35.5	35.6	19.3	19.3	98.4	97.4	bot	<0.01	0.003	<0.004	0.018	1	1
15	08:14	3.9	35.6	35.6	19.4	19.4	101.3	98.7	3.9	<0.01	<0.002	0.005	0.016	1	<1
16	08:05	3.4	35.6	35.6	19.3	19.4	100.5	98.2	3.3	<0.01	0.003	0.005	0.020	1	<1

Appendix 3: Waikiekie-Moana Pt intertidal survey, 10 Feb 2000 (HW @ 10:41 NZST). Abbreviations as in Appendix 1.

Transect A, 09:52 to 10:42

site	NZST	S_s	amm-N	NNN	DRP	TP	FC	ent
I-1	09:52	35.4	0.02	0.025	0.005	0.016	24	20
I-1	10:29	34.6	0.02	0.049	0.005	0.016	76	47
I-2	10:33	35.6	0.01	0.003	0.004	0.014	<1	<1
I-3	10:38	35.6	0.01	0.003	0.005	0.014	<1	<1
I-4	10:42	35.6	<0.01	0.003	0.005	0.012	<1	<1

Transect B, 12:12 to 12:30

site	NZST	S_s	amm-N	NNN	DRP	TP	FC	ent
I-1	12:12	30.2	<0.01	0.262	<0.004	0.014	2100	120
I-2	12:16	34.2	0.04	0.054	<0.004	0.016	6	12
I-3	12:21	35.3	<0.01	0.020	0.004	0.014	<1	3
I-4	12:30	35.6	0.02	0.004	<0.004	0.016	<1	<1

Transect C, 15:52 to 16:08

site	NZST	S_s	amm-N	NNN	DRP	TP	FC	ent
I-1	15:52	7.7	0.03	1.370	0.006	0.029	1700	19
I-2	15.57	10.0	0.02	1.090	<0.004	0.014	530	12
I-3	16:00	23.7	0.01	0.411	<0.004	0.018	120	1
I-4	16:08	26.7	<0.01	0.205	<0.004	0.025	24	6

Appendix 4: Moanaanuanu Causeway surveys. Abbreviations as in Appendix 1.

24 Jun 1999; HW @ 16:05 NZST

NZST	S_s	S_b	T_s	T_b	DO_s	DO_b	amm-N	NNN	DRP	TP	FC	ent
11:45	5.9	–	–	–	–	–	0.02	0.126	<0.004	0.008	160	<1
12:45	22.8	–	–	–	–	–	0.03	0.050	0.007	0.020	8	<10
14:45	32.4	–	–	–	–	–	0.03	0.015	<0.004	0.018	1	<10
17:00	32.5	–	–	–	–	–	0.01	0.013	<0.004	0.018	1	<10
17:35	31.1	–	–	–	–	–	0.03	0.020	0.004	0.024	2	1
19:00	20.8	–	–	–	–	–	0.02	0.058	0.005	0.018	29	13
20:00	17.2	–	–	–	–	–	<0.01	0.063	<0.004	0.016	41	24
21:00	9.4	–	–	–	–	–	0.02	0.110	<0.004	0.014	140	27
22:00	5.7	–	–	–	–	–	0.02	0.117	<0.004	0.010	120	36
23:00	5.3	–	–	–	–	–	0.02	0.125	<0.004	0.004	300	38
23:59	5.4	–	–	–	–	–	0.01	0.123	<0.004	0.004	160	28

4 Oct 1999: HW @ 14:35 NZST

NZST	S_s	S_b	T_s	T_b	DO_s	DO_b	amm-N	NNN	DRP	TP	FC	ent
11:30	31.5	–	–	–	–	–	0.03	0.010	0.009	0.026	<2	<2
13:20	33.5	–	–	–	–	–	0.02	0.003	<0.004	0.024	4	<2
15:05	34.5	–	–	–	–	–	0.01	<0.002	<0.004	0.026	<2	<2
16:10	34.3	–	–	–	–	–	0.02	<0.002	<0.004	0.020	<2	<2
17:10	30.9	–	–	–	–	–	0.02	0.007	<0.004	0.020	8	8
18:10	22.4	–	–	–	–	–	0.01	0.026	<0.004	0.020	98	14
19:10	17.3	–	–	–	–	–	<0.01	0.041	<0.004	0.020	92	32
20:11	11.5	–	–	–	–	–	0.02	0.065	<0.004	0.018	130	76
21:35	8.6	–	–	–	–	–	<0.01	0.084	<0.004	0.039	112	22
22:25	7.9	–	–	–	–	–	0.02	0.091	<0.004	0.035	200	44
23:15	9.4	–	–	–	–	–	<0.01	0.069	0.005	0.031	128	36

14 Dec 1999; HW @ 11:38 NZST

NZST	S_s	S_b	T_s	T_b	DO_s	DO_b	amm-N	NNN	DRP	TP	FC	ent
07:10	4.2	4.5	16.8	16.7	79.5	78.5	<0.01	<0.002	0.017	0.059	400	98
08:10	27.9	28.9	18.1	17.8	94.9	92.8	0.03	0.014	0.006	0.030	42	8
09:10	32.8	34.9	17.5	16.7	93.2	87.3	0.03	0.046	0.005	0.023	6	<2
10:20	35.1	35.5	17.1	16.8	–	–	0.02	0.079	0.008	0.022	2	<2
11:10	35.5	35.6	16.9	16.9	–	–	0.02	0.090	0.007	0.023	2	<2
12:20	35.1	35.1	18.2	18.2	–	–	0.02	0.074	0.008	0.022	<2	<2
13:10	33.5	33.7	19.5	19.5	–	–	0.02	0.044	0.007	0.020	2	2
14:15	25.5	29.2	20.8	20.4	–	–	0.01	0.010	<0.004	0.019	36	<2
15:10	18.6	22.2	21.1	21.1	–	–	<0.01	0.012	<0.004	0.019	44	22
16:15	8.3	15.4	20.9	21.2	–	–	0.01	<0.002	<0.004	0.034	80	30
17:10	4.8	6.7	20.5	20.8	–	–	<0.01	<0.002	0.004	0.041	150	48
18:50	3.9	8.2	19.0	20.3	–	–	<0.01	0.003	0.006	0.035	250	42

12 January 2000; HW @ 11:10 NZST

NZST	S_s	S_b	T_s	T_b	DO_s	DO_b	amm-N	NNN	DRP	TP	FC	ent
06:00	5.7	8.6	17.3	18.0	75.5	70.8	0.05	0.042	0.005	0.063	410	240
07:00	11.3	14.3	17.6	17.6	81.6	83.3	0.03	0.023	<0.004	0.053	360	120
08:00	32.6	32.8	18.5	18.6	90.4	94.0	0.01	0.008	<0.004	0.035	<10	<10
09:00	34.7	34.4	19.1	19.2	100.6	99.4	<0.01	0.005	<0.004	0.032	20	<10
11:15	34.2	34.6	19.1	19.4	102.1	102.0	0.01	<0.002	<0.004	0.028	<10	<10
12:00	34.7	34.7	19.7	19.7	102.7	103.4	<0.01	<0.002	<0.004	0.020	<10	40
13:00	33.3	33.9	20.1	20.0	104.4	105.5	<0.01	<0.002	<0.004	0.020	10	<10
14:15	28.2	28.6	20.8	20.8	111.4	113.3	<0.01	0.004	<0.004	0.020	90	20
15:00	21.6	21.7	21.3	21.4	116.9	117.4	<0.01	0.004	<0.004	0.028	110	40
16:06	15.3	16.8	21.4	21.5	118.2	119.0	<0.01	0.011	<0.004	0.030	170	10
17:00	11.6	15.0	21.2	21.5	123.4	117.9	<0.01	<0.002	<0.004	0.032	80	10
18:00	8.2	19.6	20.8	21.5	121.6	114.0	0.02	<0.002	0.004	0.042	260	30

10 Feb 2000; HW @ 10:41 NZST

NZST	S_s	S_b	T_s	T_b	DO_s	DO_b	amm-N	NNN	DRP	TP	FC	ent
05:47	10.2	12.3	18.2	18.4	72.2	71.2	0.09	0.045	0.005	0.046	360	160
07:17	28.4	30.5	19.0	19.1	79.1	89.1	0.04	0.015	0.006	0.030	36	27
10:27	35.5	35.6	20.2	20.6	102.9	101.1	0.02	0.002	0.005	0.018	<1	<1
12:20	35.1	35.1	21.6	21.5	105.2	107.1	0.01	0.004	0.005	0.020	2	1
13:10	32.9	33.8	22.8	22.6	109.9	107.4	0.02	0.004	0.005	0.022	37	17
14:30	24.4	24.7	24.6	24.5	114.7	116.6	<0.01	0.012	<0.004	0.026	80	34
16:00	17.6	18.7	25.6	25.5	119.5	118.3	0.01	0.020	<0.004	0.024	120	40
17:00	15.6	17.0	25.8	25.7	125.6	123.8	0.02	<0.002	<0.004	0.024	120	37
18:05	11.9	16.3	25.4	25.4	128.1	122.9	<0.01	0.002	0.005	0.034	150	52

Appendix 5: Lower Wentworth River surveys. Abbreviations as in Appendix 1.

Site at golf course footbridge (map reference NZMS 260, sheet T12, 654 387)

14 Dec 1999

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent	DSi
06:00	0.01	0.029	0.1	<0.004	0.010	490	90	20.1
07:00	0.01	0.029	<0.1	<0.004	0.010	610	120	20.1
08:00	0.01	0.027	<0.1	<0.004	0.009	330	90	20.1
09:00	0.01	0.027	<0.1	<0.004	0.009	400	55	20.1
12:10	0.01	0.023	0.1	<0.004	0.008	280	140	20.1
14:05	<0.01	0.023	<0.1	<0.004	0.010	310	74	20.1
16:05	0.02	0.022	<0.1	<0.004	0.011	270	110	20.2
19:00	0.01	0.024	<0.1	<0.004	0.010	480	170	20.3

12 Jan 2000

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
07:15	<0.01	0.021	<0.1	0.005	0.014	530	230
08:45	0.01	0.020	<0.1	0.005	0.012	540	190
13:49	<0.01	0.019	<0.1	<0.004	0.012	370	130
15:30	<0.01	0.019	0.1	<0.004	0.016	330	60

10 Feb 2000

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
05:30	<0.01	0.033	0.1	0.005	0.016	880	580
06:55	<0.01	0.032	0.1	0.005	0.014	590	260
11:04	<0.01	0.057	0.1	0.005	0.018	710	290
12:05	<0.01	0.029	<0.1	0.004	0.016	1100	700
14:05	<0.01	0.025	<0.1	0.006	0.012	270	240
15:40	<0.01	0.034	0.1	0.005	0.014	180	110

Appendix 6: Wentworth River longitudinal surveys. Abbreviations as in Appendix 1.

12 Jan 2000

site (NZMS260)	NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
I (T12, 603 357)	13:20	0.01	0.005	<0.1	0.004	0.006	70	30
II (T12, 610 360)	13:30	<0.01	<0.002	<0.1	<0.004	0.006	180	50
III (T12, 620 375)	13:40	<0.01	0.004	<0.1	<0.004	0.006	310	70
IV (T12, 637 381)	13:50	<0.01	0.016	<0.1	<0.004	0.016	380	60
V (T12, 645 387)	13:49	<0.01	0.019	<0.1	<0.004	0.012	370	130

10 Feb 2000

site (NZMS260)	NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
I (T12, 603 357)	13:35	<0.01	0.012	<0.1	0.006	0.008	92	24
II (T12, 610 360)	13:45	<0.01	0.009	<0.1	0.005	0.008	210	49
III (T12, 620 375)	13:51	<0.01	0.007	<0.1	<0.004	0.010	150	48
IV (T12, 637 381)	13:58	<0.01	0.025	<0.1	<0.004	0.018	210	69
V (T12, 645 387)	14:05	<0.01	0.025	<0.1	0.006	0.012	270	240

Appendix 7: Waikiekie Stream surveys. Abbreviations as in Appendix 1.

Site generally at SH25 footbridge (map reference NZMS 260, sheet T12, 638 414)

14 Dec 1999

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
13:05	0.01	0.74	0.2	<0.004	0.008	2400	200
15:05	0.01	0.77	0.1	<0.004	0.009	1500	290
17:05	0.01	0.79	0.2	<0.004	0.018	1500	240
18:45	<0.01	0.80	0.2	<0.004	0.017	1600	210

12 Jan 2000

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
06:00	0.03	1.45	0.2	<0.004	0.012	2200	390
08:00	0.03	1.58	0.2	<0.004	0.008	1100	1500
14:05	<0.01	2.08	0.2	0.007	0.016	1300	220
16:55	<0.01	2.14	0.2	0.009	0.040	4800	240
18:10	<0.01	2.14	0.2	0.004	0.014	1400	220

10 Feb 2000

NZST	amm-N	NNN	TKN	DRP	TP	FC	ent
05:39	<0.01	1.93	<0.1	0.005	0.008	740	450
10:50	<0.01	1.96	0.2	0.004	0.006	1300	540
12:15	0.02	1.86	0.5	0.006	0.049	4400	360
14:25	<0.01	1.77	0.2	0.009	0.020	1400	97
15:55	<0.01	1.76	0.2	0.006	0.016	930	140
*14:15	<0.01	1.89	0.1	<0.004	<0.004	480	73

*sample from Waikiekie Stream @ Watts Rd gate (NZMS 260, T12, 633 403)

Appendix 8: Abstract from Industrial Research Ltd's report on analysis of June 1999 foam (IRL 1999)

Four estuarine samples which were mixtures of estuarine foam and water, and a pond water sample were analysed for their constituent monosaccharides. All samples shared relatively high amounts of rhamnose and fucose as their constituent sugars. Larger samples which could be analysed in greater detail also contained an unusual sugar, a 3-*O*-methyl-6-deoxy-hexose, this included two estuarine samples and the pond water sample. Information on polymers which could be responsible for these sugars is scarce and further studies are warranted to investigate the background levels of these constituents in order to determine whether or not there is a definitive link between the estuarine and pond water samples. A course of further investigation is outlined.