Environment Waikato Technical Report 2001/04

Whangamata Harbour: Contaminant loads and Water Quality

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Whangamata Harbour: contaminant loads and estuarine and coastal water quality, summer 2001

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Summary

Four surveys of the loads of contaminants in the catchment of Whangamata Harbour were made during January-to-March 2001. Loads were calculated from measurements of stream flow and contaminant concentrations at sites on six streams and two stormwater outfalls flowing into the harbour. Loads were also measured at 11 sites in the catchment of the Wentworth River, the single largest inflow to the harbour. The water quality in two sub-estuaries of the harbour, which previous work had shown to be moderately contaminated, was determined. Samples were also collected from the coastal water flowing into and out of the harbour.

Contaminant loads in dry weather were found to be much lower than in wet weather. During the highest flow event surveyed—estimated to be a flow that is exceeded about 10% of the time—the total load of faecal coliform bacteria to the harbour was about 60 times higher than that measured during dry weather. The load of enterococci was about 30 times greater, while those of total phosphorus and total nitrogen were about 80 and 40 times higher, respectively. The high flow event appeared to flush-out the catchment to some extent, as specific yields of bacteria were much lower in a moderately-high flow survey a fortnight later.

The Wentworth sub-catchment contributed 40–60% of the total flow, and a similar proportion of many of the contaminants. The next largest sub-catchment, the Otuwheti, was also an important source of contaminants at times. The smaller Waikiekie sub-catchment contributed a disproportionate share of both the total nitrogen (30–70%) and the nitrate nitrogen (66–92%) entering the harbour. It was also an important source of faecal bacteria at times (up to 27%). In this case, most of the nitrate and perhaps half of the faecal bacteria probably enters the stream in surface and sub-surface runoff from the Whangamata wastewater spray-irrigation area.

Under conditions of light rain, the two surveyed stormwater outfalls contributed disproportionately high loads of contaminants. The combined loads of faecal bacteria were equal to about 20% of the total load from the streams, while the loads of turbidity and total phosphorus were equal to 25–40% of the stream loads.

In the Wentworth sub-catchment the area of native bush upstream of the upper-most sampling site contributed about half of the flow in the river. However, it generally contributed considerably smaller proportions of the faecal bacteria and total nitrogen, and only 10–14% of the turbidity. The rest of the loads came from the largely-pastoral area downstream of this site. Two permanent drains through areas of farmland contributed relatively high loads of nutrients and faecal bacteria.

Field measurements in the two estuaries showed that the less dense river water tended to flow downstream above a layer of more dense seawater. At the more landward sites, concentrations of faecal bacteria and nitrogen were usually higher—occasionally much higher—in the less saline near-surface layer. At the seaward sites, however, the contaminants were generally more evenly-distributed. There was no evidence of any substantial input of contaminants into the Moanaanuanu estuary in the vicinity of the Whangamata wastewater treatment pond.

On each survey, the quality of the coastal waters entering and leaving the harbour on the inflowing and outgoing tides tended to be similar. Relatively-high concentrations of faecal bacteria were measured in these waters during the high freshwater flow event. On this occasion most of the bacterial load came from the Wentworth (28–39%), Otuwheti (20–35%) and Waikiekie (4–27%) sub-catchments. Flushing of the catchment over the following fortnight, however, meant that contaminant loads at the end of the fortnight were much lower. As a result, bacterial concentrations in the harbour and coastal waters were also lower on the two surveys following the high flow event. While individual heavy rain events can reduce the suitability of the harbour and nearby coastal waters for bathing, an extended period of moderate-to-high flows appears to offset this to some extent by flushing contaminants from the catchment.

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1 Introduction

Whangamata Harbour (37.2°S, 175.9°E) is a small (4.4 km^2) estuarine embayment on the east coast of the Coromandel Peninsula (Fig. 1A). The area of the catchment draining into the harbour is just under 50 km^2, with the landcover being dominated by native forest or scrub (41%), planted forest (39%) and pasture (18%): see Table 1.

During 1999–2000 the water quality of the harbour, and two of the inflowing streams was studied (Vant 2000). That study identified several issues that warranted further investigation, as follows:

- The relative importance of all the major freshwater inflows to the harbour as sources of (1) the plant nutrients nitrogen and phosphorus, and (2) faecal indicator bacteria.[1]
- The sources of the nutrients and faecal bacteria found in the lower reaches of the main freshwater inflow to the harbour (the Wentworth River).
- The spatial variation in water quality during ebb-tide conditions in two sub-estuaries of the harbour, namely the Waikiekie and Moanaanuanu estuaries.
- Water quality under ebb-tide conditions in the vicinity of the popular surfing area at the ebb-tide delta (near Te Karaka Point).
- The effect of high freshwater flows on all of these topics. None of the surveys undertaken in 1999–2000 followed periods of high freshwater flow, and it was noted that high loads of contaminants are likely to enter the harbour during floods.

A study was therefore planned to provide information on these additional issues. Four surveys were undertaken during summer 2001. Stream flows and nutrient and bacterial concentrations were measured, as was the water quality in the Waikiekie and Moanaanuanu estuaries, and at the ebb-tide delta. This report describes the results of the study.

Table 1: Land-cover in the catchment of Whangamata Harbour in 1996. Areas in km^2. Source: Terralink (1996).

Sub-catchment	Indigenous forest and shrubland	Planted forest	Pasture	Other*	Total
Wentworth	16.37	1.84	4.90	0.67	23.8
Otuwheti	0.81	7.18	0.80	–	8.8
Waikiekie	1.77	3.49	0.60	0.09	5.9
Te Weiti	0.26	1.31	0.33	<0.01	1.9
Okauanga	0.25	0.14	0.49	–	0.9
Kaupeka	–	0.78	<0.01	–	0.8
Un-monitored	0.68	4.42	1.56	0.52	7.2
Total	**20.1**	**19.2**	**8.7**	**1.3**	**49.3**

*urban areas and inland water

2 Methods

Table 2 lists the abbreviations commonly used in this report (apart from those used in the SI system of units of measurement).

2.1 Survey dates and weather

Four water quality surveys were undertaken during January-to-March 2001 (Table 3). Samples were collected from a variety of stream, estuarine and coastal water sites as shown in Figure 1 and Table 4. Samples were collected, stored and analysed in accordance with Environment Waikato's standard procedures (e.g. Wilson 1999). In some calculations, laboratory results that were below the relevant detection limit were

[1] In this report the term "faecal bacteria" is used as a generic term to include (1) faecal coliform bacteria, (2) *Escherichia coli* bacteria (often the main type of faecal coliforms present in samples of natural waters), and (3) enterococci bacteria.

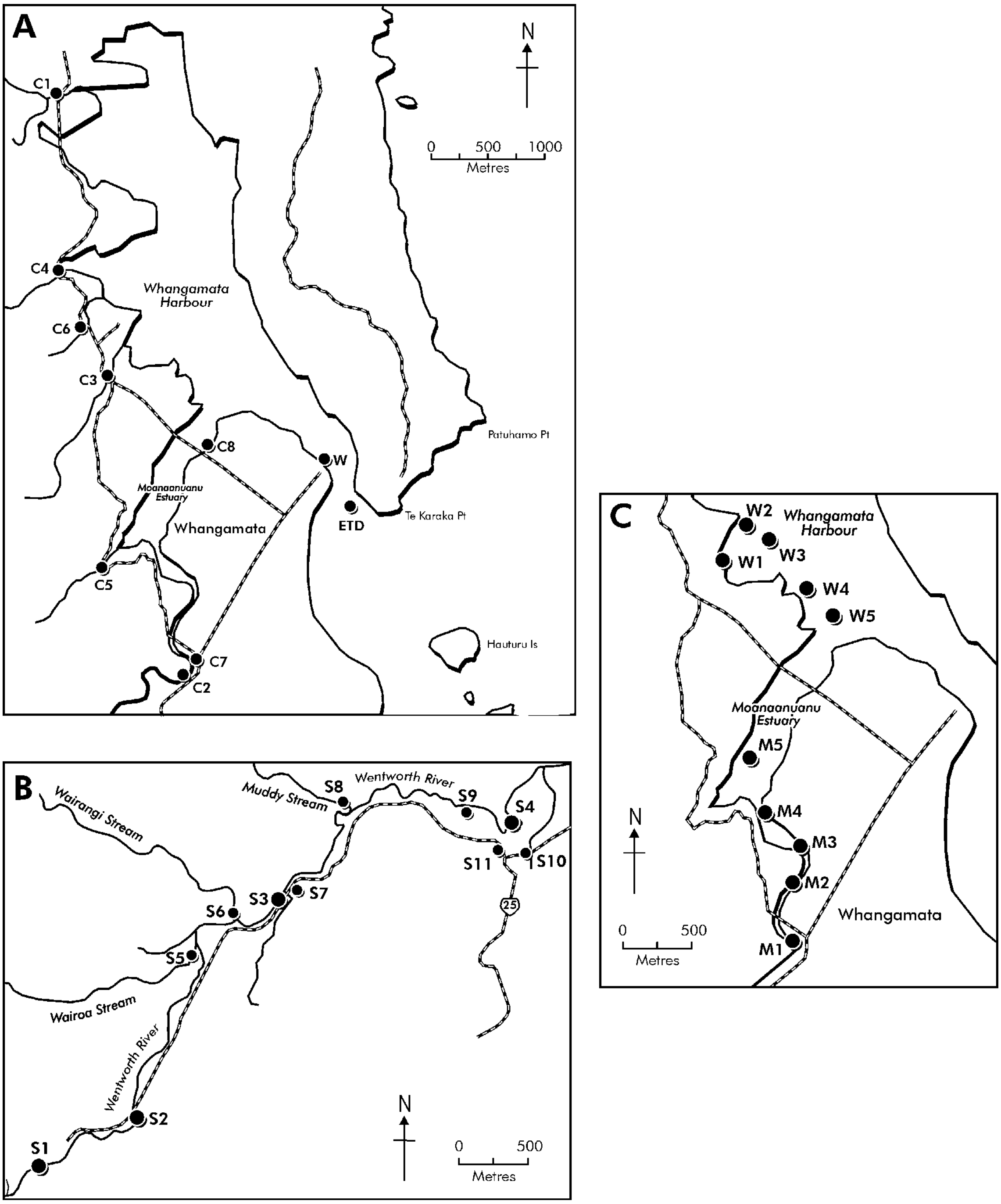

Figure 1: Location of sampling sites in the catchment of Whangamata Harbour and the associated estuarine and coastal waters. **A**, major inflows and coastal sites; **B**, Wentworth Valley sites; and **C**, estuarine sites. See Table 4 for further details.

Table 2: Abbreviations commonly used in this report.

Abbreviation	Explanation
amm-N	Ammoniacal-nitrogen, g/m^3
C	Concentration (of a generalised contaminant)
cfu	Colony forming units
DIN	Dissolved inorganic nitrogen (= NNN + amm-N), g/m^3
DRP	Dissolved reactive phosphorus, g/m^3
Ec	*Escherichia coli* bacteria, cfu/100 mL
ent	Enterococci bacteria, cfu/100 mL
fc	Faecal coliform bacteria, cfu/100 mL
L	Load
NNN	Nitrate and nitrite nitrogen*, g/m^3
NZST	New Zealand Standard Time, hh:mm
S	Salinity, no units
T	Water temperature, °C
TKN	Total Kjeldahl nitrogen, g/m^3
TN	Total nitrogen (= TKN + NNN), g/m^3
TP	Total phosphorus, g/m^3
Turb	Turbidity, nephelometric turbidity units (NTU)
z	Depth below the water surface, m

*hereafter referred to as "nitrate-N"

Table 3: Dates of Whangamata catchment and estuarine and coastal water surveys. The time of high water at Whangamata is shown. The cumulative rainfall and average stream flow rates at sites* in the nearby Wharekawa catchment are also shown. "12 h" = 12 hour period ending at noon on the survey date, "P5D" = previous five days.

Date	High water	Rainfall (mm)		Flow (m^3/s)	
(year 2001)	(NZST)	12 h	P5D	Survey date§	P5D
11 January	07:52	1.5	3.5	0.33 (94)	0.29
8 February	06:36	35.0	40.0	3.44 (9)	0.59
22 February	06:34	0.0	37.0	1.87 (20)	3.98
9 March	06:17	8.0	13.5	1.54 (25)	0.98

*rainfall from Wharekawa @ Tairua Forest (NZMS 260, sheet T12, 554 377), altitude 290 m; flow from Wharekawa @ Adams Farm Bridge (T12, 623 468), catchment area = 47 km^2: information from Environment Waikato databases; these are the closest sites to the Whangamata catchment that have current (and reasonably long-term) records

§in each case the value in brackets is the percent of the time that daily average flows greater than that reported have occurred in the nearly 10-year record for this site (which began in June 1991)

Table 5: Field and laboratory methods used to measure flows and water quality variables in stream, estuarine and coastal surveys.

Variable	Method
Field measurements	
Depth (m)	Graduated pole
Flow (L/s)	Ott current meter and channel cross-section; bucket/stopwatch
Salinity	WTW meter (LF 340)
Temperature (°C)	WTW meter (LF 340)
Laboratory measurements (g/m^3 unless stated otherwise)	
Ammoniacal-nitrogen	Phenol/hypochlorite colorimetry, APHA 4500-NH3 G
Dissolved reactive phosphorus*	Molybdenum blue colorimetry, APHA 4500-P F
Enterococci (cfu/100 mL)	Membrane filtration, mE/EIA Agars, 41.5°C, 48 h, APHA (Water) 9230
Escherichia coli (cfu/100 mL)	As for faecal coliforms, plus confirmation by NA-MUG, APHA 9222G
Faecal coliforms (cfu/100 mL)	Membrane filtration, mFC Agar @ 44.5°C, 24 h, APHA 9222
Nitrate and nitrite nitrogen	Automated cadmium reduction, APHA 4500-$NO3^-$ F
Total Kjeldahl nitrogen	Kjeldahl digestion, ammoniacal-N (see above): freshwaters only
Total phosphorus*	Persulphate digestion, colorimetry. NWASCO method 8
Turbidity (NTU)	Turbidity meter, APHA 2130B

*at times the reported value of dissolved reactive phosphorus exceeded the corresponding value for total phosphorus, but the analyst has observed that such discrepancies were "within the experimental variation of these methods"

Table 4: Location of sampling sites (see Figure 1 also). Map references are all for NZMS 260, sheet T12. Labels in brackets are those used in Vant (2000) to describe certain of the sites.

Site		Map reference
Inflows (Fig. 1A)		
C1	Otuwheti Stream @ SH25	633 438
C2 (V)	Wentworth River @ footbridge	645 387
C3 (W)	Waikiekie Stream @ SH25	638 414
C4	Kaupeka Stream @ SH25	634 423
C5	Okauanga Stream @ link road	638 397
C6	Te Weiti Stream @ SH25	636 418
C7	Achilles stormwater	646 388
C8	Hetherington stormwater	648 407
Wentworth Valley (Fig. 1B)		
S1 (I)	Above camp	603 357
S2 (II)	Ford	610 360
S3 (III)	Near quarry	620 375
S4 (IV)	Above golf course	637 381
S5	Wairoa Stream	614 372
S6	Wairangi Stream	617 374
S7	Drain near quarry	621 376
S8	Muddy Stream	626 382
S9	Drain through farm	634 383
S10	Drain near Widdison Place	638 379
S11	Drain near landfill	636 379
Waikiekie estuary (Fig. 1C)		
W1	Large pohutukawa	640 416
W2 (I-1)	Stream mouth	642 418
W3 (I-2)	Mid-bay mangroves	644 416
W4 (I-3)	Off Moana Point	646 414
W5 (I-4)	Off southern point	648 412
Moanaanuanu estuary (Fig. 1C)		
M1	Upstream of link road bridge	646 387
M2	Downstream of bridge	645 393
M3	Downstream of small island	647 395
M4	Near large pohutukawa	643 398
M5 (6)	Upstream end of main arm	642 402
Coastal water (Fig. 1A)		
W (16)	Wharf	657 406
ETD	Ebb-tide delta	660 402

regarded as being equivalent to half the detection limit. Table 5 summarises the field and laboratory methods used to determine the various water quality variables.

The weather conditions on and prior to the dates of the four surveys varied considerably (Table 3). Both rainfall and stream flows prior to the first survey (11 January) were low. However, the following two months were wet, with rainfall at the nearby Wharekawa site being about 80% higher than average.[2] This resulted in higher flows on the dates of the other three surveys (Table 3). Rainfall and flows were highest at the time of the second survey (8 February). The duration percentiles of the daily average flows in the Wharekawa River on the survey dates (Table 3) ranged from 94% (11 January) to 9% (8 February), indicating that the four survey dates encompassed a wide range of flows.

2.2 Major inflows

On each occasion, flows and contaminant concentrations were determined in six streams flowing into the harbour (sites C1 to C6, Fig. 1A, Table 4). Together, these streams drain about 85% of the harbour catchment (Table 1). Two of the dozen or

[2] Total rainfall at Wharekawa @ Tairua Forest during 11 January to 9 March (i.e. 58 days) was 422 mm. By contrast, the average combined rainfall for the months of January and February (c. 60 days) since the record for this site began in 1992 has been 231 mm.

more stormwater pipes discharging to the harbour from the town of Whangamata were also sampled (sites C7 and C8: Table 4).[3] Both were reasonably-large (0.6–0.7 m diameter), accessible, and discharged to the inner harbour. To minimise the possibility of flows being affected by high water levels in the downstream harbour, sites C1 to C8 were visited close to the time of low water (within 1.5 h).

The sampling site on the Otuwheti Stream (State Highway 25 bridge, site C1) was located in an estuarine area. Even though care was taken to visit this site at the time of low water (i.e. when the tide was out), on two occasions the stream water was noticeably brackish. On 11 January the average salinity at the time of sampling was 21.1, and on 9 March it was 6.0. On these occasions the flow of freshwater was obtained by multiplying the measured flow by the ratio $(S_{sea} - S_{stream})/S_{sea}$, where S_{sea} and S_{stream} are the salinities in seawater (= 35.4) and the stream, respectively. This meant that freshwater comprised about 40% of the flow on 11 January, and 83% on 9 March.

In principle, an analogous procedure could be used to calculate the contaminant concentrations in the freshwater component of the (brackish) water in the Otuwheti Stream on these dates.[4] In practice, however, on 9 March in particular the measured concentrations of certain of the contaminants—especially nitrogen, phosphorus and turbidity—were considerably higher than those in the other streams (see later). This suggested that an estuarine circulation cell may have been operating in the Otuwheti, such that contaminants were being retained and concentrated within the estuarine mixing zone. As a result, an alternative procedure was used to estimate the contaminant loads from the Otuwheti Stream on 11 January and 9 March (see section 2.3 below).

Flows and contaminant concentrations were also measured within the Wentworth sub-catchment (Fig. 1B, Table 4), the largest of the harbour sub-catchments (Table 1). In this case, measurements were made at sites on (1) the main-stem of the river (sites S1 to S4), (2) on several tributaries/drains, just upstream of the point where each joined the main-stem of the river (sites S5 to S9), and (3) in two small drains, some distance from the river (sites S10 and S11).

Instantaneous contaminant loads (or "mass flows") at the various sites on the inflows and in the Wentworth sub-catchment were obtained as the product of flow and concentration (i.e. $Q \times C$, where Q and C are the flow and concentration, respectively). Although these loads cannot be regarded as necessarily being typical of those carried by the various streams, they do provide a basis for identifying the <u>relative importance</u> of the sources on each occasion. In this study the optical water quality variable turbidity was used as a surrogate for suspended sediment. "Loads" of turbidity have been expressed as "turbidity units × flow units" (i.e. as NTU.m^3/s).

<u>2.3 Unmonitored inflows</u>

Water from an unmonitored area of 7.2 km^2, or about 15% of the harbour catchment, also flowed into the harbour (Table 1). The flow of water, and the loads of contaminants from this unmonitored area were estimated as follows.[5] On each occasion the total flow of water from the six monitored inflows (i.e. sites C1 to C6) was divided by the combined area upstream of the monitoring points (= 42.1 km^2) to obtain a daily-average specific yield of water (in $L/s/km^2$) for the monitored inflows.[6] The yield for each date was then multiplied by 7.2 km^2 to obtain an estimate of the flow from the unmonitored area for that occasion.

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[3] Thames Coromandel District Council refers to these outfalls as "27,802" and "50,142", respectively: see (undated) maps of Whangamata Stormwater Services received by Environment Waikato in November 2000 (DOCS #645796).

[4] Concentration of contaminant in the freshwater calculated as $[C_{stream} - (S_{stream}/S_{sea}).C_{sea}]/[1 - (S_{stream}/S_{sea})]$, where C_{stream} and C_{sea} are the measured contaminant concentrations in the stream and the sea, respectively.

[5] Note that no attempt was made to estimate the contaminant loads to the harbour from the many unmonitored urban stormwater outfalls.

[6] Note that on 11 January and 9 March the relevant flows for the Otuwheti Stream (site C1) were those of the <u>freshwater</u> (rather than the measured flows—which also included a quantity of seawater): see section 2.2.

A similar procedure was used to obtain the loads of contaminants from the unmonitored area (e.g. Vant & Hoare 1987, p. 165). For each of 8 and 22 February the total load of each contaminant at sites C1, C2, C4, C5 and C6 was divided by the combined area (= 36.1 km^2) to obtain the average specific yield of that contaminant for that occasion.[7] This was then multiplied by 7.2 km^2 to obtain an estimate of the load of the contaminant from the unmonitored area for each date. For each of 11 January and 9 March the average yields were calculated using the information for sites C2, C4, C5 and C6 only (i.e. the results for the Otuwheti Stream [site C1] were ignored). These average yields were then used to estimate the loads for each date from both (1) the unmonitored area, and (2) the Otuwheti sub-catchment (area 8.8 km^2).

2.4 Estuarine and coastal waters

Measurements were made, and samples were collected from ten sites in the Waikiekie and Moanaanuanu estuaries of the harbour (Fig. 1C, Table 4). Sites were visited during the ebbing tide, with the Waikiekie estuary being sampled in the period 1.2–2.0 hours after high water, and the Moanaanuanu being sampled during the period 2.2–3.1 hours after high water. At each site, vertical profiles of temperature and salinity were measured, and samples were collected from (1) the near-surface layer (i.e. about 0.1 m below the water surface), (2) the near-bottom layer (about 0.1–0.2 m from the bottom)—using a van Dorn sampler, and (3) at the air-water interface. This latter sample was referred to as the "surface microlayer" sample (cf. Vant 2000, p. 3).

Two nearby coastal water sites were also visited (Fig. 1A, Table 4). Samples were collected at the mouth of the harbour at the wharf (seaward end), mid-way through the incoming tide (c. 3 h before high water). These samples allowed an approximate estimate to be made of the contaminant load entering the harbour in the inflowing coastal water (see later). Samples were also collected just outside the harbour at the ebb-tide delta, mid-way through the outgoing tide (3–4 h after high water), when concentrations of catchment-derived contaminants at the popular surfing area were likely to be highest. At this site, both near-surface and surface microlayer samples were collected.

3 Results and Discussion

The complete results of the surveys are included in Appendices 1–3.

3.1 Major inflows—concentrations

The concentrations of several of the more important contaminants in the inflowing streams are listed in Table 6. Flow-weighted average results for streams other than the Waikiekie provide an indication of conditions in a "typical" stream in the harbour catchment (i.e. streams not affected by possible losses of contaminants from the wastewater spray-irrigation area). Concentrations measured in the inflowing coastal water at the wharf are also shown for comparison.

Contaminant concentrations varied markedly both between sites, and with time. Faecal coliform concentrations were especially high in the Waikiekie Stream (site C3) on 8 February (Table 6), the occasion when the highest flows were measured. However, the highest observed concentration of faecal coliforms in an inflowing stream (= 19,000 cfu/100 mL) was actually found in the (considerably smaller) Okauanga Stream (site C5) on this date (Appendix 1). (Note that an exceptionally high concentration was observed at site S9 in the Wentworth sub-catchment on 8 February: see Appendix 2 and section 3.3.)

The faecal coliform concentration in the Waikiekie Stream a fortnight later (22 February) was more than 25 times lower. In this stream, the concentration of the other

[7] Note that the loads in the Waikiekie Stream (site C3) are affected by leakage from the wastewater spray-irrigation area, so those loads were not used in these calculations.

type of faecal indicator bacteria, enterococci, was highest on 9 March, and was 50 times lower than this on 22 February. Once again, however, note that concentrations of enterococci higher than this were observed in individual inflows at times (Appendix 1), with the highest value in an inflowing stream being 6300 cfu/100 mL in the Otuwheti Stream (site C1) on 8 February (noting that a somewhat higher value was observed in the Hetherington stormwater outfall [site C8] on 9 March (Appendix 1), and that an exceptionally high value was observed in a drain in the Wentworth sub-catchment [site S9] on 8 February: see Appendix 2). By contrast, concentrations of faecal bacteria were much lower in the coastal water entering the harbour (although relatively high concentrations were observed at the time of the very wet survey on 8 February: Table 6).

TCDC (2000) reported faecal coliform concentrations in the Waikiekie Stream above and below the spray-irrigation area during May 1997 to September 2000. Paired observations of these concentrations were found to covary (Spearman's ρ = 0.63, n = 64), indicating that the processes which cause high concentrations upstream of the area also produce high concentrations downstream. Presumably surface runoff during wet weather is an important process here. The median value of the ratio C_d/C_u, where C_d and C_u are the downstream and upstream concentrations, respectively, was 2.03, suggesting that downstream concentrations were typically about twice as high as the upstream values. As a first approximation, we may therefore conclude that leakage from the spray-irrigation area contributes about half of the load of faecal coliform bacteria in the lower part of the Waikiekie Stream.

Concentrations of faecal bacteria were very high in the Kaupeka (C4), Okauanga (C5) and Te Weiti (C6) Streams on 8 February (Appendix 1).[8] The results for sites C4 and C6 were interesting, as more than 80% of the area of the catchment of each of these streams is in pine forest or native bush (Table 1). However, concentrations of faecal bacteria as high as those observed on 8 February have occasionally been found in streams draining forested catchments elsewhere on the Coromandel Peninsula.[9]

Apart from on 8 February, turbidity levels in the major inflows and the seawater were reasonably low. The high stream flows on 8 February, however, were associated with

Table 6: Contaminant concentrations in the Whangamata catchment and the nearby coastal waters on four occasions during January-March 2001. The results for a "typical stream" are the flow-weighted average values for sites C1, C2 and C4 to C6 on 8 February and 22 February, and for sites C2 and C4 to C6 on 11 January and 9 March. See Appendix 1 for complete results.

	fc	ent	Turb	TP	TN	DIN
11 January						
Typical stream	1470	1460	3.5	0.014	0.08	0.02
Waikiekie (C3)	1000	630	1.9	0.005	1.18	1.08
Coastal (site W)	5	6	2.3	0.033	–	0.03
8 February						
Typical stream	7860	4450	52.0	0.130	0.83	0.12
Waikiekie (C3)	15000	960	29.5	0.067	1.60	1.10
Coastal (site W)	130	120	2.5	0.014	–	0.04
22 February						
Typical stream	250	70	6.4	0.023	0.38	0.10
Waikiekie (C3)	550	92	3.4	0.014	2.01	1.84
Coastal (site W)	1	<1	2.4	0.018	–	0.02
9 March						
Typical stream	2700	2200	6.5	0.020	0.26	0.03
Waikiekie (C3)	2200	4900	2.6	0.009	1.49	1.29
Coastal (site W)	1	<1	3.8	0.022	–	0.01

[8] Note, however, that the fact that concentrations were lower in the much larger Wentworth and Otuwheti catchments on this occasion meant that the high concentrations in these three streams did not have a marked effect on the result for a "typical stream" as shown in Table 6.

[9] For example, the concentrations of faecal coliforms, *E. coli* and enterococci in the Wharekawa River during a high flow event on 11 March 1998 were 17,000, 17,000 and 25,000 cfu/100 mL, respectively: see Wilson 1999).

levels of turbidity which were about an order of magnitude higher (Table 6). Levels of total P were also highest on this occasion, suggesting that much of the P was present in eroding soil particles, which were themselves the main cause of the very high turbidity. On all occasions, the concentration of total P in the Waikiekie Stream was lower than the flow-weighted average value for the other major inflows.

Concentrations of both total and dissolved inorganic N, however, were much higher in the Waikiekie Stream than in the other major inflows (Table 6). This reflects the leakage of N from the wastewater spray-irrigation area (TCDC 2000). Although the concentrations of total N in the coastal waters could not be determined using the methods available in this survey, the concentrations of dissolved inorganic N were either similar to (11 January) or lower than (other three surveys) those in the non-Waikiekie major inflows to the harbour.

Samples collected upstream and downstream of the spray-irrigation area, and reported in TCDC (2000), show that the average concentration of nitrate-N downstream of the area was about 18 times greater than that upstream. Leakage from the spray-irrigation area thus accounts for most of the nitrate-N in the lower reach of the Waikiekie Stream.

3.2 Major inflows—loads

The loads of contaminants carried by each of the major inflows on each survey date were calculated, and are shown in Table 7. Figure 2 shows the loads of selected contaminants. The largest loads were observed on 8 February, when both flows and concentrations were highest (Appendix 1). Much lower loads were observed on 11 January, when both flows and concentrations were relatively low, following a period of fine weather. Compared to 11 January, total loads on 8 February were as follows:

- Loads of faecal coliforms and *E. coli* were 60 times higher.
- The load of enterococci was 30 times higher.
- Loads of turbidity and total P were about one hundred times higher.
- The load of total N was 40 times higher, and that of nitrate-N was 20 times higher.
- The total flow was about 11 times higher.

Even though flows were also relatively high on the survey conducted on 22 February, loads on that occasion were generally much lower than those observed a fortnight earlier (on 8 February). This reflects the fact that concentrations were generally substantially lower on 22 February (Table 6, Appendix 1). Presumably the high flows on 8 February, together with the generally wet weather in the following fortnight (Table 3), meant the catchment had been flushed-out in the intervening period, so that fewer contaminants were available to be carried into the harbour on 22 February.[10]

Flows and loads on 9 March were higher than on 11 January, but were generally not as high as those observed in the two surveys in February. Interestingly, however, the loads of faecal bacteria on 9 March were substantially higher than on 22 February (Fig. 2B). This suggests the catchments had begun to recover from the scouring received in February, such that greater quantities of contaminants were then available to be transported.

The results in Table 7 show that the Wentworth sub-catchment (site C2) was generally the major source of many of the contaminants, as follows:

- On 11 January it carried 50–60% of the total load of faecal bacteria, turbidity, total and dissolved reactive P, and ammoniacal N. It also contributed 62% of the total flow.
- On 8 February it carried a somewhat smaller proportion (c. 30–40%) of the total load of faecal bacteria, turbidity, total P, and total and ammoniacal N. It also contributed 41% of the total flow.

[10] A total of 180 mm of rain was recorded at the Wharekawa site in the period between the two surveys.

- On 22 February it carried about 40–70% of the total load of faecal bacteria, turbidity, total and dissolved reactive P, and total and ammoniacal N. It also contributed 58% of the total flow.
- On 9 March it carried 40–60% of the total load of faecal bacteria, turbidity, total and dissolved reactive P, and ammoniacal N. It also contributed 52% of the total flow.

The Waikiekie Stream (site C3) was also an important source of some contaminants:
- On 11 January it carried about 70% of the total N and 92% of the nitrate-N, but only 13% of the flow. (It also carried just 5–8% of the faecal bacteria, and 4–6% of the turbidity, total P and ammoniacal N.)
- On 8 February it carried about 30% of the faecal coliforms and *E. coli* (but only 4% of the enterococci), 30% of the total N, and 66% of the nitrate-N, but only 16% of the flow.
- On 22 February it carried 20% of the faecal coliforms, 41–44% of the total N and ammoniacal N, and about 70% of the nitrate-N, but only 10% of the flow. (It also carried 13% of the enterococci, and c. 6% of the turbidity and total P.)

Table 7: Loads of contaminants from sub-catchments of Whangamata Harbour on four occasions during January-March 2001. Loads from two stormwater outfalls are also shown. Values in italics are estimated (see text). "Mcfu/s" = millions of colony forming units per second.

	Flow (L/s)	L-fc (Mcfu/s)	L-Ec (Mcfu/s)	L-ent (Mcfu/s)	L-Turb NTU.m^3/s	L-TP (mg/s)	L-DRP (mg/s)	L-TN (mg/s)	L-NNN (mg/s)	L-NH4 (mg/s)
11 January										
Wentworth (C2)	304	4.6	4.6	4.6	1.0	4.3	2.7	19	3	3.0
Otuwheti (C1)	37*	*1.5*	*1.5*	*1.5*	*0.4*	*1.4*	*0.9*	*6*	*1*	*1.0*
Waikiekie (C3)	63	0.6	0.6	0.4	0.1	0.3	0.5	75	68	0.3
Te Weiti (C6)	10	0.1	0.1	0.1	<0.1	0.1	0.1	1	<1	0.1
Okauanga (C5)	3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	<0.1
Kaupeka (C4)	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	0.1
Unmonitored	*72*	*1.2*	*1.2*	*1.2*	*0.3*	*1.2*	*0.8*	*5*	*1*	*0.8*
Total	**490**	**8.0**	**8.0**	**7.7**	**1.9**	**7.3**	**5.1**	**110**	**74**	**5.4**
Achilles (C7)	<1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<1	<1	<0.1
Hetherington (C8)	0	0	0	0	0	0	0	0	0	0
8 February										
Wentworth	2190	130	130	81	90	260	44	1300	200	22
Otuwheti	1140	93	93	72	80	170	15	1000	100	11
Waikiekie	857	130	130	8	20	60	15	1400	940	4
Te Weiti	252	43	43	10	20	30	2	320	90	8
Okauanga	66	13	13	1	2	5	1	40	5	<1
Kaupeka	40	7	7	<1	<1	1	<1	10	1	<1
Unmonitored	*776*	*58*	*58*	*33*	*40*	*90*	*12*	*530*	*80*	*8*
Total	**5320**	**480**	**480**	**210**	**250**	**630**	**90**	**4600**	**1400**	**54**
Achilles	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Hetherington	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
22 February										
Wentworth	1260	2.3	1.5	0.6	9	33	14	340	80	6
Otuwheti	302	1.4	0.9	0.3	1	4	4	110	50	1
Waikiekie	227	1.2	0.7	0.2	1	3	3	460	410	7
Te Weiti	48	0.4	0.2	0.2	<1	<1	<1	30	20	<1
Okauanga	20	0.1	<0.1	<0.1	<1	<1	<1	3	1	<1
Kaupeka	10	<0.1	<0.1	<0.1	<1	<1	<1	2	<1	<1
Unmonitored	*319*	*0.8*	*0.5*	*0.2*	*2*	*8*	*4*	*100*	*30*	*2*
Total	**2180**	**6.2**	**3.9**	**1.6**	**13**	**48**	**26**	**1030**	**590**	**17**
Achilles	0	0	0	0	0	0	0	0	0	0
Hetherington	<1	<0.1	<0.1	<0.1	<1	<1	<1	1	1	<1
9 March										
Wentworth	659	18	17	14	4.3	13	3.3	150	20	3.3
Otuwheti	229*	*6*	*6*	*5*	*1.5*	*4*	*1.1*	*50*	*7*	*1.1*
Waikiekie	157	4	4	8	0.4	1	0.3	230	200	0.8
Te Weiti	28	1	1	1	0.2	1	0.1	9	3	0.1
Okauanga	7	<1	<1	<1	<0.1	<1	<0.1	1	<1	<0.1
Kaupeka	5	<1	<1	<1	0.1	<1	<0.1	1	<1	<0.1
Unmonitored	*186*	*5*	*5*	*4*	*1.2*	*4*	*0.9*	*40*	*6*	*0.9*
Total	**1270**	**33**	**32**	**32**	**7.6**	**23**	**5.7**	**490**	**240**	**6.3**
Achilles	20	1	1	1	0.2	1	<0.1	4	<1	0.1
Hetherington	74	6	6	6	1.8	8	0.1	40	2	0.4

* amount of measured flow which was freshwater (based on measured salinity)

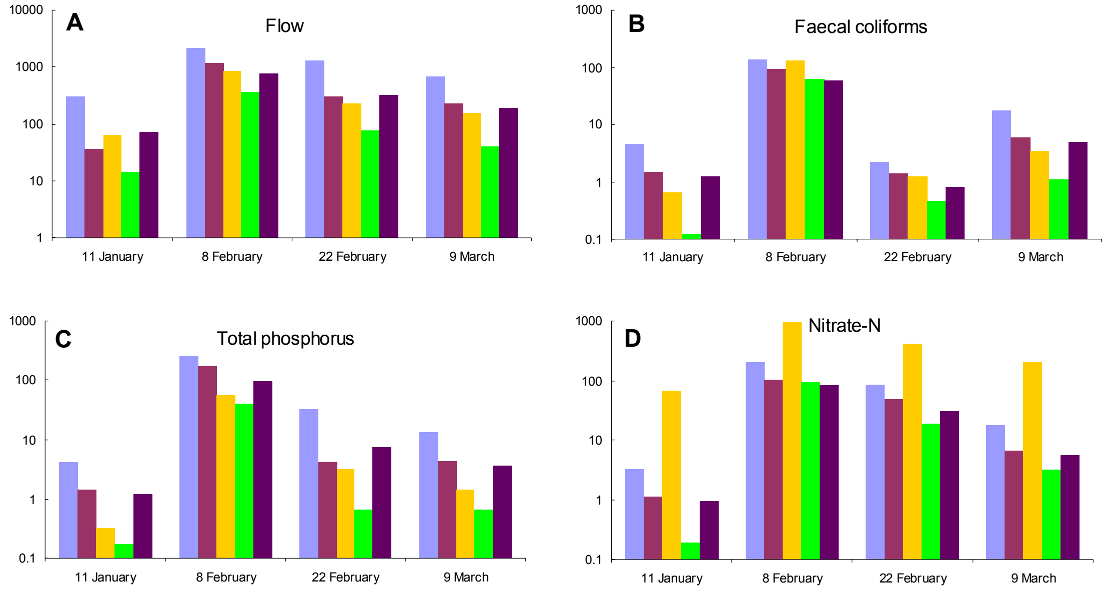

Figure 2: Flows, and loads of selected contaminants from sub-catchments of Whangamata Harbour on four occasions during January-March 2001. **A**, flow (L/s); **B**, faecal coliforms (Mcfu/s); **C**, total phosphorus (mg/s); and **D**, nitrate nitrogen (mg/s). Note that the vertical scales are logarithmic. On each occasion the vertical bars represent the results for (left-to-right): (1) Wentworth River, (2) Otuwheti Stream, (3) Waikiekie Stream, (4) combined results for the three small streams (Te Weiti, Okauanga and Kaupeka Streams), and (5) unmonitored inflows. See Table 7 for further information.

- On 9 March it carried 24% of the enterococci, 48% of the total N, and 86% of the nitrate-N, but only 12% of the flow. (It also carried just 10–11% of the faecal coliforms and *E. coli*, and c. 6% of the turbidity and the total and dissolved reactive P.)
- As noted above (section 3.1), leakage from the spray-irrigation area is likely to account for roughly half of the loads of faecal bacteria in the lower Waikiekie Stream, and most of the nitrate-N.

On two occasions the Otuwheti Stream (site C1) was also an important source of some contaminants:
- On 8 February it carried 20–35% of the faecal bacteria, turbidity, total P and ammoniacal N. It also contributed 21% of the total flow.
- On 22 February it carried about 20% of the faecal bacteria, and 13% of the flow.

During these surveys, the (instantaneous) catchment-average specific yield of nitrate-N from the Waikiekie sub-catchment ranged from 11 mg/s/km^2 (11 January) to 158 mg/s/km^2 (8 February).[11] The corresponding results for a "typical" stream in the harbour catchment were 0.13 mg/s/km^2 and 11 mg/s/km^2, respectively. The nitrogen yield from the Waikiekie catchment was thus about 90 times higher than that from the rest of the harbour catchment on 11 January, and 14 times higher on 8 February. The yield of faecal coliforms from the Waikiekie sub-catchment ranged from 0.11 Mcfu/s/km^2 (11 January) to 22 Mcfu/s/km^2 (8 February), with the corresponding results for a "typical" stream being 0.17 Mcfu/s/km^2 and 8 Mcfu/s/km^2, respectively. The yield of faecal bacteria from the Waikiekie sub-catchment was thus 40% lower than that from the rest of the harbour catchment on 11 January, and about three times higher on 8 February.

An important source of contaminants in the catchment of the Waikiekie Stream is the wastewater spray-irrigation area. Although the sizes of the contaminant loads leaking

[11] These yields are equivalent to about 4 kg/ha/yr and 50 kg/ha/yr, respectively (although it is questionable whether instantaneous loads should be expressed in these units).

from the area have not been directly measured,[12] the loads typically applied can be estimated—and thus compared with those measured in the downstream reach of the stream (i.e. at site C3). The consent for the spray irrigation area limits the 7-day average volume irrigated to 3500 m^3/d, while the "typical sewage inflow" to the retention pond is 1500 m^3/d (TCDC 2000, p. 4). The volume irrigated is thus likely to be in the range 1500–3500 m^3/d, or about 0.02–0.04 m^3/s. Typical contaminant concentrations in the effluent are currently about 28.7 g/m^3 for total nitrogen, and 100,000 cfu/100 mL for faecal coliforms (TCDC 2000, pp. 10 and 15). The average load of total nitrogen applied to the spray-irrigation area is thus about 500–1200 mg/s, while that of faecal coliforms is about 20–40 Mcfu/s. The contaminant loads measured in the Waikiekie Stream on the dry weather survey of 11 January were much lower than these applied loads (Table 7). But the loads measured in the stream in the wet survey of 8 February were higher.

The observed stormwater flows were highest on the survey of 9 March (Table 7).[13] On that occasion the combined flow at sites C7 and C8 was 94 L/s, or about 7% of the total flow of the major streams. However, the load of faecal bacteria from the two outfalls was about 20% as large as the total load from the streams, while the load of turbidity and total P was 25–40% as large as that from the streams.

These results therefore indicate that for many contaminants, the Wentworth sub-catchment was often the dominant source. This is to be expected, as it is the largest (48%) sub-catchment of the harbour, and the single largest source of water. However, the Waikiekie sub-catchment provided a disproportionate share of the nitrogen entering the harbour, and was also an important source of faecal bacteria at times. The results also show that contaminant loads in stormwater were relatively large on one occasion.

3.3 Wentworth sub-catchment—loads

The flows and contaminant concentrations measured in the Wentworth sub-catchment surveys are shown in Appendix 2. Both flows and concentrations were considerably higher on the 8 February survey than on the other occasions (so loads were highest then: see later). Rather lower concentrations were observed a fortnight later on 22 February. As with the results for the major inflows (section 3.1), this suggests the previous high flows had flushed-out the catchment to some extent. As noted above, exceptionally high concentrations of faecal bacteria were observed at site S9 (Farm drain) on 8 February. Concentrations of total P and total N, and the turbidity level were also very high at site S9 on this occasion. Contaminant levels were also high at site S9 on 22 February and 9 March.

Table 8 lists the contaminant loads in the Wentworth sub-catchment on the four survey dates. The loads at site S4 on the main-stem of the river reflect the combined effect of all the individual sources of contaminants upstream of that point (but note that sites S10 and S11 are on tributaries that join the river downstream of site S4).[14] These combined loads varied markedly between surveys, as follows:

- On 11 January, 22 February and 9 March loads of faecal bacteria were similarly low; on 8 February loads were 15–30 times higher.
- Loads of turbidity and total P were lowest on 11 January, highest on 8 February (when they were about 20 times higher), and intermediate on 22 February and 9 March.
- On 11 January, loads of total N and nitrate-N were much lower (10–50 times) than on the other three occasions.

[12] But as noted above, leakage probably accounts for most of the load of nitrate-N in the stream, and perhaps half of the faecal bacteria.

[13] Note that on this occasion the rain was not heavy, so stream flows were not particularly high (Table 3). Even so, sufficient rain had fallen by the time the stormwater outfalls were sampled to generate substantial flows in them.

[14] Note that site C2, the Wentworth River site in the "major inflows" group of sites, was actually further downstream than site S4. However, because sites S1-S11 were sampled several hours earlier than C2, it would be unwise to try to compare the results from these sites. In particular, site S4 was usually sampled 2–3 h before C2, and some results were markedly different (e.g. on 8 February the flow at C2 at 13:23 NZST was more than twice that observed at S4 at 10:08 NZST). That is, while it is reasonable to compare results within each of the "S" and "C" groups of sites, it was not intended that results should be compared between these groups.

In each case the contaminant loads increased reasonably-steadily down the main-stem of the Wentworth River (Table 8). However, the monitored tributaries/drains only accounted for some—often only a minor proportion—of the additional load between each main-stem site. The additional contaminants must have entered the river via other routes or processes. Even so, it is possible to calculate the contributions of the various monitored inflows to the loads at S4. Tributaries that contributed more than 10% of the combined load at site S4 on each occasion were as follows:

- 11 January. The Wairoa Stream (S5) contributed 10–20% of the enterococci, the total and dissolved P, and the total N, and 25–32% of the nitrate-N and ammoniacal N. It also contributed 16% of the flow. The Wairangi Stream (S6) contributed 12% of the total N and 29% of the nitrate-N (and 9% of the flow). The quarry drain (S7) contributed 11% of the total P, 22% of the total N, 10% of the nitrate-N and 35% of the ammoniacal N (and just 3% of the flow). Finally, the Muddy Stream (S8) contributed 12% of the nitrate-N (and 3% of the flow). On this occasion the drain from the landfill (S11) was not flowing, and that from Widdison Place (S10) carried only minor loads of contaminants.

Table 8: Loads of contaminants in the Wentworth River catchment on four occasions during January-March 2001. Results for sites on the main-stem of the river are shown in bold. "Mcfu/s" = millions of colony forming units per second.

	Flow (L/s)	L-fc (Mcfu/s)	L-Ec (Mcfu/s)	L-ent (Mcfu/s)	L-Turb NTU.m^3/s	L-TP (mg/s)	L-DRP (mg/s)	L-TN (mg/s)	L-NNN (mg/s)	L-NH4 (mg/s)
11 January										
A. camp (S1)	**126**	**0.8**	**0.5**	**0.5**	**0.08**	**1.0**	**1.3**	**7**	**1.1**	**0.6**
Ford (S2)	**161**	**0.7**	**0.4**	**0.8**	**0.07**	**1.3**	**1.3**	**9**	**0.8**	**0.8**
Wairoa (S5)	37	0.2	0.1	0.2	0.03	0.3	0.3	2	0.4	0.4
Wairangi (S6)	22	0.3	0.3	0.1	0.03	0.2	0.2	2	0.5	0.1
N. quarry (S3)	**214**	**2.1**	**1.9**	**1.2**	**0.39**	**1.7**	**2.1**	**12**	**0.9**	**1.1**
Quarry (S7)	7	<0.1	<0.1	<0.1	0.04	0.3	0.1	3	0.2	0.4
Muddy (S8)	7	<0.1	<0.1	<0.1	0.01	0.1	0.1	1	0.2	<0.1
Farm (S9)	1	<0.1	<0.1	<0.1	0.01	<0.1	<0.1	<1	0.1	<0.1
Golf (S4)	**236**	**3.8**	**3.8**	**1.5**	**0.74**	**2.6**	**2.1**	**13**	**1.6**	**1.2**
Landfill (S10)	0	0	0	0	0	0	0	0	0	0
Widdison (S11)	<1	<0.1	<0.1	<0.1	0.02	0.1	<0.1	1	<0.1	0.1
8 February										
Above camp	**475**	**13**	**9**	**1**	**2**	**6**	**5.7**	**110**	**18**	**14**
Ford	**548**	**18**	**13**	**2**	**2**	**6**	**3.8**	**70**	**18**	**2.7**
Wairoa	162	5	3	1	1	2	1.0	30	12	0.8
Wairangi	61	2	1	1	<1	1	0.3	10	7	0.3
Near quarry	**770**	**18**	**9**	**5**	**5**	**11**	**4.6**	**190**	**35**	**3.9**
Quarry	16	<1	<1	<1	<1	1	0.1	5	<1	0.5
Muddy	31	2	1	1	<1	1	0.3	20	7	0.3
Farm	12	18	18	17	4	9	0.1	40	4	2.2
Golf course	**1050**	**56**	**56**	**22**	**17**	**43**	**5.3**	**370**	**58**	**5.3**
Landfill	2	<1	<1	<1	<1	<1	<0.1	2	1	<0.1
Widdison	9	<1	<1	<1	<1	1	0.1	4	1	<0.1
22 February										
Above camp	**708**	**2.4**	**1.3**	**0.32**	**0.8**	**3**	**1**	**60**	**29**	**3.5**
Ford	**734**	**2.2**	**1.6**	**0.70**	**0.8**	**2**	**1**	**60**	**27**	**3.7**
Wairoa	186	0.4	0.2	0.07	0.2	1	1	30	12	0.9
Wairangi	103	0.3	0.3	0.05	0.2	1	1	10	9	0.5
Near quarry	**1100**	**3.2**	**1.8**	**0.52**	**2.4**	**2**	**2**	**110**	**52**	**5.5**
Quarry	27	0.1	<0.1	<0.01	0.1	<1	<1	10	4	1.1
Muddy	39	0.2	0.1	0.04	0.1	<1	<1	10	6	0.2
Farm	8	0.1	0.1	0.01	0.1	<1	<1	7	2	0.8
Golf course	**1310**	**3.8**	**2.2**	**0.73**	**5.8**	**12**	**14**	**210**	**77**	**6.5**
Landfill	6	<0.1	<0.1	0.02	<0.1	<1	<1	10	7	<0.1
Widdison	3	<0.1	<0.1	<0.01	<0.1	<1	<1	8	8	<0.1
9 March										
Above camp	**303**	**0.8**	**0.8**	**0.5**	**0.2**	**3.3**	**0.6**	**40**	**8**	**1.5**
Ford	**331**	**1.1**	**1.1**	**1.2**	**0.5**	**3.0**	**0.7**	**20**	**6**	**1.7**
Wairoa	89	0.3	0.3	0.3	0.1	0.4	0.2	8	3	0.4
Wairangi	54	0.2	0.2	0.1	0.1	0.3	0.1	6	3	0.3
Near quarry	**518**	**9.3**	**9.3**	**1.2**	**0.7**	**3.6**	**1.0**	**60**	**8**	**2.6**
Quarry	12	<0.1	<0.1	<0.1	0.1	0.2	<0.1	3	<1	0.6
Muddy	21	0.1	0.1	<0.1	0.1	0.3	<0.1	4	2	0.1
Farm	2	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	1	<1	0.1
Golf course	**600**	**2.7**	**2.7**	**1.1**	**1.6**	**6.6**	**1.2**	**140**	**18**	**3.0**
Landfill	2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	4	3	<0.1
Widdison	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	<0.1

- 8 February. The Wairoa Stream (S5) contributed 15–20% of the dissolved reactive P, nitrate-N and ammoniacal N, and 15% of the flow. Conversely, it only contributed 5–8% of the faecal bacteria, 4% of the total P, and 7% of the total N. The Muddy Stream (S8) contributed 12% of the nitrate-N, but only 3% of the flow. The farm drain (S9) contributed 32% of the faecal coliforms and *E. coli*, and 76% of the enterococci. It also contributed 23% of the turbidity and total P, 10% of the total N, and 41% of the ammoniacal N, but just over 1% of the flow.
- 22 February. The Wairoa Stream (S5) contributed about 10% of the faecal bacteria, and 15% of the various forms of N. It also contributed 14% of the flow. The Wairangi Stream (S6) contributed 12% of the *E. coli* and the nitrate-N, and 8% of the flow. The quarry drain (S7) contributed 16% of the ammoniacal N, but only 2% of the flow. The farm drain (S9) contributed 11% of the ammoniacal N, but less than 1% of the flow.
- 9 March. The Wairoa Stream (S5) contributed 26% of the enterococci, and 15–17% of the dissolved reactive P, nitrate-N and ammoniacal N, and 15% of the flow. The Wairangi Stream (S6) contributed 18% of the nitrate-N, and 9% of the flow. The quarry drain (S7) contributed 20% of the ammoniacal N, but only 2% of the flow.

It is therefore clear that at times the Wairoa, Wairangi and Muddy Streams contributed slightly disproportionate loads of some contaminants, while the quarry and farm drains contributed markedly disproportionate loads. The Wairoa and Wairangi Streams and the quarry and farm drains all drain reasonably large areas of farmland, and it is likely that the elevated loads of nutrients and faecal bacteria in these tributaries are at least partly due to this.[15] However, it is also clear that there must be other sources of contaminants within the Wentworth sub-catchment that this preliminary survey has not been able to identify.[16]

3.4 Water quality in estuaries

The complete results for the four estuarine surveys are given in Appendix 3. Table 9 shows some of these to provide the basis for a broad description of the observed patterns. Much of the observed variation in water quality in the estuaries reflected the recent history of freshwater inflow to the harbour. This affected the vertical and horizontal distribution of salinity and some of the contaminants.

The water quality of the Waikiekie estuary varied markedly, as follows (Table 9, Appendix 3):

- The salinity at the seaward end of the estuary (site W5) was always high (32–35). However, the surface salinity at the landward end of the estuary (site W1) varied from 13.0 on the dry weather survey (11 January) down to 1.3 on 22 February, following a particularly wet period. At site W5 there was never much difference in salinity between the surface and bottom waters. But at site W1 the difference was always marked, with the bottom waters having a salinity that was 22–31 units higher than the surface waters (i.e. a marked "salt wedge" was present).
- Concentrations of faecal bacteria varied markedly both with time (i.e. between surveys) and in space (i.e. between sites, e.g. Fig. 3A,C). Exceptionally high values were observed at site W1 on 11 January, with moderate-to-high values being observed on the other occasions. At site W5, however, concentrations were always lower—on 11 January they were much lower (Fig. 3A).
- The very high concentrations of faecal bacteria at sites W1 and W2 on 11 January may have resulted from processes connected with the estuarine circulation cell in this part of the estuary. Particulate material is known to be concentrated in zones of low salinity in estuaries (e.g. Davies-Colley et al. 1993, p. 170). Particles from the catchment are carried downstream by less dense, fresh surface waters until

[15] There is rather less farmland in the catchment of the Muddy Stream, however.

[16] For example, sources that account for the marked increase in the load of total N between the main-stem Wentworth sites at the ford and the golf course on 9 March. In this case there was an increase of more than 100 mg/s, of which only about one-fifth could be accounted for from the loads from the relevant monitored tributaries (see Table 8).

decreasing current velocities and saline-induced flocculation in the middle of the estuary cause them to settle into the denser, more saline bottom waters. These bottom waters then carry the particles back upstream. Particulate contaminants can thus be recycled and concentrated near the head of an estuary.[17]

- Concentrations of faecal bacteria also varied down through the water column (Appendix 3). This was particularly evident at the sites where salinity stratification was strong (i.e. sites W1 and W2). In these cases, concentrations of faecal bacteria in the more-saline near-bottom waters were lower—often much lower—than those shown in Table 9 for the near-surface waters. At the most seaward site (W5), however, differences between near-surface and near-bottom samples were minor (e.g. Fig. 3). This reflects the fact that vertical salinity differences at this site were always small (Table 9). The freshwater from the Waikiekie Stream was therefore always relatively well-mixed with the harbour water by the time it reached site W5.
- However, concentrations of faecal bacteria in the samples collected from the surface microlayer were often higher than those observed in the near-surface waters (Appendix 3). This is illustrated in Figure 4. Concentrations of both faecal coliforms (Fig. 4A) and enterococci (Fig. 4B) were often up to about ten times higher in the surface microlayer samples than in the corresponding near-surface sample. On average, faecal coliform concentrations in the surface microlayer samples were 4.1 times greater than in the near-surface samples, while enterococci concentrations were 3.6 times greater.
- Total phosphorus concentrations showed rather less spatial variability—either between sites, or down through the water column. But concentrations did vary between surveys, with somewhat lower values being observed on the latter two surveys (e.g. Table 9).

Table 9: Near-surface contaminant concentrations at sites in the Waikiekie and Moanaanuanu estuaries of Whangamata Harbour on four occasions during January-Match 2001. The difference in salinity (symbol ΔS) between the surface and bottom layers is also shown. See Appendix 3 for complete results.

	S	ΔS	fc	ent	Turb	TP	DIN
11 January							
W1	13.0	22.3	20000	4200	1.50	0.027	0.98
W5	35.3	0.1	18	8	1.54	0.025	0.03
8 February							
W1	1.9	30.7	5100	850	6.05	0.025	2.71
W5	32.7	0.2	170	160	2.43	0.019	0.04
22 February							
W1	1.3	29.5	190	64	2.45	0.007	1.30
W5	32.3	0.5	24	15	1.82	0.022	0.02
9 March							
W1	2.9	30.9	450	370	1.46	0.014	0.11
W5	33.9	0.0	28	13	1.62	0.014	0.02
11 January							
M1	10.9	9.1	2100	2100	1.86	0.041	0.19
M5	33.9	0.0	330	210	1.98	0.045	0.03
8 February							
M1	0.0	0.0	4900	650	10.9	0.033	0.08
M5	18.1	0.1	3100	750	7.04	0.031	0.08
22 February							
M1	0.0	0.0	470	280	5.00	0.009	0.08
M5	0.0	7.7	500	97	4.37	0.013	0.08
9 March							
M1	0.3	5.2	4000	2100	2.76	0.014	0.03
M5	25.5	0.0	320	180	2.18	0.024	0.05

[17] These processes may also have been responsible for the unusually high levels of turbidity and nutrients observed in the brackish waters (S = 6.0) in the Otuwheti Stream on 9 March (see section 2.2, Appendix 1).

- By contrast, concentrations of dissolved inorganic nitrogen varied markedly in both time and space (Fig. 5). Concentrations in the near-surface waters were much higher at the landward sites (W1, W2) than at the more seaward sites. And concentrations at sites W1 and W2 were typically much higher in the near-surface waters than in the more-saline near-bottom waters. At site W5, concentrations of DIN on all four surveys were broadly similar (e.g. 0.02–0.04 g/m^3 in the near-surface waters). But at site W1 near-surface concentrations were much lower on 9 March (0.11 g/m^3) than on 8 February (2.71 g/m^3).

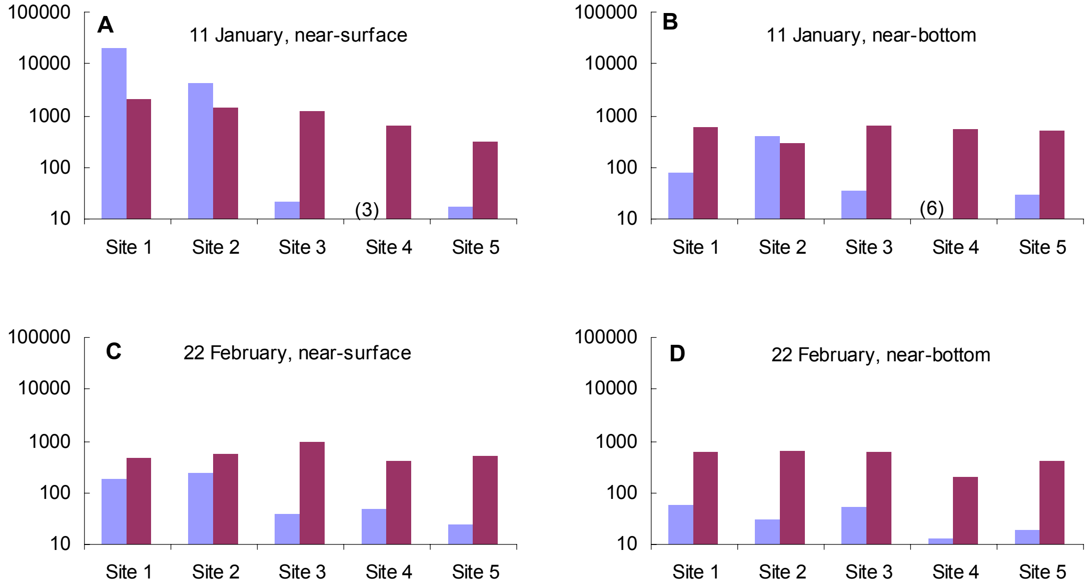

Figure 3: Faecal coliform concentrations in two estuaries of Whangamata Harbour. Light bars show the results for the Waikiekie estuary, and dark bars for the Moanaanuanu estuary. Near-surface and near-bottom results are shown for two sampling occasions. Units are cfu/100 mL. Note logarithmic scales.

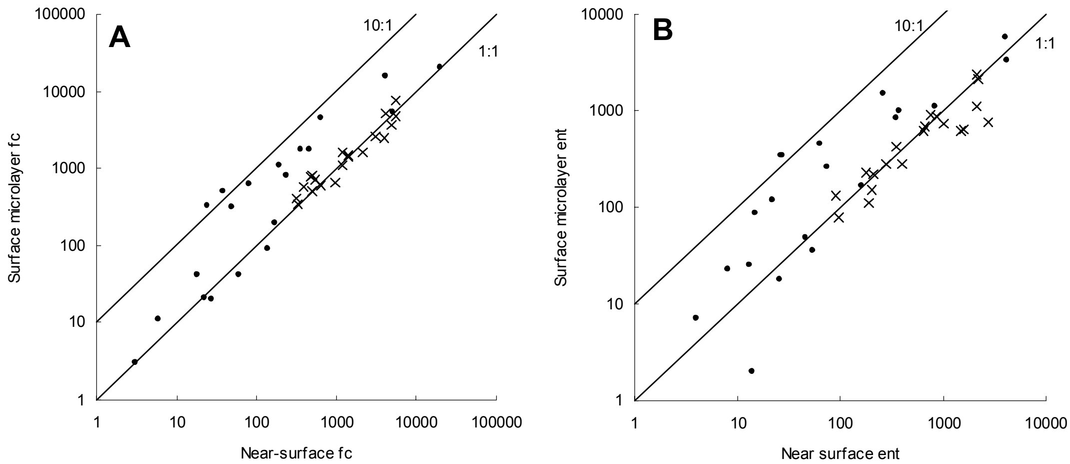

Figure 4: Concentrations of **A**, faecal coliform, and **B**, enterococci bacteria in near-surface and surface microlayer samples from two estuaries of Whangamata Harbour, January-March 2001. Results from Waikiekie estuary samples are shown as circles, and those from Moanaanuanu estuary as crosses. The lines show the 10:1 and 1:1 values of the ratio surface microlayer/near-surface. Units are cfu/100 mL.

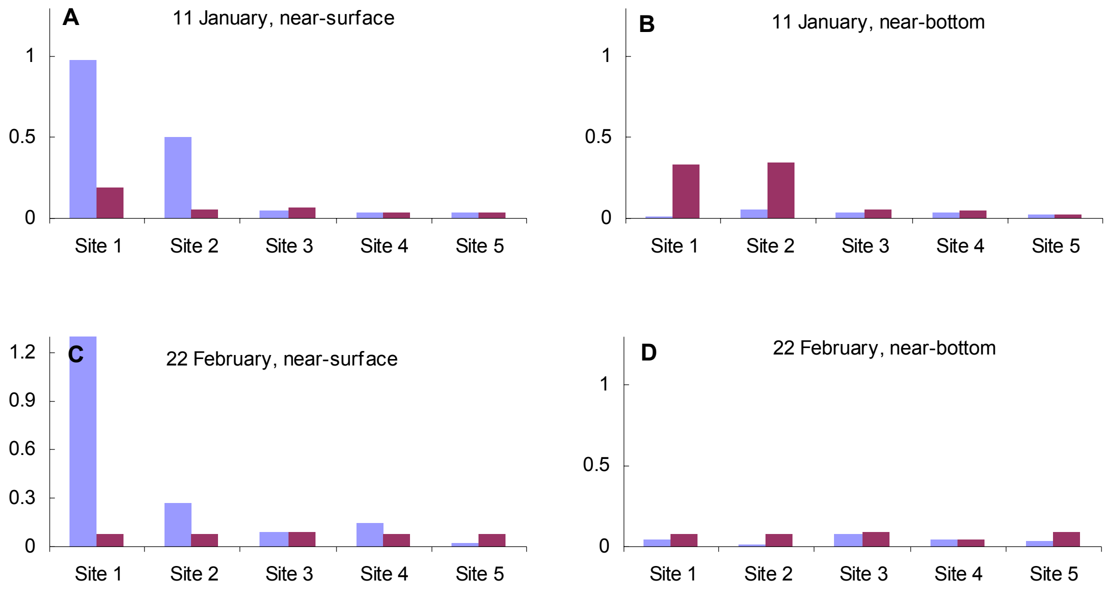

Figure 5: Dissolved inorganic nitrogen concentrations in two estuaries of Whangamata Harbour. Light bars show the results for the Waikiekie estuary, and dark bars for the Moanaanuanu estuary. Near-surface and near-bottom results are shown for two sampling occasions. Units are g/m^3.

The water quality of the Moanaanuanu estuary also varied markedly. However, some of the patterns of variability were quite distinct from those observed in the Waikiekie estuary. The patterns observed in the Moanaanuanu estuary were as follows (Table 9, Appendix 3):

- On 11 January and 9 March the salinity at the seaward end of the estuary (site M5) was reasonably high (>25), but lower values were observed on the February surveys. The surface salinity at the landward end of the estuary (site M1) was 11 on 11 January (dry weather), but was <1 on the other three occasions. On 22 February, no seawater was present as far downstream as site M3, while salinities were all <8 at the two more seaward sites (Appendix 3). Vertical stratification of salinity did occur, but was more common at the middle sites (M2 to M4) than at the most landward site (M1). In this middle region of the estuary the maximum salinity difference (ΔS) was just 3.3 on 22 February,[18] but was 14–19 on the other three occasions. Vant (2000, p.8) reported that in the (dry weather) surveys in 1999–2000, salinity stratification occurred at the Causeway site, about 0.5 km downstream of site M5. The fact that the flow in the Wentworth River was several times greater than that in the Waikiekie Stream (Table 7) meant that the salt wedge was more marked in the Moanaanuanu estuary than in the Waikiekie estuary.
- Concentrations of faecal bacteria varied markedly both with time and in space (e.g. Fig. 3). Concentrations were highest on 8 February, were high on 11 January, and were mostly moderate-to-high on 22 February and 9 March. On 11 January (Fig. 3A,B) and 9 March concentrations were considerably higher at the landward end of the estuary than at the seaward end. But on 8 February and 22 February (Fig. 3C,D) concentrations throughout the estuary were more similar to each other.
- On 11 January (Fig. 3A,B) and 9 March concentrations of faecal bacteria in the near-surface water at sites M1 to M3 were considerably higher than those in the near-bottom water. On 8 February and 22 February (Fig. 3C,D), however, the vertical differences in concentration were smaller. On all occasions, vertical differences at the most seaward site (M5) were minor (e.g. Fig. 3).
- Although there were some differences between the concentrations of faecal bacteria in the near-surface and surface microlayer samples, these were mostly minor (Fig. 4). On average, concentrations of faecal coliforms in the surface

[18] But note that it was higher (7.7) further downstream at site M5 (Table 9).

microlayer samples were only 10% higher than those in the corresponding near-surface sample (Fig. 4A), while enterococci concentrations were actually 10% lower (Fig. 4B). This contrasts with the situation often observed in the Waikiekie estuary (see above).

- As in the Waikiekie estuary, spatial variation in concentrations of total phosphorus was not marked. However, concentrations did vary between surveys, with somewhat lower values being observed on 22 February and 9 March.
- Concentrations of DIN were much less variable than in the Waikiekie estuary (e.g. Fig. 5). Concentrations were occasionally somewhat higher at the more landward sites (M1, M2), and there were minor differences between near-surface and near-bottom water samples. In general, concentrations at site M1 were considerably lower than those at W1, while concentrations at M5 were higher than at W5.
- The Whangamata wastewater treatment pond is adjacent to the Okauanga Stream, which flows into the Moanaanuanu estuary downstream of site M4. Contaminant concentrations further downstream at site M5 were generally similar to or lower than those at site M4. There was therefore no evidence from this study of any substantial leak of contaminants from the treatment pond (as also found by Vant 2000).

3.5 Water quality in coastal waters

On all four occasions, samples were collected at the wharf and the ebb-tide delta. The wharf samples were collected on an incoming tide, while the ebb-tide delta samples were collected several hours later on an outgoing tide. Near-surface samples were collected on all occasions, with surface microlayer samples also being collected at the ebb-tide delta.[19] The main results for these samples are shown in Table 10 (with the complete results in Appendix 3).

On each occasion, the results for the wharf and ebb-tide delta samples were usually similar. Salinity was highest on 11 January, with values on the subsequent, wetter, occasions being lower (particularly on 8 February and 22 February).

Concentrations of faecal bacteria were low on 22 February and 9 March, slightly-to-moderately elevated on 11 January, and moderately-high on 8 February. Concentrations in the near-surface sample and the corresponding surface microlayer sample were usually similar. However, in one instance (faecal coliforms, 9 March) the surface microlayer result was more than twice the near-surface result, while on two occasions it was 2–10 times lower (enterococci, 11 January and 8 February). The

Table 10: Near-surface contaminant concentrations at coastal water sites at Whangamata harbour on four occasions during January-March 2001. Samples from the Whangamata wharf ("W") were collected about 3 h before high water, while those from the ebb-tide delta ("ETD") were collected 3–4 h after high water. Values in brackets are for samples from the surface microlayer. See Appendix 3 for complete results.

	S	fc	ent	Turb	TP	DIN
11 January						
W	35.4	5	6	2.26	0.033	0.03
ETD	35.5	10 (9)	64 (6)	3.23	0.028	0.03
8 February						
W	32.7	130	120	2.48	0.014	0.03
ETD	30.8	190 (180)	240 (94)	3.80	0.047	0.04
22 February						
W	32.9	1	<1	2.44	0.018	0.02
ETD	29.8	3 (4)	<1 (3)	1.58	0.018	0.04
9 March						
W	34.2	1	<1	3.82	0.022	<0.01
ETD	33.6	6 (14)	2 (2)	2.54	0.018	0.01

[19] Note, however, that wave action at the latter site often meant that in practical terms there was little—if any—real distinction between the "near-surface" and "surface microlayer" water masses.

concentrations of faecal bacteria observed at the coastal water sites on the different occasions broadly reflected the magnitudes of the corresponding catchment loads (Table 7). As noted above, it is unlikely that less saline, more contaminated surface layers similar to those observed at the more landward sites in the Waikiekie and Moanaanuanu estuaries often persist past the seaward ends of these estuaries (i.e. into the coastal water area further seaward).

No marked patterns of variability were apparent in the nitrogen and phosphorus results, with all values being relatively low—apart from 11 January, concentrations were lower than those in a "typical stream" flowing into the harbour (Table 6). The dissolved inorganic nitrogen concentrations in the coastal waters were much lower than those in the Waikiekie Stream (Table 6).

Various measurements have been made of the volume of coastal water entering the harbour (Hume et al. 1986, Sheffield 1991). Using a tidally-averaged inflow rate for an incoming (spring) tide of 4.06×10^6 m^3 per half-tidal cycle (Hume et al. 1986, p. 127)—or about 180 m^3/s, and the contaminant concentrations measured in the incoming water at the wharf, it is possible to very-approximately estimate the contaminant loads entering the harbour in the coastal water. These can be compared with the total loads entering in the freshwater inflows (Table 7), to broadly compare their relative magnitudes.

On 11 January and 8 February the loads of faecal bacteria in the freshwater and incoming coastal water were of similar magnitude. However, on 22 February and 9 March the loads in the freshwater were 2–30 times greater than those entering in the coastal water. The loads of total phosphorus in the coastal water entering the harbour were greater than those in the freshwater—by a factor of 4 on 8 February, and by a factor of 70–800 on the other three occasions. The loads of dissolved inorganic nitrogen entering in the coastal water were also greater than those in the freshwater—by a factor of about 80 on 11 January, about by 4 to 6-fold on the other three occasions. These very approximate calculations therefore suggest that the freshwater inflows are often the major source of faecal bacteria to the harbour, while the inflowing coastal waters are the major source of nutrients.[20]

4 Conclusions

4.1 Catchment loads of contaminants

1. The size of the loads of contaminants entering Whangamata Harbour in the inflowing streams varied markedly between surveys. Dry weather loads were many times lower than those in wet weather. The increased loads in wet weather reflected increases in both (1) stream flow, and (2) contaminant concentration. As a result, the 11-fold increase in flow on 8 February, for example, was associated with a 60-fold increase in the faecal coliform load, while the loads of nitrogen and phosphorus increased by 40 to 80-fold. When concentrations increase with increasing flow, contaminant loads increase sharply.

2. However, factors other than instantaneous flow are also important. Flows were also relatively high on 22 February, but specific yields of contaminants on that occasion were considerably lower than on 8 February: yields of nitrogen and phosphorus in a typical stream were 6–13 times lower, while yields of faecal bacteria were 70–140 times lower. This suggested that faecal bacteria in particular had been flushed from the catchment by the preceding period of wet weather. The recent history of high flow events therefore also determines the magnitude of contaminant loads.

[20] Note that this comparison does not address the question of where the contaminants in the coastal water came from. It may be that a large proportion of the load in the inflowing coastal waters was ultimately sourced from the nearby land.

3. The Wentworth is the largest sub-catchment of the harbour (48% of the area of the harbour catchment). It is therefore not surprising that it was generally the main source of contaminants to the harbour. On any given survey date, contaminant concentrations in the various major inflows to the harbour were often broadly similar, so that the differences in loads largely reflected the differences in flow—and these in turn reflected the different sizes of the sub-catchments. Diffuse runoff from the land is probably the main source of most of the contaminant loads, rather than discharges from any (unidentified) point sources.

4. However, there were some important exceptions to this. In particular, the Waikiekie Stream provided a disproportionate share of the nitrogen, and at times provided a disproportionate share of the faecal bacteria. This was undoubtedly a result of leakage of these contaminants from the wastewater spray-irrigation area that is located in this sub-catchment. Although there are no direct measurements of the loads leaking from the area, leakage appears to account for most of the load of nitrate-N in the stream, and perhaps half of the load of faecal bacteria. The loads of nitrogen and bacteria exported from the sub-catchment on the dry weather occasion (11 January) were much lower than the average loads in the wastewater, while those exported on the wet occasion (8 February) were much higher.

5. On 8 February, high concentrations of faecal bacteria were measured in the three small streams: the Te Weiti, Okauanga and Kaupeka Streams. The catchments of the Te Weiti and Kaupeka Streams are mostly (>83%) in pine or native forest. Elsewhere on the Coromandel Peninsula, high concentrations of faecal bacteria have occasionally been observed in streams that drain predominantly-forested areas. Large populations of feral animals may be responsible for these high concentrations. As much of the harbour catchment is forested, these animals may thus be an important source of the faecal bacteria entering the harbour.

6. As it happened, the stormwater flows observed at the time of sampling the two outfalls were highest on 9 March—even though rainfall was considerably lighter than during the survey of 8 February. Under these conditions of reasonably light rain, stream flows were only moderate—with the total inflow to the harbour being more than four times lower than that on the heavy rain survey of 8 February. The combined effect of higher flows in the stormwater outfalls, and lower flows in the streams meant the contaminant loads in the stormwater were relatively high on 9 March. This was partly because the concentrations of faecal bacteria and nitrogen and phosphorus in the stormwater were considerably higher than those in the inflowing streams. This suggests that the effects on the harbour of the high levels of contaminants in stormwater are likely to be greater during periods of lighter rain. Heavy rain and high stream flows are likely to effectively swamp the contributions from the stormwater outfalls, as well as rapidly flushing them from the harbour.

4.2 Loads in the Wentworth sub-catchment

7. The contaminant loads measured at the bottom of the Wentworth sub-catchment were often higher than the combined loads of the monitored tributaries to the river. However, in wet weather in particular, contaminants are likely to directly enter the river via overland flow from the adjacent land, as well as via the (monitored) tributaries. Sources such as this presumably contributed to the loads observed in the lower reaches of the river in these surveys. There was no evidence from our inspection of the catchment of any readily identifiable and important, but un-monitored sources of contaminants.

8. The area of native bush upstream of the first sampling site (site S1) contributed about half (45–53%) of the total flow in the river (as measured at site S4). However, apart from 22 February, on average it contributed about one-quarter of the loads of faecal bacteria; and apart from 11 January, on average it contributed less than one-third of the load of total nitrogen. Most significantly, however, on all occasions the area of bush upstream of site S1 only contributed 10–14% of the

load of turbidity. This implies that the largely pastoral area downstream of site S1 contributed most of the turbidity observed at the lower end of the river, and at times contributed much of the loads of the other contaminants.

9. At times, three tributary streams contributed slightly disproportionate loads of contaminants to the Wentworth River. Two permanent drains, however, contributed markedly disproportionate loads. These drained areas of farmland, and the elevated loads of nutrients and faecal bacteria in them are likely to be at least partly due to losses from farming.

4.3 Water quality in the estuaries and coastal water

10. The relative amounts of freshwater and seawater present in the estuaries depended on the inflow of freshwater over the previous week or so. Following periods of high freshwater flow, seawater did not penetrate far up the Moanaanuanu estuary. The catchment upstream of the Waikiekie estuary was considerably smaller than that upstream of the Moanaanuanu estuary, however, so the size of the zone affected by freshwater was also smaller.

11. At the landward ends of the estuaries, less dense freshwater tended to flow downstream above a layer of more dense seawater. Contaminant concentrations in these layers were often markedly different. For example, at site W1 on 11 January the salinities in the surface and bottom waters were 13.0 and 35.3, respectively, while the corresponding concentrations of faecal coliforms were 20,000 cfu/100 mL and 80 cfu/100 mL.[21] Concentrations of nitrogen also tended to be higher in the less-saline surface layers. Dilution with relatively-clean seawater also meant that concentrations of contaminants tended to decrease along a gradient from the more landward sites to the seaward sites.

12. By contrast, at the seaward ends of the estuaries, differences in contaminant concentrations in the near-surface and near-bottom waters were minor. Further downstream in the open waters of the main body of the harbour, turbulence and mixing is likely to further reduce any vertical differences in contaminant concentrations. Even in the high flow events, when salinities were low in the Moanaanuanu estuary in particular, the salinities in the near-surface waters at the wharf and the ebb-tide delta were 84–93% of that of seawater. This means that contaminants entering the harbour in the inflowing streams are likely to usually be highly diluted with clean seawater by the time they reach the outer harbour and coastal waters.

13. In the Waikiekie estuary, considerably higher concentrations of faecal bacteria were often found in samples collected from the surface microlayer than in samples collected from the near-surface waters. This pattern was not observed in the Moanaanuanu estuary, where concentrations in the corresponding samples tended to be similar. The implications of the higher concentrations that were observed in the Waikiekie surface microlayer samples are unclear. This is because the guidelines for the risk of illness associated with bathing in contaminated waters were derived using samples collected from near-surface waters only.

14. Relatively-high concentrations of faecal bacteria were found at the coastal water sites at the wharf and the ebb-tide delta on the wet weather survey of 8 February. These probably resulted from the high loads of bacteria measured in the inflows to the harbour on that occasion. Most of the bacterial load then came from the Wentworth (28–39%), Otuwheti (20–35%) and Waikiekie (4–27%) sub-

[21] Note that this concentration in the near-surface waters was 20-fold higher than that measured further upstream on the same day (site C3), suggesting contaminants were being concentrated within an estuarine circulation cell on this occasion. This phenomenon was not observed during the other surveys, however.

catchments.[22] These results suggest that the harbour and nearby coastal waters are unlikely to be satisfactory for bathing during periods of high freshwater flow.[23]

15. However, it is also worth noting that the moderately-high flows on 22 February carried a much smaller load of faecal bacteria into the harbour (and thus to the coastal area seaward of it). As a result of this, concentrations of faecal bacteria at the coastal water sites on that occasion were much lower than on 8 February. The extent to which the catchment has been flushed-out by earlier high-flow events therefore also determines the suitability of the coastal waters for bathing.

4.4 Overview

16. The studies during 1999–2000 (Vant 2000) showed that during fine weather, water quality was good over a large area of the harbour. Concentrations of faecal bacteria were generally low, and the water was suitable for bathing (although probably not for shellfish-gathering in the southern part of the harbour). Water quality was also high at the bathing area near the wharf, and at the main coastal beaches outside the harbour.

17. However, water quality was found to be poorer in two areas where moderately contaminated stream water mixed with harbour water. This meant that contaminant concentrations were moderately high at times in the Moanaanuanu and Waikiekie estuaries of the harbour.

18. The summer 2001 studies have added considerably to our understanding of the area's water quality by (1) more thoroughly describing conditions in the two sub-estuaries of the harbour, (2) sampling the water at the ebb-tide delta mid-way through the outgoing tide, (3) identifying the relative contributions of the major inflowing streams to the total loads of contaminants entering the harbour, (4) identifying the direct contributions of several tributaries and drains that flow through areas of pasture to the contaminant loads in the major inflow to the harbour (the Wentworth River), and (5) identifying the effects of wet weather and high flows on contaminant loads and harbour water quality.

19. Taken together, the results of the two studies show that water quality is high over large areas of the harbour during fine weather. However, in estuarine areas near the mouths of inflowing streams, concentrations of contaminants brought into the harbour in the streams can be high. In wet weather, contaminant loads in the inflowing streams can be high, so concentrations can be moderate-to-high over large areas—including at the ebb-tide delta outside the harbour. Most of the contaminants come from diffuse runoff from the pasture, pine forest and bush in the catchment as a whole, but leakage from the wastewater spray-irrigation area in the Waikiekie sub-catchment is a major source of the nitrogen entering the harbour.

[22] As noted above, we may conclude that perhaps half of the load in the Waikiekie Stream represented leakage from the wastewater spray-irrigation area (although this was not directly measured).
[23] This conclusion is consistent with information previously obtained for coastal waters of the Coromandel Peninsula: Vant (1999, fig. 3).

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Appendix 1: Inflow surveys. Flows and contaminant concentrations at various sites.

11 Jan 2001; HW @ 07:52 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
C1	Otuwheti	14:05	91	720	720	586	7.03	0.041	0.013	0.1	0.004	0.01
C2	Wentworth	13:33	304	1500	1500	1500	3.42	0.014	0.009	<0.1	0.011	0.01
C3	Waikiekie	13:02	63	1000	1000	630	1.88	0.005	0.008	0.1	1.08	<0.01
C4	Kaupeka	12:40	2.2	240	14	15	20.4	0.021	0.013	0.2	0.003	0.04
C5	Okauanga	13:18	2.9	63	30	250	2.02	0.010	0.014	<0.1	<0.002	<0.01
C6	Te Weiti	12:51	9.5	1200	1200	770	3.64	0.010	0.008	0.1	0.019	<0.01
C7	Achilles	13:50	0.5	600	320	490	18.5	0.194	0.156	0.4	0.109	0.06
C8	Hetherington	13:55	0	–	–	–	–	–	–	–	–	–
W	Wharf	04:55	–	5	4	6	2.26	0.033	0.008	–	0.004	0.03

8 Feb 2001; HW @ 06:36 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
C1	Otuwheti	12:48	1140	8200	8200	6300	72.0	0.153	0.013	0.8	0.091	0.01
C2	Wentworth	13:23	2190	6100	6100	3700	40.5	0.120	0.020	0.5	0.093	0.01
C3	Waikiekie	12:27	857	15000	15000	960	29.5	0.067	0.018	0.5	1.10	<0.01
C4	Kaupeka	11:55	40	18000	18000	1100	10.5	0.036	0.011	0.2	0.034	0.01
C5	Okauanga	11:38	66	19000	19000	970	27.1	0.083	0.017	0.5	0.073	<0.01
C6	Te Weiti	12:10	252	17000	17000	4100	74.2	0.133	0.009	0.9	0.353	0.03
C7	Achilles	13:40	0.1	4400	1700	2900	8.18	0.046	0.031	0.3	0.053	0.02
C8	Hetherington	13:12	1.0	2600	1300	5500	10.7	0.040	0.032	0.2	0.101	<0.01
W	Wharf	03:25	–	130	130	120	2.48	0.014	0.006	–	0.015	0.02

22 Feb 2001; HW @ 06:34 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
C1	Otuwheti	12:40	302	470	300	110	4.11	0.014	0.014	0.2	0.162	<0.01
C2	Wentworth	13:23	1260	180	120	51	6.93	0.026	0.011	0.2	0.067	<0.01
C3	Waikiekie	12:17	227	550	300	92	3.38	0.014	0.013	0.2	1.81	0.03
C4	Kaupeka	11:54	9.7	280	190	31	9.22	0.012	0.013	0.2	0.005	<0.01
C5	Okauanga	11:39	20	270	170	80	8.89	0.008	0.014	0.1	0.025	<0.01
C6	Te Weiti	12:04	48	790	450	350	4.73	0.008	0.011	0.2	0.38	<0.01
C7	Achilles	13:52	0	–	–	–	–	–	–	–	–	–
C8	Hetherington	13:12	0.3	100	9	140	0.54	<0.004	0.008	0.2	2.54	<0.01
W	Wharf	03:24	–	1	1	<1	2.44	0.018	0.006	–	0.003	0.02

9 Mar 2001; HW @ 06:17 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
C1	Otuwheti	12:29	275	900	900	700	112	0.273	<0.004	1.4	0.047	<0.01
C2	Wentworth	13:12	659	2700	2600	2100	6.49	0.020	0.005	0.2	0.027	<0.01
C3	Waikiekie	12:10	157	2200	2200	4900	2.60	0.009	<0.004	0.2	1.29	<0.01
C4	Kaupeka	11:37	4.9	210	150	41	20.8	0.026	0.004	0.3	0.003	<0.01
C5	Okauanga	11:22	7.1	210	210	110	4.34	0.009	0.005	<0.1	0.025	<0.01
C6	Te Weiti	11:58	28	3600	3600	5200	5.22	0.016	<0.004	0.2	0.104	<0.01
C7	Achilles	13:33	20	5100	3800	5800	8.45	0.042	<0.004	0.2	0.017	<0.01
C8	Hetherington	12:58	74	7700	7700	8400	24.0	0.112	<0.004	0.5	0.027	<0.01
W	Wharf	03:05	–	1	1	<1	3.82	0.022	<0.004	–	<0.002	<0.01

Appendix 2: Wentworth Valley surveys. Flows and contaminant concentrations.

11 Jan 2001; HW @ 07:52 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
S1	Above camp	07:05	126	600	390	410	0.61	0.008	0.010	<0.1	0.009	<0.01
S2	Ford	07:38	161	460	260	520	0.46	0.008	0.008	<0.1	0.005	<0.01
S3	Near quarry	08:40	214	1000	900	570	1.84	0.008	0.010	<0.1	0.004	<0.01
S4	Golf course	11:41	236	1600	1600	650	3.16	0.011	0.009	<0.1	0.007	<0.01
S5	Wairoa Stm	08:05	37	460	240	430	0.72	0.009	0.009	<0.1	0.011	0.01
S6	Wairangi Stm	08:25	22	1600	1600	590	1.24	0.009	0.008	<0.1	0.022	<0.01
S7	Quarry drain	08:56	6.8	470	410	290	5.26	0.041	0.008	0.4	0.025	0.06
S8	Muddy Stm	09:15	6.9	780	390	650	2.13	0.017	0.013	<0.1	0.028	<0.01
S9	Farm drain	09:35	0.8	650	490	570	17.2	0.038	0.009	0.3	0.063	0.02
S10	Widdison Pl*	10:42	0.3	660	510	490	70.2	0.280	0.009	2.2	0.029	0.19
S11	Landfill drain	12:00	0	–	–	–	–	–	–	–	–	–

*at time of sampling, the bottom sediment at this site was disturbed (by eel or similar), so results may well be affected by this

8 Feb 2001; HW @ 06:36 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
S1	Above camp	07:07	475	2700	1800	280	4.33	0.012	0.012	0.2	0.037	0.03
S2	Ford	07:40	548	3200	2300	420	4.30	0.010	0.007	0.1	0.032	<0.01
S3	Near quarry	08:43	770	2300	1200	710	5.95	0.014	0.006	0.2	0.046	<0.01
S4	Golf course	10:08	1050	5300	5300	2100	16.6	0.041	0.005	0.3	0.055	<0.01
S5	Wairoa Stm	08:06	162	2900	1700	670	4.00	0.010	0.006	0.1	0.072	<0.01
S6	Wairangi Stm	08:26	61	2700	1800	920	3.93	0.010	0.005	0.1	0.114	<0.01
S7	Quarry drain	08:56	16	1100	820	410	5.99	0.039	0.005	0.3	0.017	0.03
S8	Muddy Stm	09:16	31	6100	3600	2800	13.0	0.043	0.009	0.3	0.217	0.01
S9	Farm drain	09:45	12	150000	150000	140000	335	0.794	0.007	2.8	0.311	0.18
S10	Widdison Pl	10:28	9.3	4100	2800	5500	16.3	0.050	0.011	0.4	0.053	<0.01
S11	Landfill drain	06:45	2.2	6000	2900	2900	3.48	0.029	0.007	0.5	0.61	0.02

22 Feb 2001; HW @ 06:34 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
S1	Above camp	07:05	708	340	190	45	1.12	0.005	<0.004	<0.1	0.041	<0.01
S2	Ford	07:43	734	300	220	96	1.10	<0.004	<0.004	<0.1	0.037	<0.01
S3	Near quarry	09:06	1100	290	160	47	2.17	<0.004	<0.004	<0.1	0.047	<0.01
S4	Golf course	10:50	1310	290	170	56	4.44	0.009	0.011	0.1	0.059	<0.01
S5	Wairoa Stm	08:18	186	220	130	39	1.14	0.005	0.007	0.1	0.066	<0.01
S6	Wairangi Stm	08:43	103	330	260	48	1.78	0.007	0.010	<0.1	0.091	<0.01
S7	Quarry drain	09:29	27	310	160	12	4.00	0.016	<0.004	0.2	0.168	0.04
S8	Muddy Stm	09:46	39	380	170	96	2.92	0.009	<0.004	0.1	0.159	<0.01
S9	Farm drain	10:09	8.3	960	570	94	14.1	0.053	0.021	0.6	0.24	0.09
S10	Widdison Pl	10:20	3.4	66	39	63	1.10	<0.004	<0.004	0.2	2.26	0.01
S11	Landfill drain	10:40	6.4	170	130	250	1.58	0.005	<0.004	0.4	1.16	<0.01

9 Mar 2001; HW @ 06:17 NZST

	site	NZST	Flow	fc	Ec	ent	Turb	TP	DRP	TKN	NNN	amm-N
S1	Above camp	07:23	303	260	260	150	0.72	0.011	<0.004	0.1	0.025	<0.01
S2	Ford	08:00	331	340	340	350	1.55	0.009	<0.004	<0.1	0.019	<0.01
S3	Near quarry	09:04	518	1800	1800	230	1.42	0.007	<0.004	0.1	0.015	<0.01
S4	Golf course	10:33	600	450	450	190	2.60	0.011	<0.004	0.2	0.030	<0.01
S5	Wairoa Stm	08:30	89	290	290	330	1.01	0.004	<0.004	<0.1	0.035	<0.01
S6	Wairangi Stm	08:47	54	460	400	170	1.54	0.006	<0.004	<0.1	0.060	<0.01
S7	Quarry drain	09:20	12	160	70	27	3.84	0.020	<0.004	0.2	0.023	0.05
S8	Muddy Stm	09:36	21	270	270	120	2.62	0.016	<0.004	0.1	0.085	<0.01
S9	Farm drain	09:56	2.1	540	520	160	17.0	0.033	<0.004	0.4	0.21	0.03
S10	Widdison Pl	10:21	0.5	20	16	39	2.45	0.008	<0.004	0.2	0.21	0.04
S11	Landfill drain	10:15	2.4	80	60	170	1.26	0.004	<0.004	0.6	1.10	<0.01

Appendix 3: Estuarine and coastal water quality surveys. Note: the maximum depth at each site is the greatest depth (symbol z) shown in the temperature/salinity profiles.

A3.1 11 Jan 2001; HW @ 07:52 NZST

site	NZST	fc	Ec	ent	Turb	TP	DRP	NNN	amm-N
Near-surface									
W1	09:12	20000	20000	4200	1.50	0.027	0.018	0.93	0.05
W2	09:22	4200	4000	4100	1.77	0.027	0.012	0.44	0.06
W3	09:35	22	19	26	1.86	0.023	0.010	0.009	0.03
W4	09:40	3	2	14	2.25	0.025	0.006	0.006	0.03
W5	09:50	18	12	8	1.54	0.025	0.006	0.003	0.03
M1	10:18	2100	1100	2100	1.86	0.041	0.027	0.016	0.17
M2	10:30	1400	1400	2200	1.78	0.026	0.015	0.028	0.03
M3	10:40	1200	1200	1600	1.10	0.024	0.014	0.023	0.04
M4	10:50	650	370	400	1.64	0.024	0.014	0.008	0.03
M5	11:00	330	270	210	1.98	0.045	0.011	0.002	0.03
ETD	11:40	10	7	64	3.23	0.028	0.004	0.007	0.02
W	04:55	5	4	6	2.26	0.033	0.008	0.004	0.03
Near-bottom									
W1	09:12	80	77	140	1.71	0.023	<0.004	0.006	0.01
W2	09:22	410	330	330	1.48	0.023	0.004	0.037	0.02
W3	09:35	34	23	33	2.40	0.025	0.006	0.009	0.02
W4	09:40	6	3	9	10.7	0.045	<0.004	0.002	0.03
W5	09:50	29	17	28	1.50	0.027	<0.004	0.006	0.02
M1	10:18	610	330	530	7.07	0.074	0.046	0.024	0.31
M2	10:30	290	200	280	1.35	0.060	0.054	0.010	0.33
M3	10:40	640	420	460	2.22	0.026	0.014	0.016	0.04
M4	10:50	560	350	430	1.81	0.024	0.011	0.009	0.03
M5	11:00	500	280	280	2.11	0.027	0.010	0.003	0.02
Surface microlayer									
W1	09:12	20000	20000	3300	–	–	–	–	–
W2	09:22	16000	16000	5800	–	–	–	–	–
W3	09:35	21	21	18	–	–	–	–	–
W4	09:40	3	3	2	–	–	–	–	–
W5	09:50	42	30	23	–	–	–	–	–
M1	10:18	1600	1100	2400	–	–	–	–	–
M2	10:30	1400	1300	2100	–	–	–	–	–
M3	10:40	1100	600	650	–	–	–	–	–
M4	10:50	600	310	280	–	–	–	–	–
M5	11:00	340	320	220	–	–	–	–	–
ETD	11:40	9	6	6	–	–	–	–	–

W1			**W2**			**W3**			**W4**			**W5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	18.2	13.0	0.0	18.0	23.7	0.1	18.8	35.3	0.1	18.9	35.3	0.1	18.9	35.3
0.2	18.8	33.2	0.2	18.6	33.7	0.7	18.9	35.3	0.9	18.9	35.4	0.7	18.9	35.4
0.4	18.8	35.0	0.4	18.7	35.1									
0.6	18.7	35.1	0.6	18.8	35.3									
0.8	18.7	35.2	0.8	18.9	35.4									
1.0	18.7	35.3	1.0	18.9	35.4									
1.2	18.8	35.3	1.1	18.9	35.4									
1.35	18.8	35.3												

M1			**M2**			**M3**			**M4**			**M5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	19.0	10.9	0.0	19.0	18.6	0.0	19.0	26.4	0.0	19.1	32.4	0.0	19.0	33.9
0.2	19.1	12.0	0.2	19.0	19.5	0.2	19.0	28.5	0.3	19.1	32.4	0.4	19.0	33.9
0.4	19.0	12.7	0.4	19.0	19.7	0.4	19.0	28.6	0.6	19.0	32.4	0.8	19.0	33.9
0.6	18.9	13.8	0.6	18.9	26.5	0.6	19.0	29.7	0.9	19.1	32.4	1.2	19.0	33.9
0.8	19.0	20.0	0.8	18.9	29.5	0.8	19.0	32.3				1.3	19.0	33.9
			1.0	19.0	32.6	0.9	19.0	32.4						
			1.15	19.1	32.8									

Wharf			**ETD**		
z	**T**	**S**	**z**	**T**	**S**
0.0	18.9	35.4	0.0	19.1	35.5

A3.2 8 Feb 2001; HW @ 06:36 NZST

site	NZST	fc	Ec	ent	Turb	TP	DRP	NNN	amm-N
Near-surface									
W1	07:45	5100	3200	850	6.05	0.025	0.005	2.69	0.02
W2	07:52	630	380	350	2.90	0.019	0.005	0.310	0.03
W3	08:02	140	140	54	2.64	0.021	0.005	0.013	0.04
W4	08:07	60	60	46	2.87	0.019	0.006	0.013	0.03
W5	08:15	170	170	160	2.43	0.019	0.004	0.020	0.02
M1	08:45	4900	3600	650	10.9	0.033	0.005	0.080	<0.01
M2	08:55	5500	3900	660	10.1	0.029	0.006	0.109	0.01
M3	09:05	5600	3900	1000	9.01	0.029	0.004	0.119	0.02
M4	09:15	4200	2100	2800	7.40	0.029	0.010	0.085	0.01
M5	09:25	3100	2700	750	7.04	0.031	0.011	0.060	0.02
ETD	10:10	190	120	240	3.80	0.047	0.005	0.019	0.02
W	03:25	130	130	120	2.48	0.014	0.006	0.015	0.02
Near-bottom									
W1	07:45	1800	1200	280	16.9	0.060	0.005	0.104	0.03
W2	07:52	510	510	50	3.39	0.023	0.004	0.020	0.03
W3	08:02	120	120	72	3.13	0.025	0.005	0.014	0.03
W4	08:07	74	74	60	2.89	0.021	0.006	0.013	0.03
W5	08:15	170	170	140	3.55	0.025	0.005	0.018	0.02
M1	08:45	5000	3000	890	12.6	0.037	0.011	0.087	0.02
M2	08:55	3300	2100	860	8.72	0.035	0.010	0.078	0.03
M3	09:05	3500	2700	490	22.6	0.068	0.009	0.080	0.02
M4	09:15	2400	1200	700	10.7	0.041	0.011	0.060	0.02
M5	09:25	3700	2500	820	18.4	0.064	0.008	0.060	0.02
Surface microlayer									
W1	07:45	5500	3800	1100	–	–	–	–	–
W2	07:52	4600	4600	840	–	–	–	–	–
W3	08:02	92	92	36	–	–	–	–	–
W4	08:07	42	42	48	–	–	–	–	–
W5	08:15	200	200	170	–	–	–	–	–
M1	08:45	3700	2600	620	–	–	–	–	–
M2	08:55	4700	3000	690	–	–	–	–	–
M3	09:05	7600	3800	740	–	–	–	–	–
M4	09:15	5100	2900	750	–	–	–	–	–
M5	09:25	2600	1700	900	–	–	–	–	–
ETD	10:10	180	180	94	–	–	–	–	–

W1			**W2**			**W3**			**W4**			**W5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	17.8	1.9	0.0	18.1	10.1	0.0	19.6	32.8	0.0	19.8	33.0	0.0	19.7	32.7
0.2	17.7	3.2	0.2	19.0	30.1	0.7	19.6	32.9	0.88	19.8	33.1	0.7	19.8	32.9
0.4	19.2	31.2	0.4	19.2	32.1									
0.6	19.3	32.4	0.6	19.5	32.6									
0.8	19.4	32.5	0.8	19.6	32.6									
1.0	19.4	32.6	1.0	19.6	32.8									
1.2	19.5	32.6	1.25	19.7	32.9									

M1			**M2**			**M3**			**M4**			**M5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	17.4	0.0	0.0	17.6	1.1	0.0	17.8	3.8	0.0	18.2	9.2	0.0	18.8	18.1
0.2	17.3	0.0	0.2	17.5	1.1	0.2	17.8	4.0	0.2	18.4	11.2	0.2	18.8	18.1
0.4	17.4	0.0	0.4	17.5	1.4	0.4	17.8	4.3	0.4	18.4	14.1	0.4	18.8	18.2
0.6	17.3	0.0	0.6	17.5	1.6	0.6	17.8	4.6	0.65	18.6	16.2	0.6	18.7	18.2
0.65	–	–	0.8	17.7	3.7	0.8	18.5	21.8				1.2	18.7	18.2
			0.91	17.9	12.1	0.86	18.7	21.6						

Wharf			**ETD**		
z	**T**	**S**	**z**	**T**	**S**
0.0	19.8	32.7	0.0	19.5	30.8

A3.3 22 Feb 2001; HW @ 06:34 NZST

site	NZST	fc	Ec	ent	Turb	TP	DRP	NNN	amm-N
Near-surface									
W1	07:45	190	140	64	2.45	0.007	0.008	1.28	0.02
W2	07:50	240	150	75	2.05	0.018	<0.004	0.26	0.01
W3	08:00	38	23	27	1.76	0.022	0.005	0.054	0.04
W4	08:05	49	28	22	2.32	0.022	0.005	0.120	0.03
W5	08:15	24	21	15	1.82	0.022	<0.004	0.013	<0.01
M1	08:50	470	340	280	5.00	0.009	0.009	0.076	<0.01
M2	09:05	550	370	200	4.73	0.016	0.007	0.078	<0.01
M3	09:15	960	560	90	4.03	0.009	0.006	0.083	<0.01
M4	09:23	390	290	190	4.60	0.009	0.006	0.078	<0.01
M5	09:40	500	340	97	4.37	0.013	0.007	0.068	0.01
ETD	10:30	3	3	<1	1.58	0.018	<0.004	0.015	0.02
W	03:24	1	1	<1	2.44	0.018	0.006	0.003	0.02
Near-bottom									
W1	07:45	56	34	29	1.80	0.022	<0.004	0.038	0.01
W2	07:50	31	21	8	1.82	0.022	<0.004	<0.002	<0.01
W3	08:00	53	29	27	1.62	0.027	0.006	0.033	0.04
W4	08:05	13	10	2	3.90	0.038	0.004	0.013	0.03
W5	08:15	19	9	3	1.90	0.018	<0.004	0.008	0.02
M1	08:50	610	310	170	5.06	0.009	0.006	0.078	<0.01
M2	09:05	660	350	180	5.39	0.011	0.008	0.077	<0.01
M3	09:15	600	390	120	4.68	0.011	0.007	0.080	<0.01
M4	09:23	200	160	95	3.93	0.018	<0.004	0.034	0.01
M5	09:40	420	240	55	8.57	0.018	0.007	0.057	0.03
Surface microlayer									
W1	07:45	1100	470	450	–	–	–	–	–
W2	07:50	810	380	260	–	–	–	–	–
W3	08:00	510	340	350	–	–	–	–	–
W4	08:05	310	160	120	–	–	–	–	–
W5	08:15	330	230	88	–	–	–	–	–
M1	08:50	780	440	280	–	–	–	–	–
M2	09:05	710	370	150	–	–	–	–	–
M3	09:15	670	390	130	–	–	–	–	–
M4	09:23	580	320	110	–	–	–	–	–
M5	09:40	500	280	79	–	–	–	–	–
ETD	10:30	4	2	3	–	–	–	–	–

W1			W2			W3			W4			W5		
z	T	S	z	T	S	z	T	S	z	T	S	z	T	S
0.0	17.3	1.3	0.0	17.8	0.7	0.0	19.2	11.2	0.0	19.7	12.6	0.0	22.5	32.3
0.2	17.3	1.4	0.2	17.7	3.9	0.2	21.1	28.6	0.2	21.0	28.8	0.2	22.3	32.7
0.4	19.7	23.9	0.4	19.8	21.8	0.4	21.4	30.0	0.4	21.9	30.6	0.4	22.3	32.8
0.6	21.4	30.6	0.6	21.4	31.8	0.6	21.6	30.3	0.57	22.1	30.8	0.42	–	–
0.8	21.7	30.8	0.8	21.8	31.7									
0.97	21.8	30.8	0.83	–	–									

M1			M2			M3			M4			M5		
z	T	S	z	T	S	z	T	S	z	T	S	z	T	S
0.0	17.9	0.0	0.0	18.5	0.0	0.0	19.8	0.0	0.0	19.0	0.2	0.0	–	0.0
0.2	17.4	0.0	0.2	17.7	0.0	0.2	18.0	0.0	0.2	18.5	0.4	0.2	19.9	4.5
0.4	17.3	0.0	0.69	17.6	0.0	0.59	17.9	0.0	0.4	18.7	1.4	0.4	19.8	5.8
0.6	17.3	0.0							0.6	18.7	3.5	0.6	19.9	5.7
0.8	17.2	0.0							0.64	–	–	0.8	20.1	6.8
												1.0	20.2	7.7
												1.08	–	–

Wharf			ETD		
z	T	S	z	T	S
0.0	–	32.9	0.0	23.3	29.8

A3.4 9 Mar 2001; HW @ 06:17 NZST

site	NZST	fc	Ec	ent	Turb	TP	DRP	NNN	amm-N
Near-surface									
W1	07:30	450	450	370	1.46	0.014	<0.004	0.065	0.04
W2	07:35	360	360	260	1.72	0.014	<0.004	0.041	0.03
W3	07:45	80	60	28	1.48	0.014	<0.004	0.032	0.02
W4	–	6	6	4	2.72	0.018	<0.004	<0.002	0.03
W5	08:02	28	28	13	1.62	0.014	<0.004	<0.002	0.02
M1	08:30	4000	3200	2100	2.76	0.014	<0.004	0.029	<0.01
M2	08:42	1200	1200	870	2.84	0.014	<0.004	0.033	<0.01
M3	08:52	1400	1400	1500	2.80	0.022	<0.004	0.035	0.01
M4	09:02	500	500	350	2.37	0.014	<0.004	0.027	0.01
M5	09:12	320	320	180	2.18	0.024	<0.004	0.014	0.04
ETD	09:55	6	6	2	2.54	0.018	<0.004	<0.002	0.01
W	03:05	1	1	<1	3.82	0.022	<0.004	<0.002	<0.01
Near-bottom									
W1	07:30	50	50	45	2.45	0.022	<0.004	0.010	0.02
W2	07:35	210	210	180	3.36	0.022	<0.004	0.057	0.01
W3	07:45	26	26	9	1.83	0.014	<0.004	<0.002	0.04
W4	–	14	14	11	2.91	0.022	<0.004	<0.002	0.02
W5	08:02	29	28	19	1.57	0.014	<0.004	<0.002	0.02
M1	08:30	2900	2600	1500	4.48	0.026	<0.004	0.030	0.02
M2	08:42	210	200	110	4.23	0.060	<0.004	0.002	0.17
M3	08:52	470	470	260	7.67	0.043	<0.004	0.019	0.04
M4	09:02	460	460	260	2.58	0.016	<0.004	0.012	0.02
M5	09:12	350	330	260	2.37	0.016	<0.004	0.013	0.01
Surface microlayer									
W1	07:30	1800	1700	1000	–	–	–	–	–
W2	07:35	1800	1700	1500	–	–	–	–	–
W3	07:45	630	630	340	–	–	–	–	–
W4	–	11	11	7	–	–	–	–	–
W5	08:02	20	19	25	–	–	–	–	–
M1	08:30	2500	2500	1100	–	–	–	–	–
M2	08:42	1600	1400	870	–	–	–	–	–
M3	08:52	1500	1500	620	–	–	–	–	–
M4	09:02	810	810	420	–	–	–	–	–
M5	09:12	410	410	230	–	–	–	–	–
ETD	09:55	14	14	2	–	–	–	–	–

W1			**W2**			**W3**			**W4**			**W5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	17.7	2.9	0.0	18.7	13.0	0.0	20.5	29.6	0.0	21.1	33.0	0.0	21.5	33.9
0.2	17.9	5.0	0.2	18.4	15.0	0.2	20.9	31.6	0.2	21.5	33.7	0.68	21.5	33.9
0.4	20.5	33.3	0.4	20.9	32.7	0.4	21.4	34.0	0.4	21.5	33.7			
0.6	21.1	33.6	0.6	21.2	33.6	0.6	21.5	34.0	0.6	21.5	33.8			
0.8	21.2	33.8	0.8	21.3	33.8	0.8	21.5	34.0	0.8	21.5	33.8			
1.0	21.2	33.8	1.0	21.4	34.0	0.82	–	–	0.82	–	–			
1.16	–	–	1.15	–	–									

M1			**M2**			**M3**			**M4**			**M5**		
z	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**	**z**	**T**	**S**
0.0	17.6	0.3	0.0	18.0	2.6	0.0	18.6	5.7	0.0	19.7	14.4	0.0	20.9	25.5
0.2	17.3	0.5	0.2	17.9	2.7	0.2	18.6	6.5	0.2	19.7	15.1	0.2	20.9	25.5
0.4	17.3	1.0	0.4	17.8	3.0	0.4	19.0	10.0	0.4	19.9	16.5	0.4	20.9	25.9
0.6	17.4	1.5	0.6	18.0	4.5	0.6	19.5	19.5	0.6	20.5	23.9	0.6	20.9	25.8
0.8	17.6	5.5	0.8	19.7	21.5	0.8	20.4	24.3	0.8	20.7	28.2	0.8	20.9	25.6
0.83	–	–	0.87	–	–	0.98	–	–	0.97	–	–	1.0	20.9	25.5
												1.14	–	–

Wharf			**ETD**		
z	**T**	**S**	**z**	**T**	**S**
0.0	21.7	34.2	0.0	21.8	33.6