Waiuku Estuary: Aquatic Environment Information Review

February 2014 Technical Report TR2014/003

Auckland Council
Technical report 2014/003

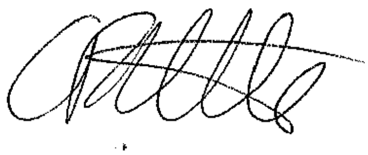
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927266-84-7 (Print)
ISBN 978-1-927266-85-4 (Pdf)

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference

Submitted for review on 16 January 2014
Review completed on 28 February 2014
Reviewed by two reviewers

Approved for Auckland Council publication by:



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Date: 28 February 2014

Recommended citation:

Mills, G. (2014). Waiuku Estuary: Aquatic environment information review. Prepared by Diffuse Sources Limited for Auckland Council. Auckland Council technical report, TR2014/003.

Waiuku Estuary: Aquatic Environment Information Review

Dr Geoff Mills

Diffuse Sources Ltd

Executive Summary

The Franklin Local Board has requested a review of information and data on shellfish, sediment, ecology and water quality monitoring for the Waiuku Estuary (Figure 1-1).

This report reviews readily available information to provide a summary of environmental state and trends, and to identify key information gaps. The purpose of the report is to inform the Franklin Local Board of the major issues facing the Waiuku estuary and therefore to assist in prioritizing management interventions that the local board may wish to champion.

The stock take aims to assess the quality of available information, look at what the information tells us about the state of the environment, what trends are detectable, and to identify key information gaps.

The review has found a variety of information on the Waiuku Estuary; however there are still a number of gaps. Good information was found for water quality (more so for estuarine, but freshwater monitoring is underway) and sediment quality (in particular for heavy metals associated with the NZ Steel discharge). A smaller amount of information was found for shellfish quality, although the NZ Steel discharge monitoring has accumulated a great deal of chemical (metals) and condition data.

Key findings of the review were:

Freshwater quality: Data reviewed were limited to one regional monitoring site (Waitangi Stream). This had a fairly typical rural water quality "signature", the most notable feature being elevated levels of nitrogen (mainly nitrate). The water quality was rated as "poor" in 2011 and "good" in 2012, reflecting variability over short time scales. Continued monitoring will provide a more robust picture of water quality.

Estuarine water quality: Based on Auckland Council monitoring, Waiuku Estuary water quality is rated as "fair", falling in the middle ground between high quality open coastal waters and inner estuary waters impacted by point source and diffuse source discharges. Water quality appears to be generally improving slowly over time at the estuary mouth (Clarks Beach long term monitoring site).

Sediment quality: There is a considerable amount of sediment chemistry data, in particular for heavy metals associated with the NZ Steel discharge. Data indicate that sediment quality is generally good (in the Environmental Response Criteria (ERC)-Green sediment quality guideline range), apart from a localised zone near the steel mill discharge, which has elevated zinc levels. The NZ Steel data indicate that sediment metals' concentrations have decreased over time in the vicinity of the outfalls.

Shellfish quality: This has been fairly well characterised, particularly from NZ Steel monitoring data. Organic contaminant concentrations are generally low, except for polycyclic aromatic hydrocarbons (PAHs) at one site (Needles) close to the NZ Steel site. Metals' concentrations are low-to-moderate compared with the wider Manukau Harbour, except for zinc around the NZ Steel outfalls (especially the Northside outfall). Trend data indicate that no major changes in metals' concentrations are occurring over time, although concentrations in the vicinity of the NZ Steel discharge are possibly decreasing slowly. Microbiological quality is not as well defined, but is probably poor in the upper estuary, and limited data suggests that the Waiuku Wastewater Treatment Plant (WWTP) discharge might have some impact.

Ecological health: Limited information was found in the review. Data from one site in the head of the estuary indicates that benthic ecological health is poor, and that sediment muddiness is likely to be a key influencing factor.

Effects of NZ Steel discharges: A comprehensive monitoring programme shows a marked effect on the concentrations of zinc, and to a lesser degree copper, in oysters in the estuary close to the discharge. Effects on sediments are less pronounced and more localised. Effects on receiving water metals' concentrations are not directly monitored, but the discharges are (from limited recent data) within consent compliance limits.

Effects of Waiuku wastewater treatment plant discharge: Increases in the concentrations of nutrients, indicator bacteria, and ammonia in estuary receiving waters downstream of the discharge have been measured. Ammonia levels were considered unlikely to reach those considered toxic to aquatic life after initial mixing. Visual clarity and dissolved oxygen levels in receiving waters were largely unaffected. Microbiological inputs are considered unlikely to render estuary waters downstream of the discharge unsuitable for contact recreation. However, the effects of the discharge on shellfish microbiological quality are unclear. The very limited data are not definitive, but indicate general microbiological quality in upper estuary is probably poor, and that the Waiuku WWTP might have some impact on shellfish microbiological quality. Effects on sediment contamination were very minor. Overall, apart from the uncertainty associated with microbial effects and the timing of sampling, the effects of the Waiuku WWTP discharge on the estuary appear relatively minor.

Key information gaps identified during this review include the following:

- Catchment loads and sources (urban, rural, point, and diffuse) of nutrients, sediment, and microbes. These are key parameters affecting the quality of the estuary receiving waters, so an improved quantitative understanding of their sources, fate, and future trends is considered important. This should include an assessment of sedimentation rates in the estuary.
- Quantitative description of the behaviour and fate of effluent from the Waiuku and Clarks Beach WWTP discharges in the estuary (although it is understood that modelling work is being undertaken for the Clarks Beach WWTP, but this was not available for inclusion in this review). Assessment of human health risks associated with microbial contamination in estuary waters and shellfish, in particular with regard to inputs from the two wastewater treatment plant discharges (but see note above re the Clarks Beach WWTP).
- A better understanding of estuary hydrodynamics (including physical processes such as wind, waves, currents, tides and rainfall) to assess the fate and consequence of both diffuse and point-source discharges into the estuary.
- More detailed spatial coverage of ecological condition, and assessment of zones requiring on-going monitoring for potential future impacts (in particular from sedimentation).

- Calculating a zinc budget for the estuary, in order to assess the contribution from NZ Steel compared with other sources, and to estimate the proportions retained within, and exported from, the estuary.
- Effects of mangrove expansion and removal on sediment movement and deposition, and on estuarine ecology.

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1.0 Introduction

The Franklin Local Board has requested a review of information and data on shellfish, sediment, ecology and water quality monitoring for the Waiuku Estuary (Figure 1-1).

This report reviews available data to provide a summary of environmental state and trends information, and to identify key information gaps. The purpose of the report is to inform the Franklin Local Board of the major issues facing the Waiuku Estuary and therefore to assist in prioritizing management interventions that the local board may wish to champion.

The stock take aims to assess the quality of available information, look at what the information tells us about the state of the environment, what trends are detectable, and to identify key information gaps.

The scope was to include assessment of the following key areas of interest:

- An overview of status and trends in freshwater and estuarine water quality, sediment quality, and aquatic ecological health, based primarily upon available information from Auckland Council monitoring data and reports;
- Effects of the NZ Steel discharge, based on receiving water, sediment, and shellfish monitoring data associated with the discharge consent;
- Effects of the Waiuku wastewater treatment plant (WWTP) and (if information is available) the Clarks Beach WWTP discharges on estuarine receiving water quality. Brief commentary on the proposed monitoring conditions for the Waiuku WWTP discharge was also requested;
- Emerging contaminant data for Taihiki estuary, based on NIWA studies and reports;
- Sedimentation, its sources and effects (including mangrove expansion issues).

The review relied on information readily accessible at the time of reporting, rather than detailed analysis of raw data or expansive literature search/reviews. However, some additional data analysis and presentation have been undertaken where it was felt that a significant contribution to the review would be obtained.

While the Waiuku Estuary was the primary area of interest, the review has included relevant information from the neighbouring Taihiki Estuary and adjacent margins of the Manukau Harbour (Figure 1-1).

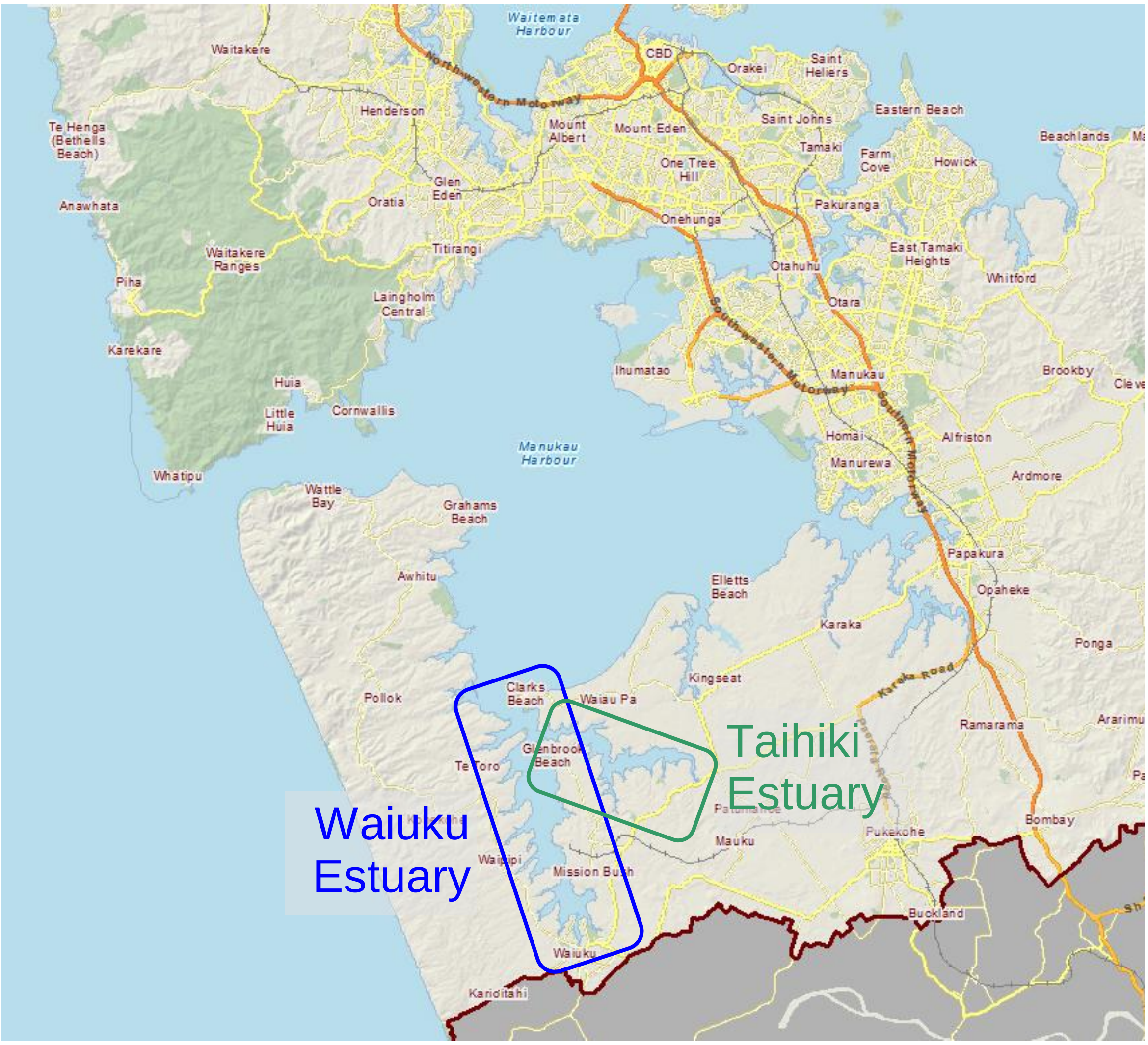

Figure 1-1 Map of Manukau Harbour, showing locations of Waiuku and Taihiki estuaries

2.0 Setting and key influences

2.1 General setting

Kelly (2009) provides a wealth of information on the Manukau Harbour and its tidal arms. The following notes are taken primarily from this review.

The Waiuku River estuary is one of the four main branches of the Manukau Harbour (Figure 2-1), running about 11 km from its mouth at Clarks Beach upstream to Waiuku. The estuary is considered to be an ancient discharge point for the Waikato River, which was cut off by lava flows from the South Auckland volcanic field around 3 million years ago. The Taihiki River estuary is a major offshoot of the Waiuku, which extends eastward from a junction between Clarks and Glenbrook Beaches.

A large proportion of the water within the Waiuku Estuary drains at low tide.

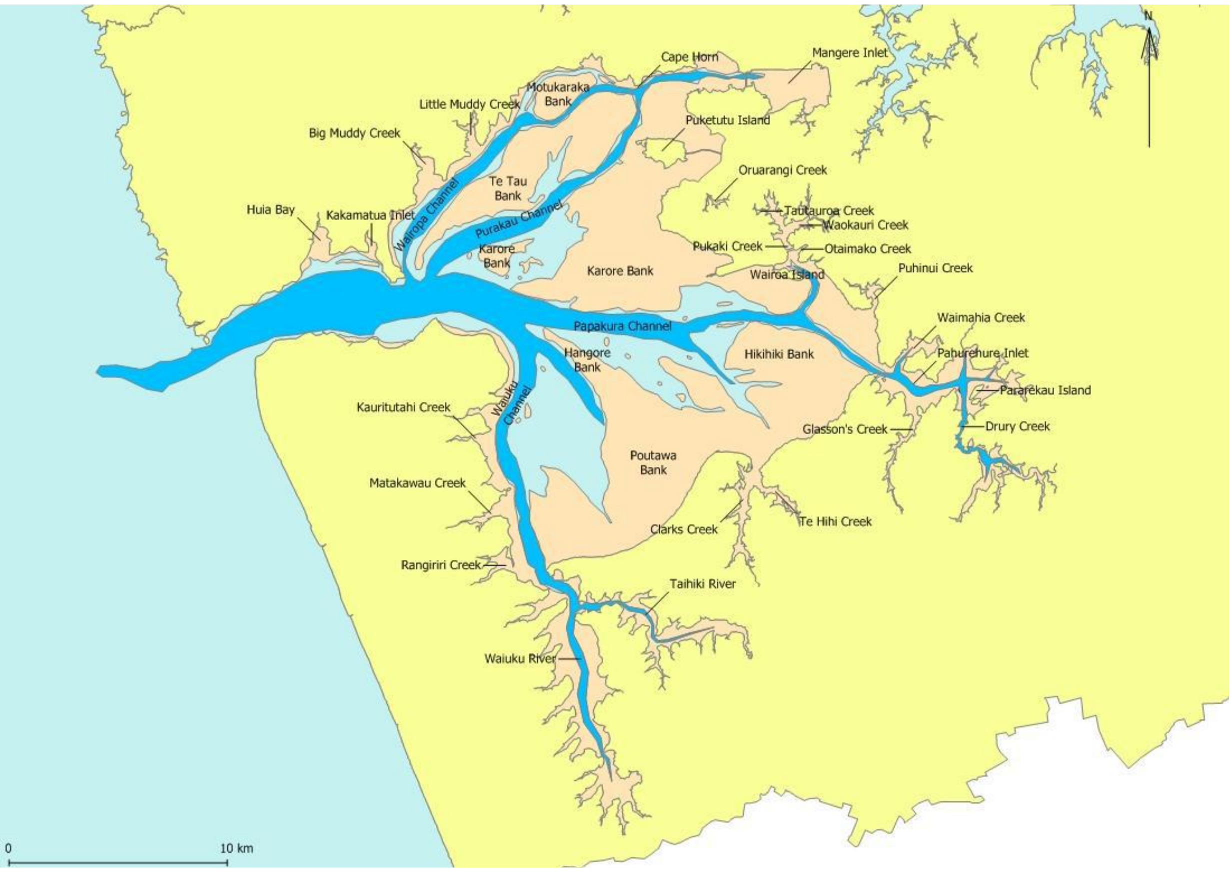

Figure 2-1 Major channels, inlets and intertidal sand and mud banks in Manukau Harbour (from Kelly 2009)

The Waiuku Estuary (including the Taihiki arm) receives fresh water inputs from a catchment totalling approximately 300km^2 (Wood 2012). Land use in the Waiuku and Taihiki river catchments is predominantly rural, with several small rural townships present. These include Waiuku, Clarks Beach, Patamahoe, and Glenbrook. Rural activities in the catchment include dairy and dry stock farming, horticulture and market gardening. Some 79% of the catchment is in pastoral vegetation and approximately 12% is in native vegetation. Only a very small part of the catchment is in urban use and therefore only 2% of the area is impervious, which is low in comparison to the regional average of 9% (Wood 2012).

The presence of the BHP New Zealand Steel (hereafter referred to as “NZ Steel”) steel mill is a notable feature in the Waiuku Estuary catchment. This is among the largest heavy industrial sites in the Auckland Region, and discharges stormwater and process water into the estuary.

The Taihiki Estuary is comprised of diverse sheltered harbour habitats ranging from predominantly sandy intertidal flats, to mangroves and to pockets of saltmarsh. It is considered to be an important nursery area for young flounder and grey mullet. This remains one of the least impacted of these harbour habitats in the Manukau because of the lack of major inputs of sediment from the catchment, and its vegetated shoreline.

Outside the mouth of the Waiuku Estuary, the Manukau Harbour has very high ecological values. North of the mouth, at Awhitu, a range of habitats are found along the shores of Awhitu Regional Park and in the Kauritahi Stream. These support a large range of wading and coastal birds in addition to a number of threatened coastal fringe birds that dwell in the saline vegetation. The area is an integral part of the Manukau Harbour, an internationally important wetland selected by the Department of Conservation as an Area of Significant Conservation Value (ASCV).

East of the mouth, from Clarks Beach to Karaka Point is an area of intertidal banks and shell banks forming a complex habitat for a variety of animal and plant communities. The extensive gently-graded predominantly fine sand flats support the greatest diversity and abundance of intertidal sand flat organisms in the Manukau Harbour. They are an excellent feeding ground for many thousands of international migratory and New Zealand endemic wading birds including a number of threatened species. Several shell banks have developed just offshore at Karaka since the early to mid 1980’s and are now numerically the most important roost on the Manukau Harbour, most notably for waders, but also for a variety of coastal birds. There are a number of other roosts along the shore, most notably near Seagrove, the second most important roosting site on the harbour. The Department of Conservation has selected the roosts and closely adjacent intertidal banks as an ASCV.

Sediments in the Waiuku Estuary range from predominantly sandy, through to mud. The exposed mud and sand banks provide valuable habitat for a range of bird species, and benthic fauna. Several species of fish are likely to use the estuary, including anchovy, flatfish, and mullet. The natural character of the estuary has been modified to varying degrees by urban development, sedimentation, and mangrove expansion.

A number of small freshwater stream inlets enter the estuary along its length. The inlets are characterised by mudflat and mangrove communities, where streams discharge into the embayments via shallow channels. Small areas of rocky intertidal habitats are present on the fringes of some inlets. Biological communities are dominated by mud snails (*Amphibola crenata*) within mangrove areas, large numbers of cockles (*Austrovenus stutchburyi*) in the sandy mid-tide habitats, and abundant crabs and shrimps lower on the shoreline. Pacific oysters (*Crassostrea gigas*) are well established with numerous localised clumps present along the coastline.

The Waiuku Estuary serves both amenity and practical purposes. In terms of direct human use of the estuary it has been reported that there is limited contact recreation, however, it is utilised for boating, fishing and shellfish gathering. Local iwi have a highly valued cultural, spiritual, historical and environmental relationship with the Waiuku Estuary.

2.2 Key influencing factors

Key factors that are likely to have had a major influence on the environmental quality in the estuary are:

- Sedimentation – build up of fine-grained muddy sediment, and the change in sediment texture from sandy to muddy has almost certainly changed the benthic ecology of much of the estuary.
- Mangrove proliferation, which is related to the increased build up of fine sediments.
- The quality of the freshwater inflows to the estuary, particularly during rainfall events when contamination by microorganisms, suspended sediments, and (to a lesser degree) urban-sourced contaminants such as heavy metals is greater. Nutrient inputs from the primarily rural catchment are likely to be a significant factor for the estuary's, and possibly the wider harbours', biological productivity.
- Discharges from the NZ Steel mill, which add metals (principally zinc) to the estuary.
- The Waiuku and Clarks Beach WWTP discharges, which add nutrients, suspended sediments, and potentially pathogenic microorganisms to the estuary.

These aspects are discussed in various sections of this review. Of these, the greatest impact (at least on estuarine ecology) has probably come from increased sedimentation. Unfortunately, at this stage, it appears that this is the issue we have least quantitative information about.

3.0 Freshwater quality

3.1 Information sources

There is no known long term freshwater monitoring data for any of the major freshwater inflows into the Waiuku Estuary. However, a relatively new Auckland Council monitoring site on the Waitangi River (Figure 3-1) has been sampled, at monthly intervals, since January 2009. Data have been reported in Lockie and Neale (2012 & 2013). The information summarised in section 3.2.1 has been drawn from these reports.

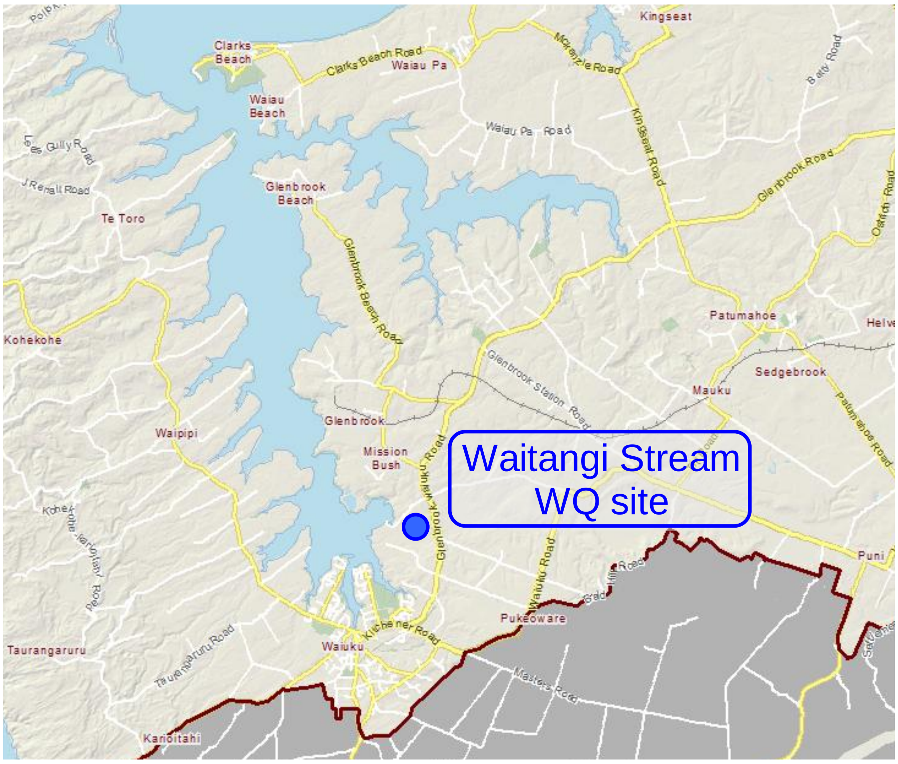

Figure 3-1 Location of the Auckland Council Waitangi River water quality monitoring site

Water quality (and ecology) studies for Waiuku, Rangiwhea, and Golf Course Streams have also been undertaken, and reported in a draft Integrated Catchment Management Plan (ICMP) by Fraser Thomas (2008). However, a final version of this report was not available at the time of this review (the copy available was in draft form) and therefore this information has not been presented here in any detail. A brief summary of (draft) findings is given.

Investigations of the Ruakahua, Kahawai, and Northside Streams – which are heavily modified channels associated with the NZ Steel mill site operations – have been described in the resource consent application to authorise Industrial or Trade Process discharges (mainly stormwater) by Tonkin and Taylor (2012). It is understood that these are not currently considered to be of immediate concern to the Franklin Board, and they have therefore not been considered further here.

3.2 Water quality characteristics

3.2.1 Waitangi River

The water quality at the Waitangi River site has a “typical” rural stream signature:

- Elevated oxidised nitrogen levels (nitrate + nitrite), probably largely nitrate-N. The median was approximately 2 mg/L. The oxidised-N and total N were markedly elevated, being the second highest of all the Auckland Council regional monitoring network sites;
- Moderate phosphorus levels (with elevated total phosphorus during rain events);
- Moderate faecal coliform numbers (median 790 MPN/100 mL, maximum 7900 MPN/100 mL). Also moderately elevated *E. coli* – median of 450 cfu/100 mL, with a maximum of 11,500 cfu/100 mL;
- Fairly low median total suspended solids (TSS) level (2 mg/L), but high maximum level (93 mg/L). Turbidity was also relatively low on average, but with high maximum level (113 NTU);
- Dissolved oxygen was slightly low on average (86% saturation), with very low minimum (32%, recorded in March/April 2010) and slightly elevated maximum (107%).
- A maximum temperature of 21.8°C, which is about 3°C above the acceptable limit of 19°C used in the Council Water Quality Index (WQI).

Apart from the elevated nitrogen levels, the Waitangi Stream water quality did not stand out in comparison with the other Auckland Regional water quality sites.

The Auckland Council use a water quality index (WQI) system to group the streams into various quality classes, based on how they compare with “natural” conditions, as reflected in reference stream water quality (see Lockie and Neale 2012 & 2013 for details). The Waitangi River rated as “poor” (water quality index score of 46.8) in 2011, but improved to a “good” grade (WQI score 76.8) in 2012. This was a large change, and reflected lower TSS, ammonia-N, total phosphorus, and *E. coli* in 2012. In 2011, the overall water quality ranked 26th best out of 34 sites, and in 2012 9th best. Because of this variability, it is likely to take several more years to obtain a robust picture of overall water quality.

3.2.2 Waiuku, Rangiwhea, and Golf Course Streams

Some information on these small urban/rural streams is provided in Fraser Thomas (2008). Samples collected in January 2008 showed that stream waters at the time of survey had moderate dissolved oxygen and low biochemical oxygen demand (BOD). Water clarity was variable between sites. Dissolved inorganic nitrogen concentrations showed evidence of catchment agricultural activity with elevated nitrate nitrogen concentrations at some sites. Copper and lead concentrations were very low at all sites and zinc, although measurable, was also low. Microbiological water quality was poor and probably unsuitable for contact recreation.

Fraser Thomas (2008) detail the physical and ecological condition of these small urban/rural streams. They are typically small, drain low gradient landscapes, are soft bottomed, often suffer from streambank erosion due to grazing damage, are generally poorly shaded, have high aquatic plant biomass (i.e. water celery, oxygen weed, willow weed), and have low habitat diversity (i.e. predominantly runs and pools). However, there are reaches with good aquatic ecological values.

3.3 Trends over time

There are currently insufficient monitoring data to assess trends over time in freshwater water quality. Typically a minimum of 5 years' data is necessary before trends analysis can be undertaken.

3.4 Summary

In summary the freshwater information for the Waiuku Estuary catchment is as follows:

- Status: Regular monitoring data are available for only one freshwater quality site (Waitangi), first sampled in 2009. Characteristics are reasonably well defined, but there is high variability in the water quality index scores obtained so far. Other catchment streams are small, and include urban streams in Waiuku – these have been studied as part of an ICMP but inclusion of this information was beyond the scope of this review. Nutrient and TSS load modelling is underway (Catchment Land Use for Environmental Sustainability (CLUES) modelling by NIWA for Auckland Council) and may provide data on total catchment inputs (useful for putting point source discharge inputs into perspective).
- Trends: Currently insufficient data, but regional trends analysis will be available in 2014.

Gaps and opportunities: Continued monitoring of Waitangi River will provide trend data over the next 10–20 years. The status of the Waiuku ICMP could be reviewed to assess whether restoration of any small urban/rural streams has occurred or where further opportunities exist. CLUES catchment load modelling could be used to asses relative contributions of sediment and nutrients from different streams in the catchment. A better understanding of estuary hydrodynamics would be useful to assess the fate and consequence of both diffuse and point-source discharges into the estuary.

4.0 Estuary water quality

4.1 Information sources

The primary information source on water quality is the Auckland Council's saline water quality monitoring programme, which has two sites in the Waiuku Estuary (Figure 4-1):

- Clarks Beach, at the mouth of the estuary. This site has been monitored monthly since 1987; and
- Waiuku Town Basin, in the upper reaches of the estuary. Monitoring at this site began in August 2012.

A third site, approximately 9 km north of the estuary mouth in the Manukau Harbour at Grahams Beach is also shown in Figure 4-1.

Results are reported annually by Auckland Council (Walker 2012, Walker & Vaughan 2013), and the raw data was made available for analysis in this review.

There are also data from two investigations of the effects of the Waiuku wastewater treatment plant (WWTP) discharge reported by Bioresearches (2000, 2007). Water quality was assessed at five sites on one occasion in February 2000, and at four sites on three occasions in February, March, and April 2007.

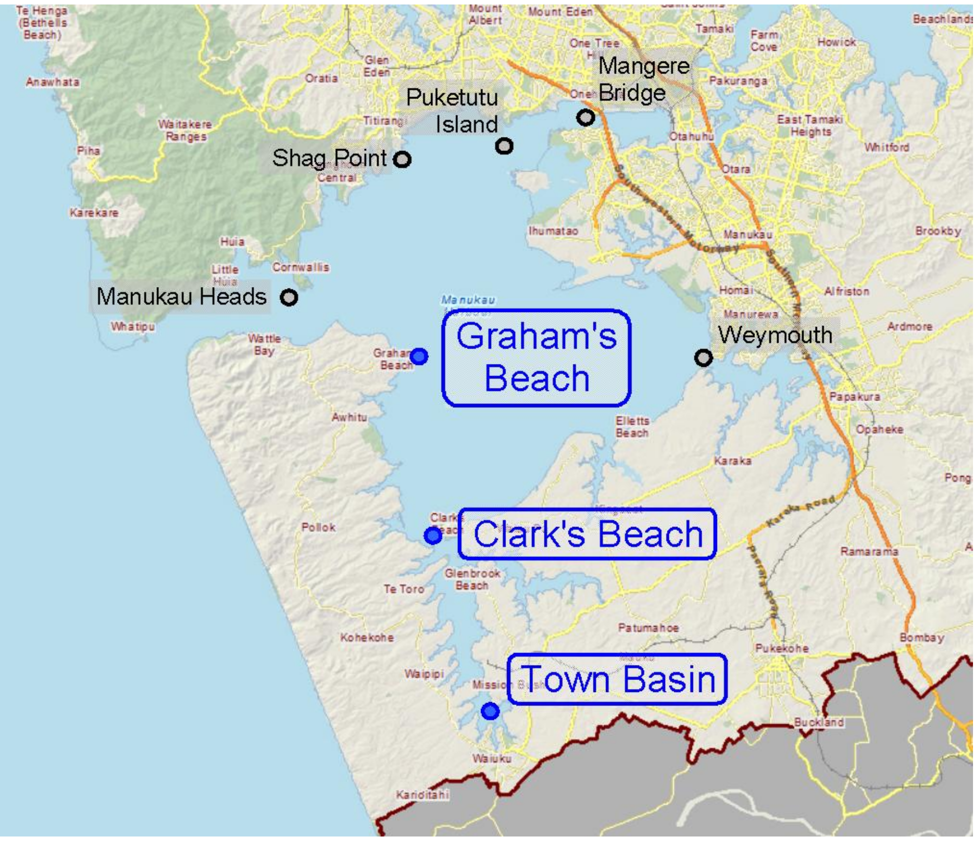

Figure 4-1 Auckland Council saline water quality monitoring sites in the Manukau Harbour, with Waiuku Estuary sites and Grahams Beach highlighted.

4.2 Water quality characteristics

Water quality in the Waiuku Estuary shows characteristics typical of rural estuarine environments. Water quality is poorest near the head of the estuary where the effects of freshwater inflows are greatest, and is best at the mouth of the estuary where cleaner water from the outer harbour has a greater influence. The upper estuary waters have higher and more variable nutrient concentrations, lower dissolved oxygen, and higher turbidity and suspended sediment concentrations. The salinity at the Waiuku Town Basin is lower than at other Manukau Harbour monitoring sites, reflecting its upper estuary location affected by freshwater inflows from the catchment.

Water quality characteristics are shown graphically in Figure 4-2 and Figure 4-3, which plot the results for nine key water quality parameters at the 8 monitoring sites in the Manukau Harbour (including the Waiuku Town Basin and Clarks Beach sites). To ensure direct comparability across the sites, the data used for this assessment was for the period 1st August 2012 to 24th May 2013 (10 monthly samples), which is the monitoring period for Waiuku Town Basin site.

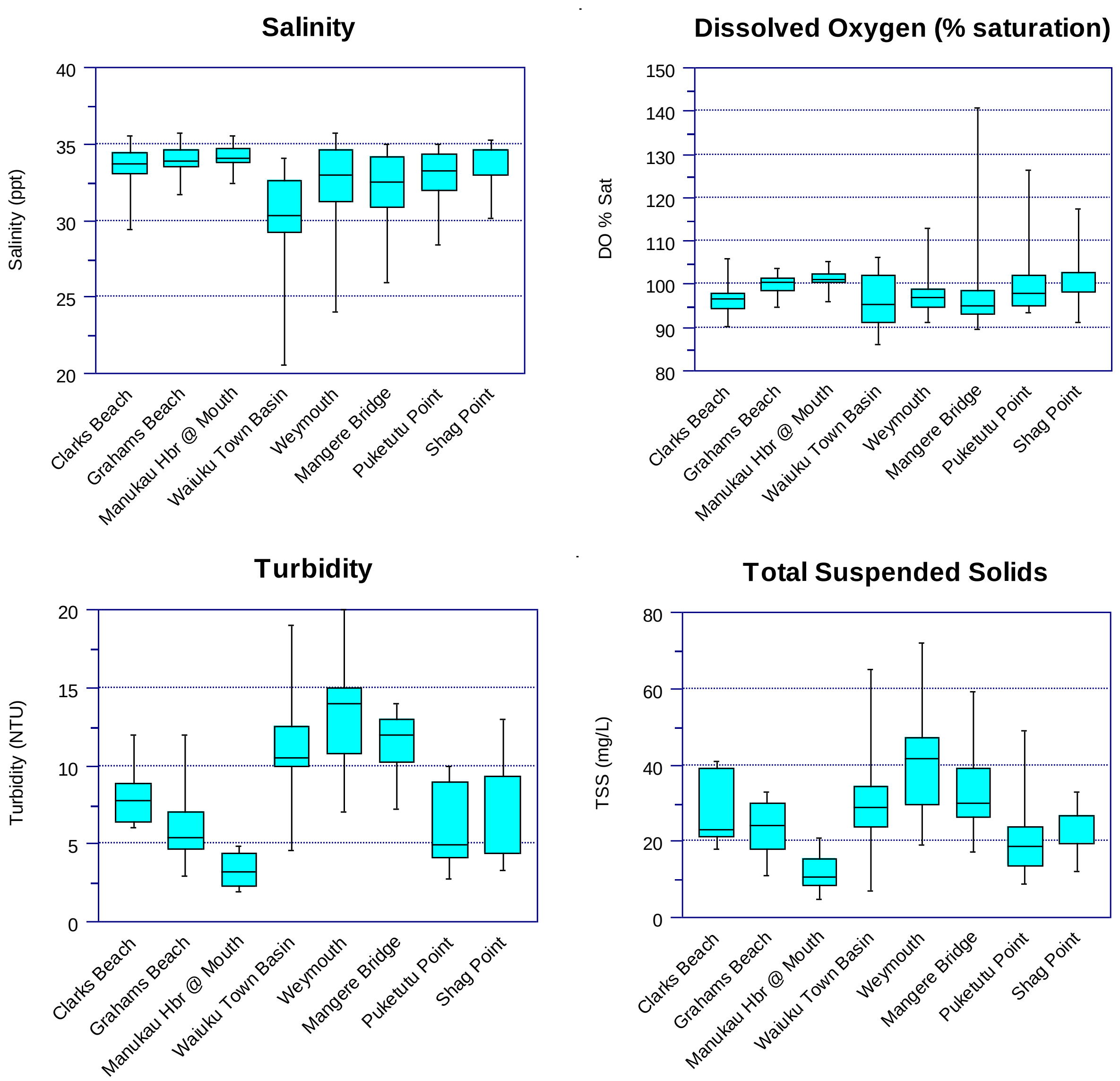

Figure 4-2 Comparison of Manukau Harbour saline water quality monitoring sites.
Data are from the Auckland Council water quality database, for the period 1st August 2012 to 24th May 2013 (the total monitoring period for the Waiuku Town Basin site). Box plots show the range of the data, with the coloured boxes spanning the 25%-ile and 75%-ile of the data, with the median crossing the box.

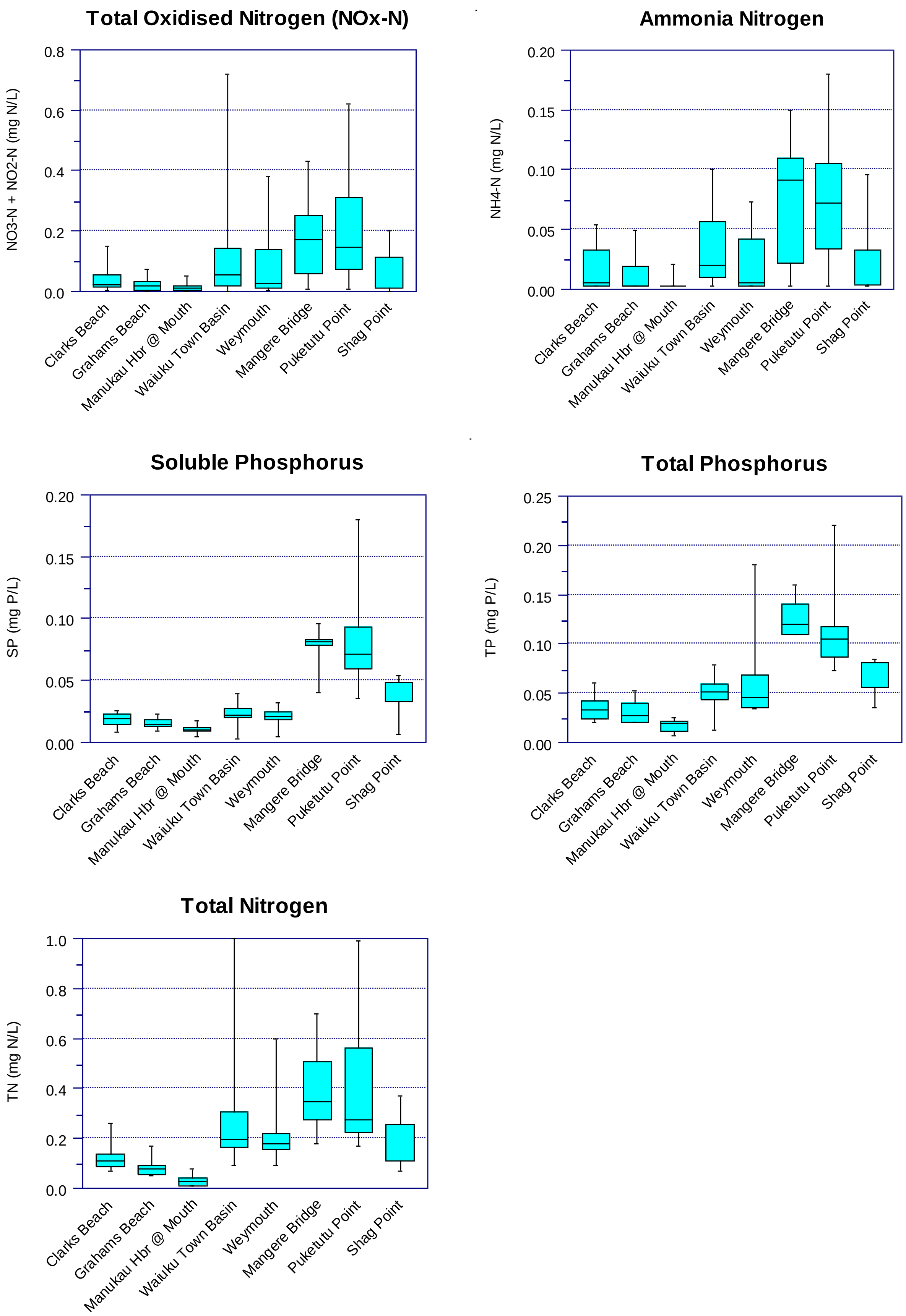

Figure 4-3. Comparison of Manukau Harbour saline water quality monitoring sites.
Data are from the Auckland Council water quality database, for the period 1st August 2012 to 24th May 2013 (the total monitoring period for the Waiuku Town Basin site). Box plots show the range of the data, with the coloured boxes spanning the 25%-ile and 75%-ile of the data, with the median crossing the box.

Key water quality characteristics shown by the saline monitoring programme were as follows.

Dissolved oxygen levels at all Manukau Harbour sites were good – best at Manukau Harbour Mouth and Grahams Beach (close to 100% saturation with little variation). Levels at Waiuku Town Basin were slightly lower (median approximately 95% saturation) and comparable with other “inner” harbour sites (Weymouth, Mangere Bridge).

The Town Basin site has moderately high and variable turbidity and Total Suspended Solids (TSS). There was not a great deal of difference between the medians at the Town Basin (inner estuary) and Clarks Beach (estuary mouth) sites. However, the Town Basin site showed a greater range (i.e. was more variable).

Highest nutrient levels in the Manukau Harbour were at sites influenced by the Mangere WWTP discharge (Puketutu and Mangere Bridge). Total oxidised nitrogen (NOx-N), which is mainly nitrate nitrogen, was elevated and highly variable at the Town Basin site, reflecting the effects of freshwater inflows. Levels at Clarks Beach were lower and less variable. Soluble phosphorus was low at all sites (including the Town Basin site) except those influenced by the Mangere WWTP. Total phosphorus was slightly elevated at the Town Basin site (compared with Clarks Beach) but much lower than at the Mangere WWTP-influenced sites.

Ammonia levels were low compared with aquatic toxicity thresholds (ca. 0.9 mg/L), but moderate compared with other Manukau Harbour sites.

Enterococci levels were mostly below detection limits (DL; <10 MPN/100 mL) at all sites. Elevated levels occurred on occasion, probably during or shortly after rainfall events.

4.3 Comparison with other regional monitoring sites

An assessment of water quality in the Waiuku Estuary in comparison with other Manukau Harbour sites can be made by using a simple ranking with six key water quality indicators, as summarised in Table 4-1. The data used were medians for the period 1st August 2012 to 24th May 2013.

Table 4-1 Ranking of overall water quality at Manukau Harbour saline water quality sites

Site	DO	Turbidity	NO_x-N	NH_4-N	SP	Chl *a*	Sum of ranks	Overall Ranks
Manukau Hbr Mouth	1	1	1	1.5	1	1	6.5	1
Grahams Beach	2	3	2	1.5	2	3	13.5	2
Clarks Beach	6	5	3	4	3	4	25	3
Puketutu Point	4	2	7	7	7	2	29	4=
Shag Point	3	4	5	6	6	5	29	4=
Weymouth	5	8	4	3	4	7	31	6
Waiuku Town Basin	7	6	6	5	5	8	37	7
Mangere Bridge	8	7	8	8	8	6	45	8

Based on this ranking the Waiuku Town Basin had the second worst water quality overall of the Manukau Harbour sites, ranking poorly for dissolved oxygen (DO), turbidity, nitrogen (total oxidised nitrogen; NOx-N, and ammonia; NH_4-N), and chlorophyll *a* (a measure of algal enrichment).

Water quality at Clarks Beach was third best, behind Grahams Beach and the Manukau Harbour Mouth. As outlined previously, this illustrates how water quality improves with distance from sources of contamination –freshwater inflows from rural or urban catchments, and point sources such as wastewater discharges.

To compare water quality across all the regional saline water quality monitoring sites, Auckland Council uses a more sophisticated water quality index system, developed by the Canadian Council of Ministers for the Environment (CCME). The CCME approach uses water quality results to produce four water quality indices, and these indices can be used to assign a water quality class to each monitoring site. The four indices are (Walker 2012):

- Scope – the percentage of parameters that failed to meet the objective at least once during the time period under consideration (the lower this index, the better).
- Frequency –the percentage of all individual tests that failed to meet the objective during the time period under consideration (the lower this index, the better).
- Magnitude – the amount by which failed tests exceeded the objective (the lower this index, the better). This is based on the collective amount by which individual tests are out of compliance with the objectives and is scaled to be between 1 and 100. This is the most complex part of the index derivation and the reader is referred to CCME (2001) for full details.
- WQI – this represents an overall water quality index based on a combination of the three indices described above.

The resultant values range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality. The WQI index is used by Auckland Council to assign a water quality class to each site using the following ranges;

- Greater than 90 = excellent water quality
- Between 75 and 90 = good water quality
- Between 60 and 75 = fair water quality
- Lower than 60 – poor water quality

The above indices are calculated for each site based on nine water quality parameters, similar to those used in the simple ranking shown in Table 4-1.

Using this rating system, Clarks Beach and Grahams Beach rated as fair-to-poor with water quality indices of 60.7 (14^{th} best of 36 sites) and 54.9 (17^{th} best of 36 sites) respectively in the 2012 monitoring (Walker & Vaughan 2013). Waiuku Town Basin ranked 15^{th} of 36 sites, with a WQI score of 59.9 (poor). This indicates that water quality in the Manukau Harbour is relatively poor by regional standards. The highest quality Manukau Harbour site, Manukau Heads (Mouth), rated as only fair (12^{th} best of the 35 sites).

4.4 Suitability for recreational uses

4.4.1 Contact recreation

Suitability for contact recreation (e.g. swimming) is carried out by comparison with Ministry for the Environment guidelines (MfE 2003). The microbiological indicator recommended to assess the suitability for contact recreation in marine waters is enterococci. Analysis of the enterococci data showed that:

- for Clarks Beach, the Hazen 95%-ile enterococci was 26.1 cfu per 100 mL (N=135 samples, for the period 8/01/1998 to 3/08/2009). The DL was 2 cfu/100 mL for this period. The waters would be rated as having an “A” microbiological assessment category (MAC) grade (<40 per 100 mL). After 1/09/2009, analysis changed from units of cfu to MPN, with a DL of 10. All values bar one value of 10 MPN/100 mL were <DL. The Hazen 95%-ile was therefore also <40 per 100 mL (MAC Grade A).
- for Waiuku Town Basin, only 10 sampling rounds have so far been undertaken. This is the minimum for calculating the Hazen 95%-ile. There were 6 values of <10, 3 of 10, and one of 130 MPN/100 mL. The 95%ile was 130 per 100 mL. This gives a MAC grade of “B” (41–200 per 100 mL).

The Waiuku WWTP discharge enters the Waiuku Estuary in its upper reaches, approximately 500 m downstream of the Town Basin water quality monitoring site. Because of the presence of this discharge, even though the water quality meets recreational use guidelines based on bacterial indicators, the possible presence of more environmentally persistent and virulent microorganisms such as viruses from the discharge means that the potential human health risks may be higher than indicated from the guidelines.

4.4.2 Shellfish gathering

The MfE (2003) guideline for shellfish gathering is a median faecal coliform level in the water for the shellfish gathering season of <14 MPN/100 mL, with <10% of samples >43 per 100 mL.

For Clarks Beach, there are no faecal coliform monitoring data, and therefore the comparison with the guideline cannot be made.

For Waiuku Town Basin, the median faecal coliform level from monitoring conducted between October 2012 and May 2013 (the data available at the time of this review) was 18 cfu/100 mL, with 1 value (out of 7) >43 cfu/100 mL (14%). Based on this very small data set, it would appear that the Town Basin waters would not meet shellfish gathering guidelines. The surveys conducted by Bioresearches (2000, 2007b) also indicated this is likely to be the case.

4.4.3 Better assessing suitability for recreational uses

The current monitoring data are not optimal for assessing suitability of the estuary waters for recreational use (i.e. the human health risks associated with recreational use) because the detection limits of the method used in the regional saline water monitoring programme are too high.

This is because the regional saline water quality programme is not designed to measure the suitability of water for bathing as this factor is covered by the bathing beach water quality programme.

Because there is a wastewater discharge into the estuary, comparison with the existing microbiological guidelines cannot provide a definitive statement about the suitability of the estuary water for safe contact recreation or shellfish gathering. To do so, a Quantitative Microbiological Risk Assessment (QMRA) is required to assess public health risks associated with viruses and other virulent pathogens that are not accounted for in the MfE guidelines.

4.5 Trends in water quality

Trends over time in water quality can be assessed at the Clarks Beach saline water quality monitoring site, but not at the Waiuku Town Basin site because the latter site had too few monitoring data at the time of this review (less than a year).

Trends at Clarks Beach were assessed using the seasonal Kendall trend test using Council monitoring data. Values below detection limits (<DL) were replaced by 0.5 x DL before conducting the trend test. Results are summarised in Table 4-2 and data are shown graphically in Figure 4-4 and Figure 4-5.

Table 4-2 A summary of trends in water quality at Clarks Beach saline water quality monitoring site. Results from seasonal Kendall trend test. *Red values in italics are significant ($p<0.05$)*. RSSE (relative Sen slope estimator) is the Sen slope (trend) expressed as a percentage of the median value per year. The "Years" and "Months" columns refer to the trend assessment period (e.g. 15 years 5 months for Total Oxidised Nitrogen)

Analyte	Period	Years	Months	Median value	Median annual Sen slope	RSSE (% per yr)
Total oxidised nitrogen (mg N/L)	1998 to 2013	15	5	0.041	*-0.001*	*-2.44*
Dissolved oxygen (% saturation)	1987 to 2013	25	8	96	0.00	0.00
Turbidity (NTU)	1987 to 2013	25	8	8	*-0.16*	*-2.00*
Total suspended solids (mg/L)	1991 to 2013	21	8	22.8	*-0.64*	*-2.80*
Chlorophyll a (mg/L)	2001 to 2013	11	11	0.0029	0.00	0.00
Ammonia nitrogen (mg N/L)	1989 to 2013	24	1	0.023	*-0.0004*	*-1.74*
Total nitrogen (mg N/L)	2009 to 2013	4	3	0.13	0.0017	1.31
Soluble phosphorus (mg P/L)	1989 to 2013	24	1	0.023	*-0.0002*	*-0.87*
Total phosphorus (mg P/L)	1989 to 2013	24	1	0.05	*-0.0016*	*-3.20*
Faecal coliforms (MPN/100 mL)	1987 to 2009	21	10	2	0.0	0.0

The data indicate that there have been significant decreases (i.e. improvements) over the duration of the monitoring in nutrients (oxidised nitrogen and phosphorus), ammonia, turbidity and suspended solids, while bacteria were consistently low and showed no trend over the data period.

Examination of the plots shown in Figure 4-4 and Figure 4-5 reveals that the data show a high degree of temporal variability, reflecting the effects of short term episodic events (e.g. rainfall and storms), regular seasonal patterns, longer-term variations due to factors such as the El Niño–Southern Oscillation, and major changes in land use or point source discharges (e.g. for the Manukau Harbour, the upgrade of the Mangere WWTP in the early-mid 2000s). While the overall trend may be a decrease, there may be periods within the long term trend record where increases occur. The results from trend analysis are therefore very much dependent on the period examined.

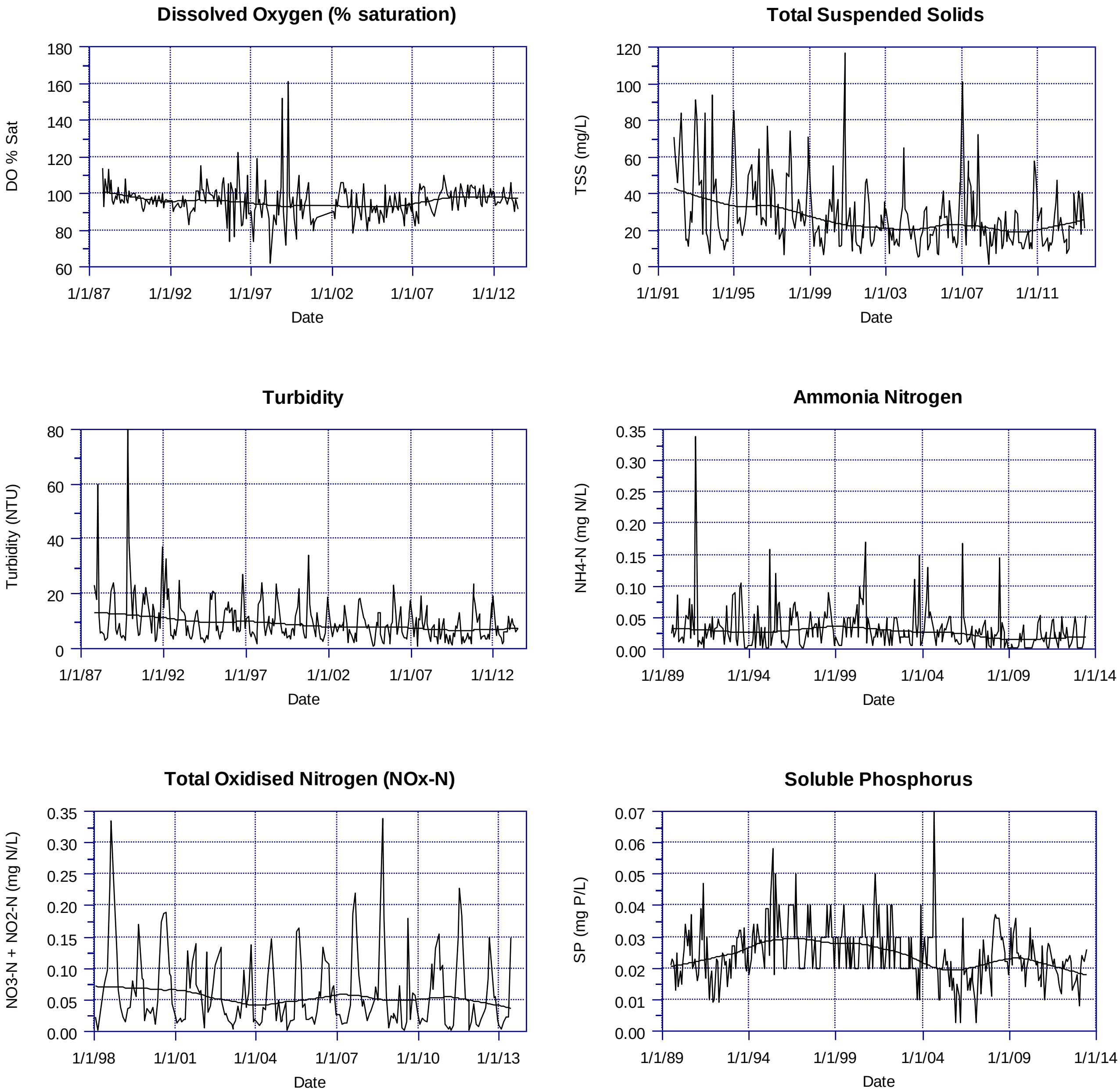

Figure 4-4 Water quality trend plots for Clarks Beach monitoring site. The line of best fit is a LOWESS (30% smoothing span, TimeTrends software).

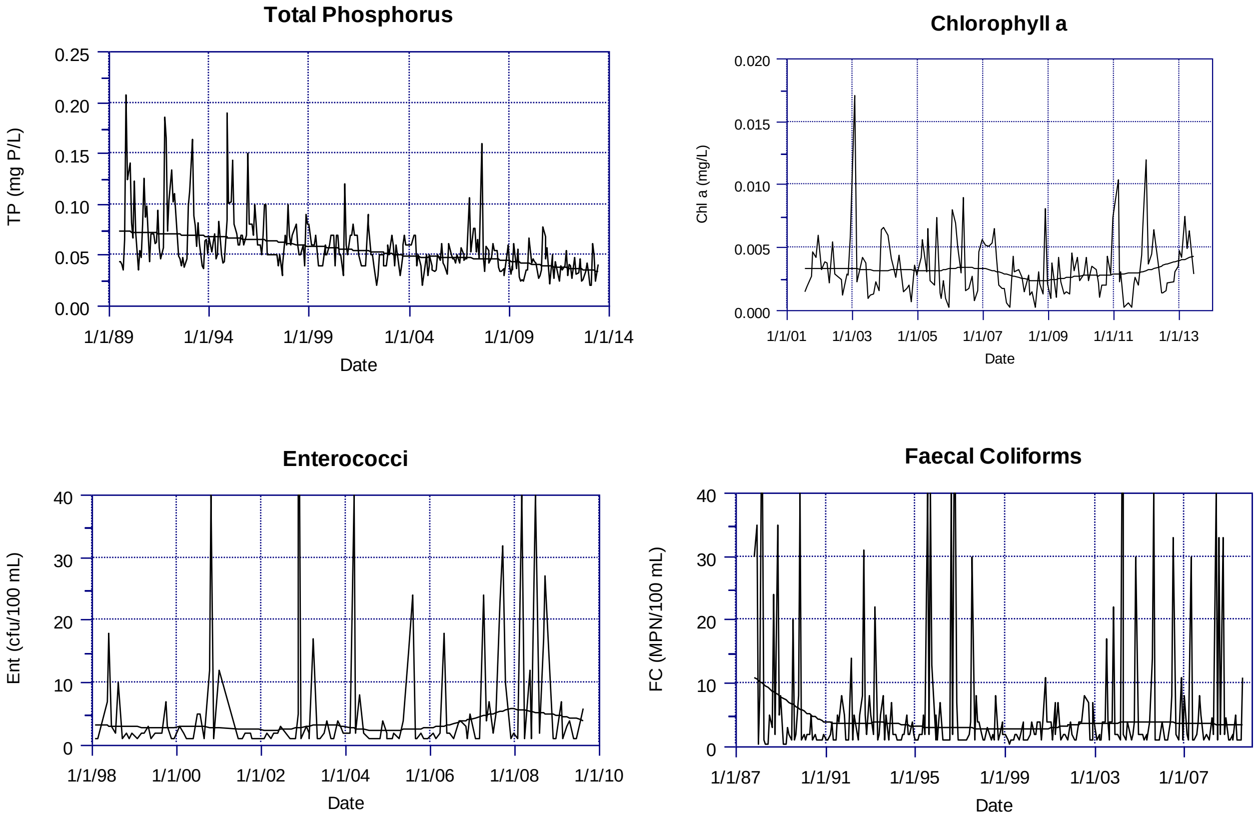

Figure 4-5 Water quality trend plots for Clarks Beach monitoring site (continued). The line of best fit is a LOWESS (30% smoothing span, TimeTrends software).

4.6 Effects of the Waiuku WWTP discharge on estuary water quality

Background information and summary information on the overall effect of the Waiuku WWTP is provided in section 10.1. Estuarine water quality was included in two field studies conducted in February 2000 (Bioresearches 2000) and in February–April 2007 (Bioresearches 2007b) that investigated the effects of the Waiuku WWTP discharge on the Waiuku Estuary. In each of these studies, water quality upstream and downstream of the Waiuku WWTP discharge was assessed. Results are summarised in the following sections.

4.6.1 February 2000 study

Water quality samples were taken on one occasion (3rd February 2000) from one site 200 m upstream of the discharge, at the discharge point “boil” where the discharge enters the estuary, and at four sites downstream of the discharge (at 50 m, 200 m, 500 m and 1000 m downstream). Figure 4-6 shows the approximate sampling locations.

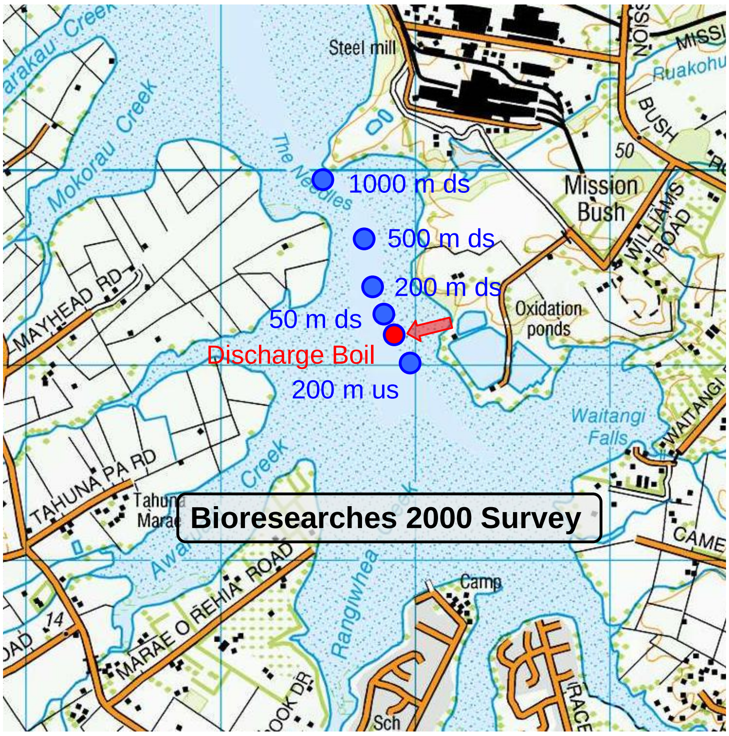

Figure 4-6 Sampling locations used in the Bioresearches (2000) water quality surveys upstream and downstream of the Waiuku wastewater treatment plant discharge.

At each site, three replicate samples were taken. Samples were analysed for a complete suite of water quality parameters including nutrients (N and P), TSS, BOD, indicator bacteria (faecal coliforms, enterococci, and *E. coli*), and ammonia. Field measurements included temperature, DO, clarity (Secchi disk), and salinity.

The Waiuku WWTP discharge occurs on the ebb tide, starting 30–60 minutes after high tide and occurring for 3 hours. The sampling times were recorded in Bioresearches (2000), but it is not clear from the report at what tidal stage the sampling occurred. Because the effluent dilution (and possibly dispersion, as the plume is more confined in the low tide channel) will reduce as the tide falls, the effects in the receiving waters will depend on when in the ebb tide stage the survey was done.

The changes in selected water quality parameters with distance along the estuary (above and below the discharge point) measured in the survey are shown in Figure 4-7 and Figure 4-8. Data below detection limits (DL) have been plotted at 0.5 x DL.

The monitoring data showed the following key features:

- Temperature, suspended solids (TSS), dissolved oxygen (DO), and BOD_5 (all <2 mg/L) were essentially unaffected by the discharge.
- Water clarity was somewhat variable, but there was little effect from the discharge. Bioresearches noted that the Secchi disk was visible, but on the bottom of the river, for some measurements at the first two sites below the discharge. The "decrease" in clarity shown in the plotted data may reflect this (rather than any real decrease).

- Nitrate levels were elevated upstream of the discharge and did not increase as a result of the discharge (except in the discharge boil itself). Concentrations decreased with distance downstream.
- Total nitrogen levels above the discharge were elevated, increased as a result of the discharge, then dropped with distance. Upstream levels were reached by 500–1000 m downstream of the outfall. Ammonia followed the same pattern as total nitrogen.
- Phosphorus (mostly in dissolved form) also increased markedly at the outfall, then dropped with distance to reach the above-discharge “background” level by 1000 m.
- Faecal coliforms and *E. coli* increased markedly at the discharge, then decreased to reach upstream background levels by 1000 m downstream. Enterococci were lower and more variable, but showed a similar pattern to the other bacterial indicators (note the elevated result at 1000 m, due to one of the three replicates having 17 cfu/100 mL, compared with <2 per 100 mL for the other two reps).

Overall, the monitoring showed that no DO depletion occurred and visual clarity was essentially unaffected. Significant increases in the concentrations of nutrients, indicator bacteria, and ammonia resulted from the discharge. These effects diminished with distance downstream, presumably reflecting the effects of dilution and dispersion.

Bioresearches (2000) noted that the ammonia concentration at the boil was probably at the long term exposure criterion level for chronic toxicity to aquatic life. However, the ammonia concentration reduced to approximately half the toxicity criterion within 50 m of the discharge, and continued to reduce with distance downstream. Ammonia toxicity was therefore considered unlikely to be a significant problem.

It was also noted that nutrient concentrations in the receiving waters were generally elevated compared with Australian and New Zealand Environment and Conservation Council (ANZECC 2000) water quality guidelines, raising the possibility of nutrient-enrichment issues in the estuary. Bioresearches (2000) reported seeing no evidence in terms of gross effects typical of elevated nutrient concentrations (e.g. excessive algal growth observed during their field surveys).

Enterococci numbers were low, with 10 cfu/100 mL measured in the discharge boil. The Bioresearches (2000) report compared these numbers with MfE (2003) guidelines for contact recreation (<40 per 100 mL). However, the MfE (2003) guidelines do not apply where there is a likely influence from human-sourced wastewater, because of the risks associated with more virulent and more persistent microorganisms (e.g. viruses) that are not accounted for in the guidelines. A microbial risk assessment incorporating viruses would be required to assess this aspect.

The faecal coliform results showed median numbers of 94 cfu/100 mL at 50 m below the discharge, 32 per 100 mL at 200 m downstream, 7 per 100 mL at 500 m, and <2 per 100 mL at 1000 m downstream. The area between the discharge and 500m downstream may not, therefore, meet the recreational shellfish-gathering water quality guidelines (median of 14 MPN/100 mL; MfE 2003).

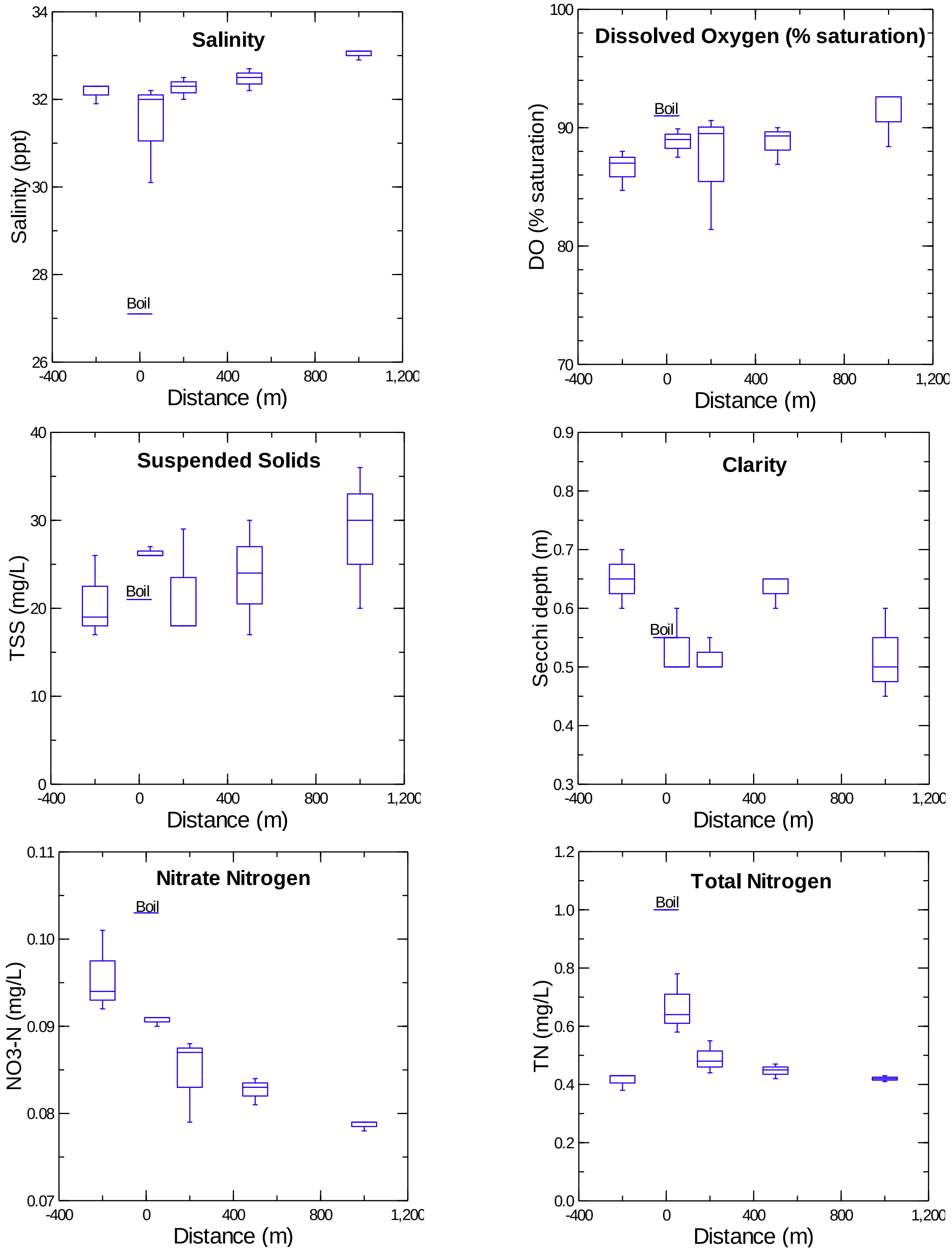

Figure 4-7 Water quality in the Waiuku Estuary upstream (plotted as -200 m) and downstream of the Waiuku WWTP discharge in February 2000. The data measured at the outfall point ("0 m") is labelled as "Boil". Box plots show the range of the data, with the horizontal line being the median (n=3, except "boil" n=1). Data taken from Bioresearches (2000).

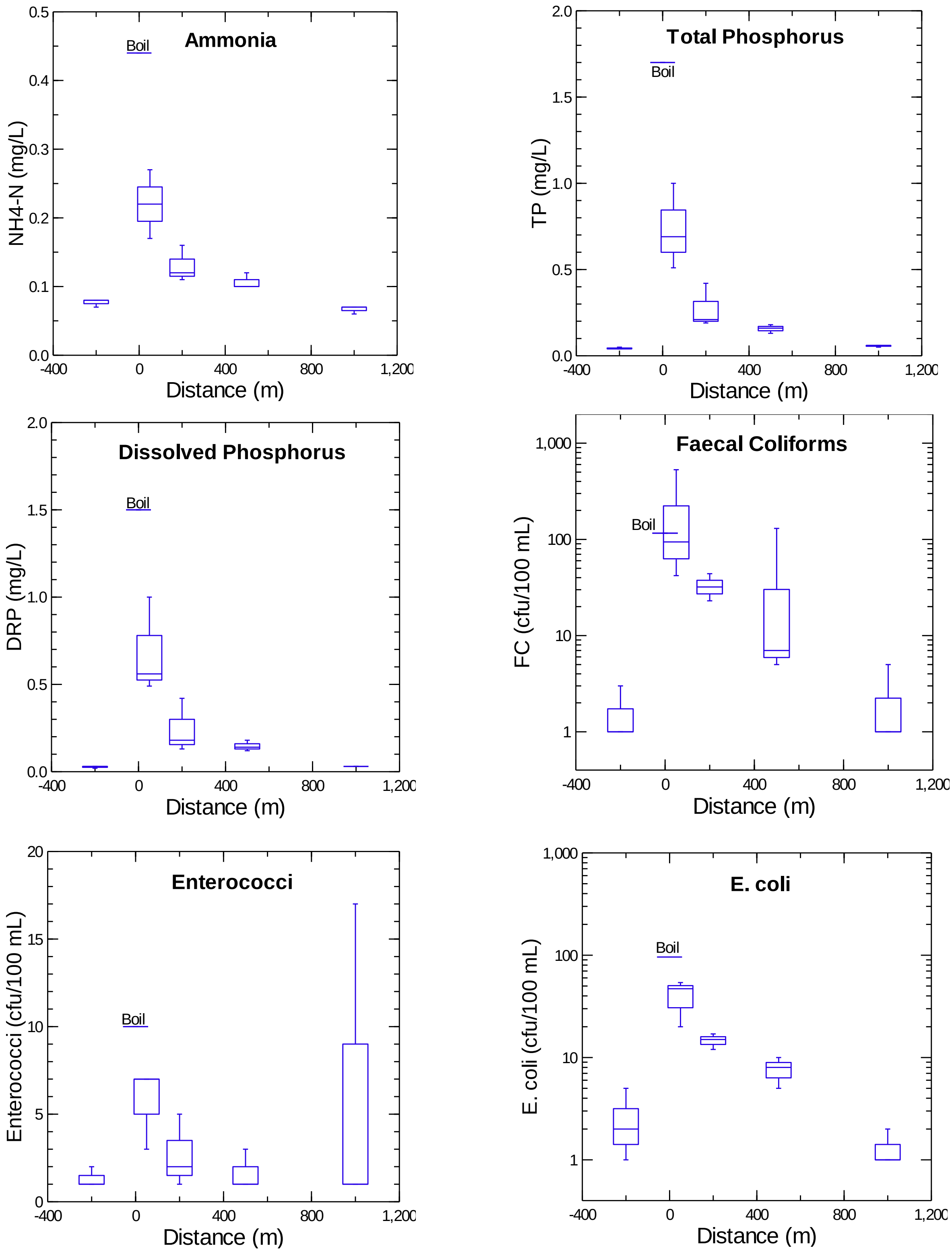

Figure 4-8 Water quality in the Waiuku Estuary upstream (plotted as -200 m) and downstream of the Waiuku WWTP discharge in February 2000. The data measured at the outfall point ("0" m) is labelled as "Boil". Box plots show the range of the data, with the horizontal line being the median (n=3, except "boil" n=1). Data taken from Bioresearches (2000).

4.6.2 February–April 2007 study

Three surveys were conducted in February, March, and April 2007 from 4 sites – one approximately 500 m upstream of the discharge outfall[1], and three downstream, at approximately 2.5 km (Okohaka Point), 7 km (Kahawai Point), and 10 km (Karaka Point) below the discharge (Figure 4-9). Weather was dry for two of the samplings, but heavy rain preceded the March sampling[2].

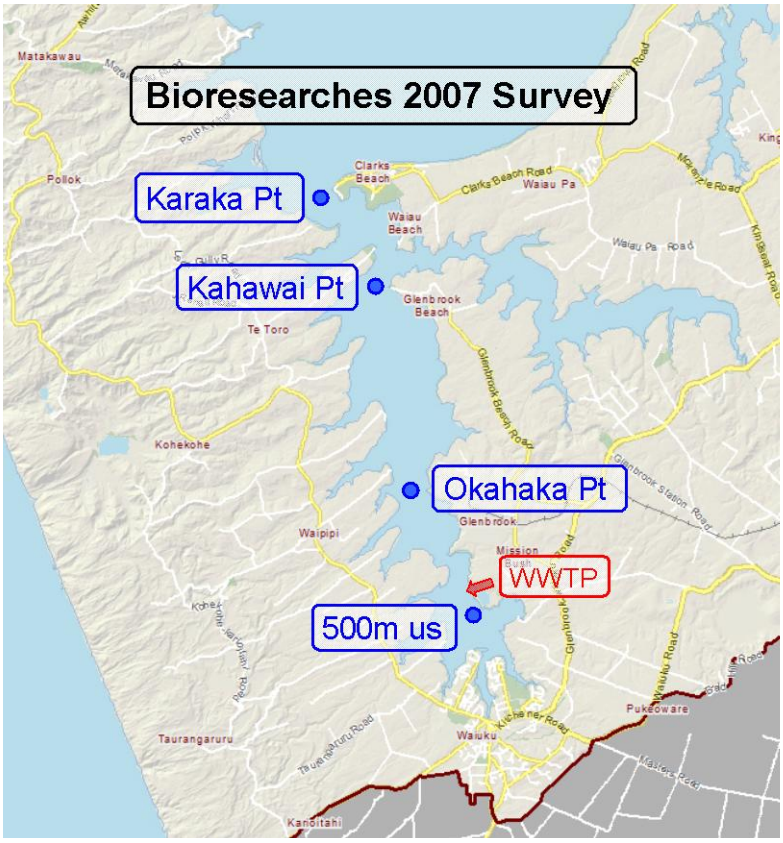

Figure 4-9 Sampling locations used in the Bioresearches (2007) water quality surveys upstream and downstream of the Waiuku wastewater treatment plant discharge.

1.0

[1] Approximate distances based on sampling locations shown in Figure 1 of Bioresearches (2007b). The upstream site is in approximately the same location as the Auckland Council's "Waiuku Town Basin" saline water quality monitoring site.

[2] This did not have any marked effect on the water quality measured in the estuary – the only major difference compared with the other two surveys was an extremely elevated total phosphorus (TP) level of 3.78 mg/L recorded at the upstream site. This was assumed to be an error and was omitted from the data analysis.

A full suite of water quality variables were measured on each sampling occasion. The results for key selected parameters, using data given in Tables 2.1 and 2.2 of Bioresearches (2007b), are plotted in Figure 4-10. Note that microbiological indicators (e.g. enterococci or faecal coliforms) were not measured.

No consistent effects related to the discharge were observed from the survey data. The salinity increased with distance down the estuary, showing the greater influence of harbour water at sites closer to the mouth. Nutrients (nitrogen and phosphorus) and ammonia also decreased in concentration with distance downstream, indicating the effects of dilution of enriched freshwater inflows to the estuary with cleaner harbour water. Suspended solids (and turbidity, not shown in Figure 4-10) were elevated and variable throughout the estuary, which is consistent with the generally turbid nature of the estuary and of Manukau Harbour waters (e.g. the median TSS at the Town Basin, Clarks Beach, and Grahams Beach regional monitoring sites for 2012-13 were 29, 24, and 23 mg/L respectively – not a great difference between the upper estuary and harbour sites).

The only effect that could be attributable to the discharge was a decrease in dissolved oxygen (DO) by a few percent between the upstream monitoring site and the first downstream monitoring site. Dissolved oxygen had recovered to the upstream levels at the second downstream site (Kahawai Point), but then dropped again at the most distant sampling site (Karaka Point). The drop in DO observed below the discharge point occurred on 2 of the 3 sampling occasions, while the decrease between Kahawai Point and Karaka Point occurred on all three sampling occasions. These effects are therefore reasonably consistent. The Taihiki Estuary joins with the Waiuku Estuary between Kahawai Point and Karaka Point, and this may be having an effect if the Taihiki waters are higher in oxidisable organic matter or lower in DO than the Waiuku Estuary.

It is worth noting that the DO levels measured in the Bioresearches (2007b) surveys were lower than those measured in the Auckland Council saline water quality monitoring (for Town Basin, Clarks Beach, and Grahams Beach). The median Council DO (% saturation) levels were 96%, 97%, and 100% respectively for these sites (for the 10 month period in 2012–13 when all sites were monitored). These values compare with 90% and 86% for the “upstream” (approximately the same location as the Town Basin site) and Karaka Point (same location as Clarks Beach site) measured in the Bioresearches surveys.

Other water quality parameters (e.g. turbidity, TSS, nutrients, ammonia) were also “worse” (i.e. higher median concentrations) in the Bioresearches survey than in the Council monitoring. This may be attributable to differences in the timing of the sampling – samples taken closer to low tide (on the ebb tide) would be expected to have poorer water quality than those taken closer to high tide, when dilution by cleaner outer harbour water is greater. The Bioresearches Waiuku WWTP survey samples were taken on the late ebbing tide, after the mid-falling tide. The AC saline survey sampling is undertaken 2.5–4 hours after high tide for the Manukau Harbour sites. The timing is generally similar, although the Council sampling may occur earlier in the ebbing tide than the Bioresearches sampling. This may account for the differences in water quality observed between the data sets.

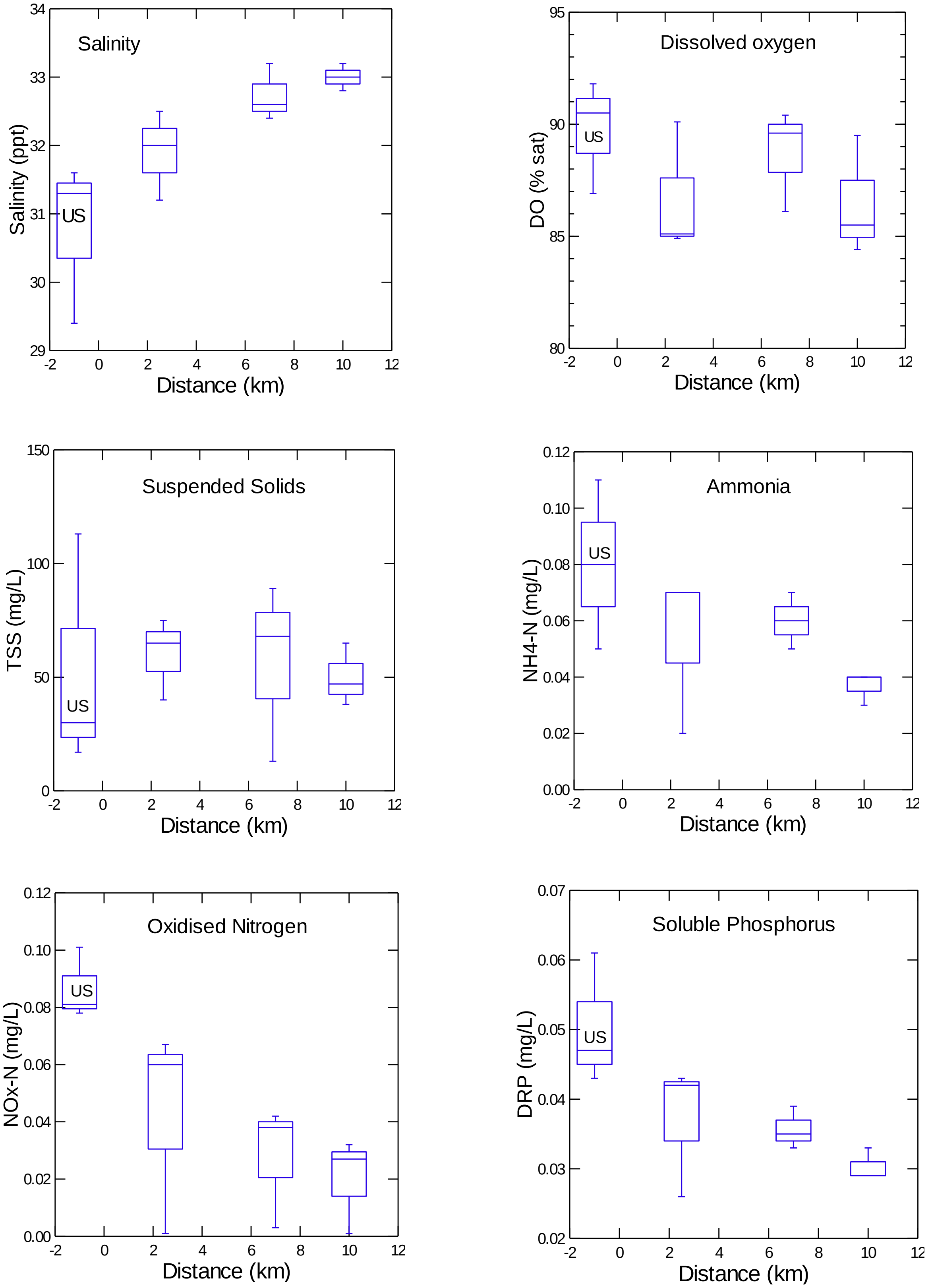

Figure 4-10 Waiuku Estuary water quality upstream (US) and downstream of the Waiuku wastewater discharge outfall. Approximate distance below the discharge point of sampling sites plotted on x-axis. Data are from three surveys conducted in February, March, and April 2007 (Bioresearches 2007b).

4.7 Water quality summary and information gaps

There are two Auckland Council long term saline water quality monitoring sites in the estuary (Waiuku Town Basin and Clarks Beach), and another site approximately 9 km north of the mouth at Grahams Beach.

Water quality in the Waiuku Estuary varies with location, being poorer in the upper reaches close to catchment inflows, and better towards the mouth and open waters of the Manukau Harbour.

Monitoring data indicate that the estuary water quality is fairly poor compared with the full range of regional sites (which include the highest quality open water East Coast sites). This is also the case for Manukau Harbour water quality generally, with even the best quality site (at the harbour mouth) being rated as only “fair”. The Water Quality Index values for Clarks Beach, Grahams Beach, and Waiuku Town Basin ranked among the middle (14^{th} to 17^{th}) of the 36 regional monitoring sites in 2012.

However, the highly variable nature of water quality means these grades can vary substantially on an annual basis due to climatic drivers having a strong influence on water quality in estuaries and harbours. This variability makes ranking sites from one year to the next problematic.

Based on a simple ranking score, using data collected from August 2012 to May 2013, the Waiuku Town Basin had the second worst water quality of the Manukau Harbour monitoring sites, scoring poorly for dissolved oxygen (DO), turbidity,TSS, nitrogen (total oxidised nitrogen; NOx-N, and ammonia; NH_4-N), and chlorophyll *a* (a measure of algal enrichment). Water quality at Clarks Beach was 3rd best, behind Grahams Beach and the Manukau Harbour Mouth.

Long term trend data indicate a general improvement in water quality at Clarks Beach since 1987.

The broad-scale effects of the Waiuku WWTP discharge on estuary water quality were assessed in two separate surveys conducted by Bioresearches (2000, 2007b). The first survey results showed increases in nutrients, indicator bacteria, and ammonia attributable to the discharge. Visual clarity and dissolved oxygen levels were largely unaffected. The microbiological inputs may render the estuary waters unsuitable for contact recreation and shellfish gathering – a quantitative risk assessment would be required to reliably assess this. The contribution to overall estuarine nutrient enrichment from the discharge was not reported, and it would be worthwhile assessing this. The timing of sampling, including discharge parameters and antecedent weather conditions, could also have influenced the results gained during these surveys.

In summary:

- Status: The Waiuku town basin site is still very new and further data is needed to make valid comparisons to other sites in the Manukau Harbour. However, the wider harbour is well enough characterised to assess overall quality and to compare with other regional locations. Generally the water quality is fair-to-poor quality, worse in upper estuary, better at mouth and in the open harbour. Quality is generally fairly poor compared with the best regional sites. The Waiuku WWTP has a measurable impact on nutrients and microbial water quality.

- Trends: There is a general long term improvement in water quality at the estuary mouth (Clarks Beach site). The monitoring period is not yet long enough to assess trends in the upper estuary (Town Basin site).
- Gaps and opportunities: Conduct a Quantitative Microbial Risk Assessment (QMRA) to quantify the public health risks associated with the Waiuku WWTP discharge. Quantify the contribution to nutrient loads from the Waiuku WWTP and wider catchment sources to provide a basis for assessing potential nutrient enrichment issues. A better understanding of estuary hydrodynamics would be useful to assess the fate and consequence of both diffuse and point-source discharges into the estuary.

5.0 Estuarine sediment quality

5.1 Information sources

Estuarine sediment chemistry (metals and organic contaminants) and texture data were available from:

- NZ Steel discharge consent monitoring reports;
- Data from the Auckland Council Regional Sediment Chemistry Monitoring Programme (RSCMP) sites in the urban reaches of the Waiuku Estuary, and from Clarks Beach (outside the estuary mouth, in the Manukau Harbour);
- Investigations of the effects of the Waiuku Wastewater Treatment Plant discharge into the Waiuku Estuary; and
- Analyses of contaminants of potential environmental concern (CPEC) in sediments taken from a site in the Taihiki Estuary.

The locations of these sites are shown in Figure 5-1.

The data from these information sources have been summarised and shown graphically to examine:

- Spatial distribution of metals in sediments around the outfalls, including comparisons with metals' concentrations in sediments measured elsewhere in the Waiuku Estuary;
- Contaminant "status", from comparisons of the concentrations with Sediment Quality Guidelines (SQG) for the protection of aquatic life; and
- Trends in the concentrations of metals over time (there are too few data for other contaminants to assess trends).

In addition to the information sources given above, a comprehensive and detailed review of heavy metals' data in the Manukau Harbour was published by Williamson et al. (1992). This review covered data collected in 1985 from 135 sites throughout the Manukau Harbour (including 10 from the Waiuku Estuary), samples from up to 10 sites in the Waiuku Estuary collected as part of the NZ Steel monitoring between 1985 to 1990, and Auckland Regional Water Board monitoring downstream of the steel mill discharge from 1985 to 1988. These data have not been included in the current review, partly because more recent data are now available, and partly because of differences in the analytical methods used in these older surveys, which make reliable comparisons with recent data problematic. However, the general conclusions from the earlier surveys, for example in relation to the impact of the steel mill discharge, are consistent with those obtained from the more recent data reviewed here. Readers are recommended to read the Williamson et al (1992) report to obtain useful background information on historical pollution sources and the spatial distribution of metal contaminants in the Manukau Harbour.

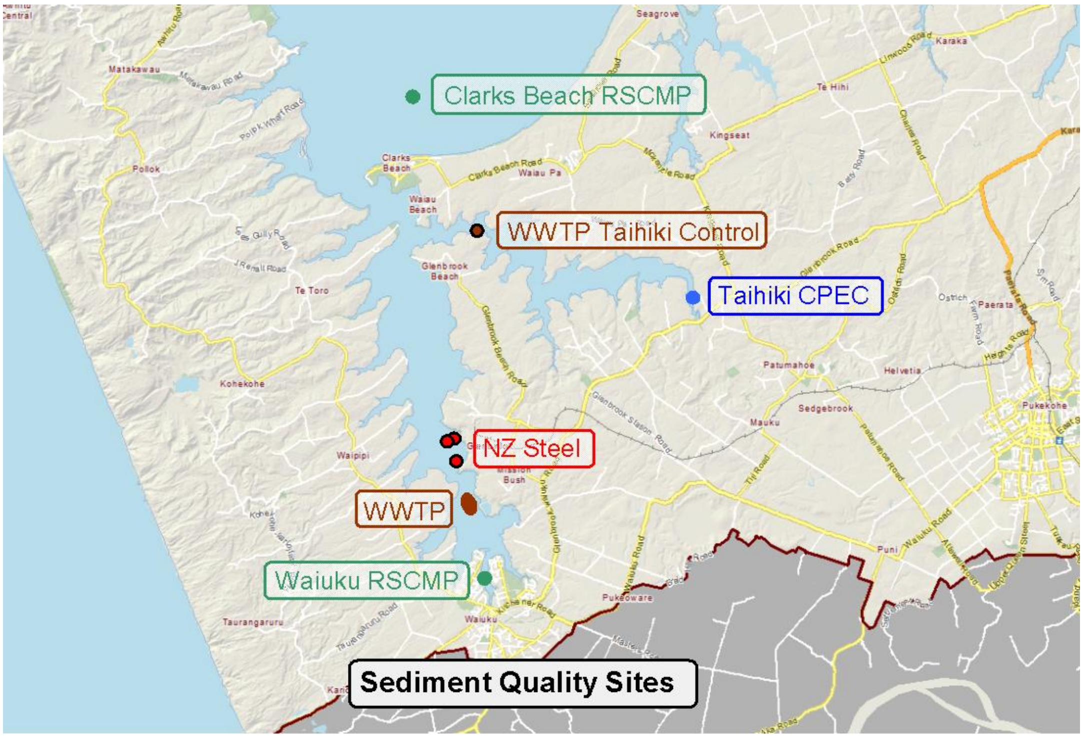

Figure 5-1 Locations of sediment quality sampling sites

5.1.1 Overview of NZ Steel discharge consent monitoring

Background information and summary information on the overall effect of the NZ Steel discharge is provided in section 9.0. A component of the NZ Steel discharge consents monitoring programme requires monitoring of sediments within and adjacent to the mixing zones of the Northside and Southside discharges. Sampling for metals and sediment texture is undertaken every two years, and started in 2003. Data have been reported in the consent monitoring reports (Bioresearches 2003, 2005, 2007a, 2009, 2011).

Two sites are sampled near the Northside outfall – site A, 160 m from the outfall and site B, 325 m from the outfall. One site is sampled near the Southside outfall – site C, 160 m from outfall. These sites are shown in Figure 5-2.

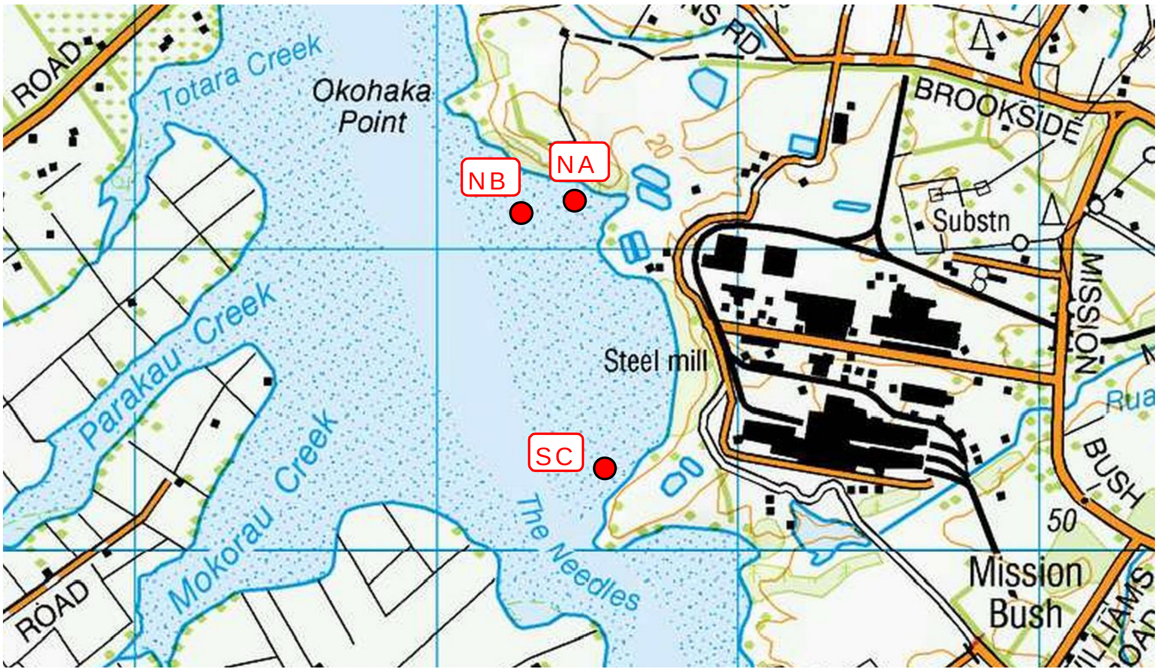

Figure 5-2 NZ Steel sediment sampling locations

At each site, 3 replicate samples for metals' analysis and 1 sample for sediment texture are collected using the ARC "Blueprint for monitoring in urban receiving environments" sampling protocol (Technical Publication 168, ARC 2004). Sediments are analysed for extractable metals in the <63 µm (mud) fraction, and for total recoverable metals. Metals analysed are cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn).

Because the extractable metals are measured on a limited particle size fraction, they are less affected by differences in sediment texture between sites or over time. They are therefore used for comparing sites and assessing trends. The total recoverable metals are used to compare with sediment quality guidelines (SQG) – the ARC Environmental Response Criteria (ERC; ARC 2004) – to assess potential adverse effects on benthic aquatic life. The ARC blueprint protocol states that for sites in sediment Settling Zones (SZ), the ERC should be compared with the total recoverable metals' concentrations.

For sites in Outer Zones (OZ), where less sediment accumulation occurs, the ERC are compared with the higher of the total recoverable or extractable metals' concentrations. This provides additional protection to aquatic life from potentially contaminated fine sediments that may be intermittently deposited and transported through these generally less muddy environments.

The "Northside A" site is located in a SZ adjacent to the Northside outfall. Stations "Northside B" and "Southside C" are located in OZ areas (Bioresearches 2011).

5.1.2 Overview of Waiuku Wastewater Treatment Plant discharge sampling

Background information and summary information on the overall effect of the Waiuku WWTP is provided in section 10.1. Sediment quality was included in an investigation of the effects of the Waiuku wastewater treatment plant discharge into the Waiuku Estuary (Bioresearches 2007b).

Sampling was conducted in February 2007 from 10 sites – 9 in the Waiuku Estuary from 25 m to 250 m from the outfall, and one site in the lower Taihiki River estuary (as a “control”). Sites were:

- 25 m, 50 m and 100 m upstream (southward) of the discharge point;
- 25 m, 50 m, 100 m and 250 m downstream (northward) of the discharge point;
- 25 m west and 25 m east of the discharge point; and
- 1 site in the middle of the lower Taihiki River estuary.

Five replicate surficial sediment samples were collected using a 180 mm x 110 mm x 250 mm stainless steel boat-operated box dredge. The five replicate samples were then thoroughly mixed and subsampled to produce a single composite sample for each sampling location (Bioresearches 2007).

Samples were analysed for total recoverable Cu, Pb, and Zn, and sediment texture.

The exact sample locations were not given (or shown) in the Bioresearches (2007b) report, but the descriptions (as given above) are sufficiently accurate for the data summary presented here. Approximate locations, as inferred from the descriptions, are shown in Figure 5-3.

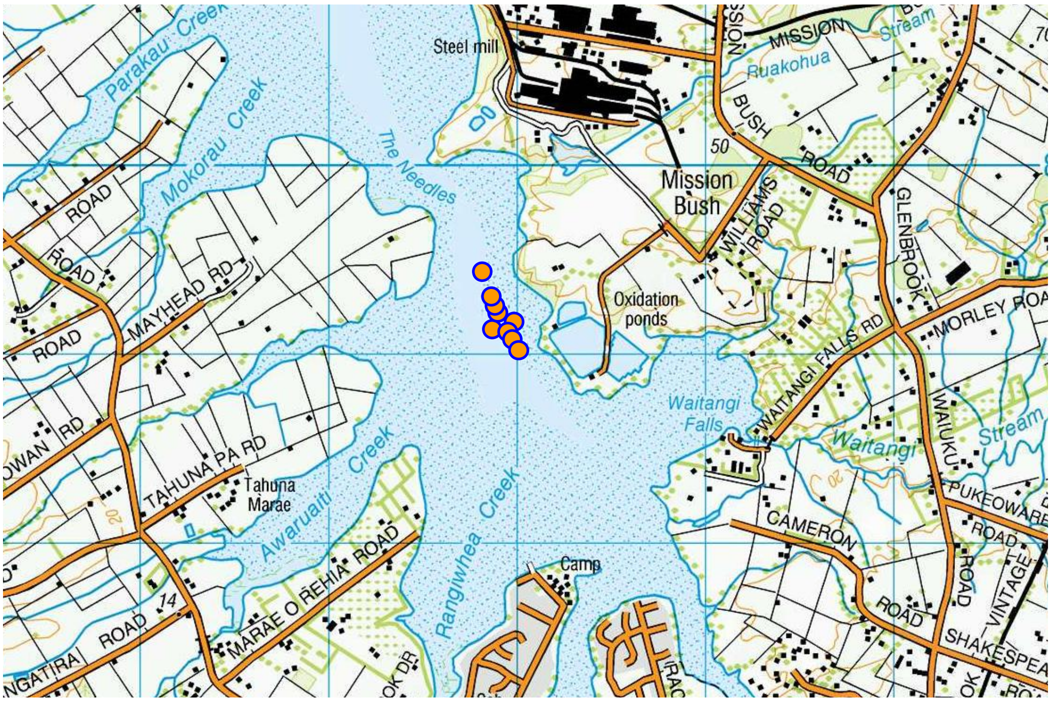

Figure 5-3 Sediment sampling locations used in the Waiuku WWTP effects investigation. Locations are indicative only, based on general descriptions given in Bioreseaches (2007b).

5.1.3 Regional Sediment Chemistry Monitoring Programme

There are two sites in the Auckland Council Regional Sediment Chemistry Monitoring Programme (RSCMP):

- The Waiuku site, located in the upper, urban, reaches of the Waiuku Estuary. This SZ site has been sampled twice – in 2002 and again in 2012.

- The Clarks Beach site, located approximately 1.5 km offshore from the beach, on a large exposed intertidal sand flat in the Manukau Harbour. This OZ site has been sampled once, in 2002, as part of the former Regional Discharges Project (RDP).

Site locations are shown in Figure 5-4.

Figure 5-4 Locations of the Waiuku and Clarks Beach regional sediment chemistry monitoring programme (RSCMP) sites.

These sites were sampled using the ARC blueprint protocol. Samples were analysed for Cu, Pb, and Zn (extractable and total recoverable metals; 3 replicates per site), and sediment texture (1 composite sample per site).

In addition to the metals, the Waiuku site has recently been analysed for persistent organic contaminants – polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs).

The OCPs and PCBs are legacy chemicals, being no longer in use. However, residues are still found in the sediments and shellfish in most estuarine areas around Auckland (Mills 2013; Stewart et al. 2013). This is likely to continue, at decreasing levels, into the future as contaminated catchment soil, and sediment within the estuaries, is mobilised into (and within) the marine receiving environment.

PAHs, however, are still being produced, primarily by the combustion of organic material (e.g. fuel, wood, coal). PAHs are therefore recognised as a "primary" contaminant for stormwater management (ARC 2004).

5.1.4 Emerging contaminants in the Taihiki Estuary

Sediments from 13 estuarine locations around Auckland were taken in March 2008, and analysed for 34 of the key "chemicals of potential environmental concern" (CPEC)[3] that could be analysed by commercial laboratories at the time (Stewart et al. 2009). The sediment samples collected in 2008 from these sites were subsequently analysed for 46 pharmaceuticals (a European Union suite of compounds), 33 of which are listed in the NZ Pharmac 2007 schedule. The results have been reported by Stewart (2013).

One of the sites was located in the upper reaches of the Taihiki Estuary (Figure 5-5). The upstream catchment is predominantly rural (agriculture and horticulture), and is drained by the Mauku Stream. The sediment here is muddy.

Two replicate samples from the top 3 cm were taken randomly within a 50 x 50 cm quadrat. The samples therefore represent a small scale "snapshot" compared with the more representative samples obtained by the ARC blueprint method (generally taken over a 50 x 20 m area).

As well as emerging contaminants, the samples were analysed for extractable and total recoverable Cu, Pb, and Zn.

1.0

[3] "Emerging contaminants" or "chemicals of potential environmental concern" (CPEC) are a very broad class of chemicals found in many products of day-to-day use, which are often manufactured or consumed in high-volume. They include, among others, plastics, resins and plastic additives (plasticisers, flame retardants), pharmaceuticals and personal care products (e.g. disinfectants, antibiotics, fragrances, sunscreens, drugs, natural and synthetic hormones), detergents and other cleaning agents, various petroleum products, pesticides and biocides (e.g. weed killers, fumigants, wood preservatives, antifouling agents), and compounds derived from wastewater and drinking water treatment, landfill or incineration.

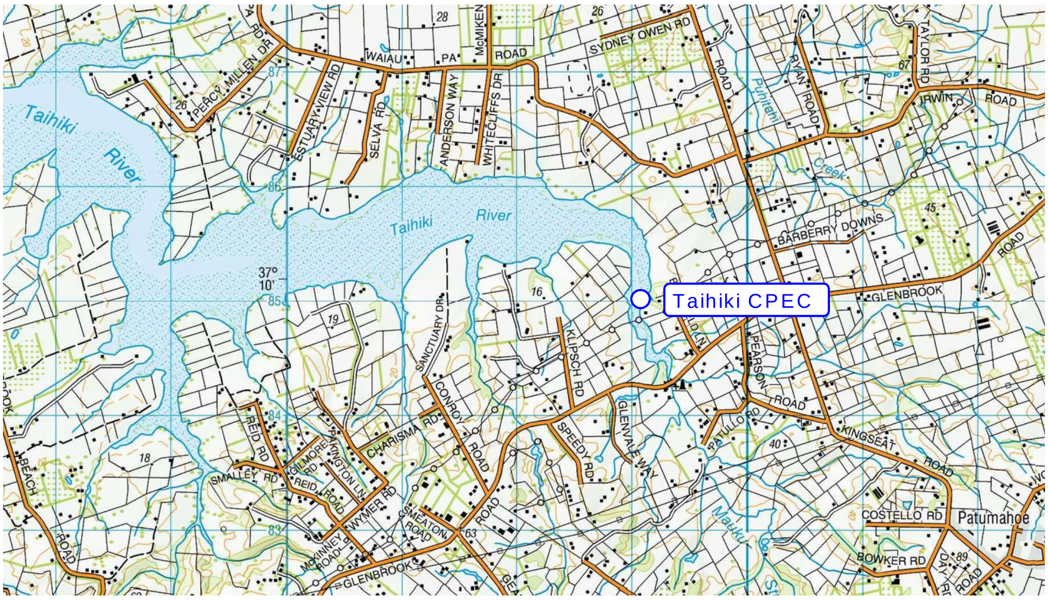

Figure 5-5 Location of the site sampled in 2008 for analysis of emerging contaminants (Stewart et al. 2009, Stewart 2013).

5.2 Contaminant status

5.2.1 Metals

Metals' concentrations and ERC gradings are summarised in Table 5-1. All sites, with the exception of the NZ Steel Northside outfall site A (in the SZ, closest to the outfall), were ERC-Green. This indicates that the concentrations of Cu, Pb, and Zn are unlikely to be high enough to cause adverse effects on benthic aquatic life.

Northside A was rated as ERC-Red, because of elevated total recoverable Zn. It is therefore probable that the Zn concentration at this site is sufficiently high to adversely affect benthic life. The benthic community health was assessed at Station Northside A in October 2011 using the Auckland Council Benthic Health Model, and ranked as 4, which is indicative of poor ecological condition.

It is interesting that the extractable Zn was not particularly elevated, suggesting the Zn is in a coarser particle size than 63 µm[4], or in a form that is less soluble in the weaker 2 M HCl extractable acid solution.

1.0

[4] In the ARC blueprint protocol, the extractable metals are measured in the <63 µm fraction, whereas the total recoverable metals are measured in the <500 µm fraction

Table 5-1 Summary of sediment metal concentrations and mud content (% sediment <63 um) in samples from the Waiuku and Taihiki estuaries.

Data are medians. Concentrations of metals are in mg/kg (d.w.), and mud content in % by weight. The NZ Steel and RSCMP data are the latest available. Colour coding refers to the Environmental Response Criteria (ERC) – ERC apply to the concentrations of metals in the <500 µm fraction for Settling Zone (SZ) sites, and to the greater of the <63 µm or <500 µm concentrations in Outer Zone (OZ) sites.

					Extractable Metals (<63 um fraction)					Total Recoverable Metals				
Estuary	Location	Sites	Year	% Mud	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
Waiuku	NZ Steel Northside outfall	A, 160 m from outfall (SZ)	2011	55.4	<0.05	13.6	5.0	10.5	72.0	0.19	32.0	8.9	13.7	174.0
		B, 325 m from outfall (OZ)	2011	79.8	<0.05	12.1	4.7	9.8	53.0	0.08	27.0	8.5	12.8	98.0
	NZ Steel Southside outfall	C, 160 m from outfall (OZ)	2011	67.7	<0.05	13.1	5.0	11.4	60.0	0.07	24.0	7.8	12.3	83.0
Waiuku	WWTP outfall	9 sites, 25-250 m from outfall (OZ)	2007	10.7								6.1	10.9	61.8
Waiuku	Upper estuary, urban site	Auckland Council RSCMP site (SZ)	2012	92.0			7.6	16.5	88.4			10.7	16.1	99.0
Waiuku	Clarks Beach	Auckland Council RSCMP site (OZ)	2002	4.3			5.0	7.7	37.0			2.0	3.2	26.4
Taihiki	Lower estuary, control site	WWTP Control site (OZ)	2007	19.9								5.9	8.5	44.0
Taihiki	Upper estuary	CPEC site (SZ)	2008	19.9			7.6	17.0	79.5			14.0	16.5	85.0

Environmental Response Criteria (ARC 2004)					
ERC	Cd	Cr	Cu	Pb	Zn
Green	<0.7	<52	<19	<30	<124
Amber	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Red	>1.2	>80	>34	>50	>150

5.2.2 Organic contaminants

The concentrations of organic contaminants in the Waiuku RSCMP site sediment sampled in 2012 are summarised in Table 5-2. All were well below ERC amber (PAH) or red (OCPs and PCBs) thresholds.

Table 5-2 Organic contaminant concentrations in sediments at Waiuku RSCMP site in 2012.
Values are concentrations, expressed in ng/g (µg/kg or parts per billion, ppb) and also normalised to 1% total organic carbon (TOC) for comparison with Environmental Response Criteria (ERC; ARC 2004).

	ERC (ng/g at 1% TOC)			Waiuku (2012)	
Compound	Green	Amber	Red	ng/g	ng/g at 1% TOC
p,p'-DDE	< 2.1	no values for OCPs or PCBs	>2.1	0.39	0.20
p,p'-DDD	< 1.2		>1.2	0.10	0.05
p,p-DDT	< 3.2		>3.2	<0.06	<0.03
Total DDTs	< 3.9		>3.9	0.66	0.34
chlordane	< 2.3		>2.3	0.07	0.03
dieldrin	< 0.72		>0.72	0.18 (EMPC)	<0.09
lindane	< 0.3		>0.3	<0.07	<0.04
Total PCBs	< 22		>22	3.5	1.62
HW PAHs	660	660 - 1700	>1700	200	103

"Total DDTs" is the sum of o,p'- and p,p'- isomers of DDE, DDD, and DDT.
"Chlordane" is the sum of cis- and trans-chlordane.
Dieldrin concentration of 0.18 ng/g is the "estimated maximum possible concentration" (EMPC), so in effect the concentration may be less than this.
"HW PAHs" are "high molecular weight" PAH, as defined by ANZECC (2000). They are the sum of benzo[a]anthracene, benzo[a]pyrene, dibenzo[a,h]anthracene, chrysene, fluoranthene, and pyrene.
TOC content of the Waiuku sediment was 1.95%.

5.2.3 Status summary

Concentrations of metals and (at one site) organic contaminants in sediments from the Waiuku and Taihiki estuaries were, with only one exception (NZ Steel Northside A), in the ERC-Green range. This indicates that these contaminants, while probably elevated above background levels, are unlikely to cause adverse effects on benthic fauna at the sites sampled. However, Auckland Council assessment of benthic health at the Waiuku RSCMP site in 2012 gave a grading of "unhealthy with low resilience", the poorest grade (see section 7.2 for further explanation). The poor benthic health at this site is not consistent with the relatively low (ERC-Green) concentrations of sediment contaminants, suggesting other factors, in particular sediment muddiness, are the primary influence on benthic health. In contrast, the benthic health at Clark's Beach (Manukau Harbour site) was rated as "good" (the second highest rating).

At one site, the NZ Steel Northside outfall “A” site (the closest site to the discharge), Zn was ERC-Red. This indicates localised contamination at concentrations high enough to cause adverse ecological effects. Benthic health at the NZ Steel Northside A site has been assessed as poor, which is consistent with the elevated Zn concentration.

5.3 Spatial distributions in metals’ concentrations

The concentrations of Cu, Pb, and Zn in sediments from these sites are summarised in Table 5-1 and shown graphically in Figure 5-6 and Figure 5-7.

The total recoverable metals’ data showed that:

- Lowest concentrations of these metals, both total and extractable, were present at Clarks Beach. This is an exposed, sandy, harbour site, which would not be expected to accumulate contaminants to any significant extent. The data support this.
- Concentrations of total Zn were markedly higher at the NZ Steel Northside outfall A site (as discussed previously). Zn levels at the Waiuku RSCMP site (urban) and the Taihiki Upper (rural) were comparable with the other two NZ Steel sites (Northside B and Southside C). Taihiki Lower had lower total Zn, but this site was markedly less muddy than the NZ Steel or Waiuku RSCMP sites.
- Total Pb concentrations were similar across all the estuary sites. The lower mud content may be contributing to the lower total Pb level at the Taihiki Lower site.
- Total Cu concentrations were higher at the Taihiki Upper site, and to a slightly lesser degree at the Waiuku RSCMP site. These may reflect the influences of horticulture (Taihiki Upper) and urban runoff (Waiuku RSCMP) respectively.
- The Waiuku WWTP sites did not show markedly elevated metals’ concentrations. This suggests little impact on sediment contamination from this discharge.

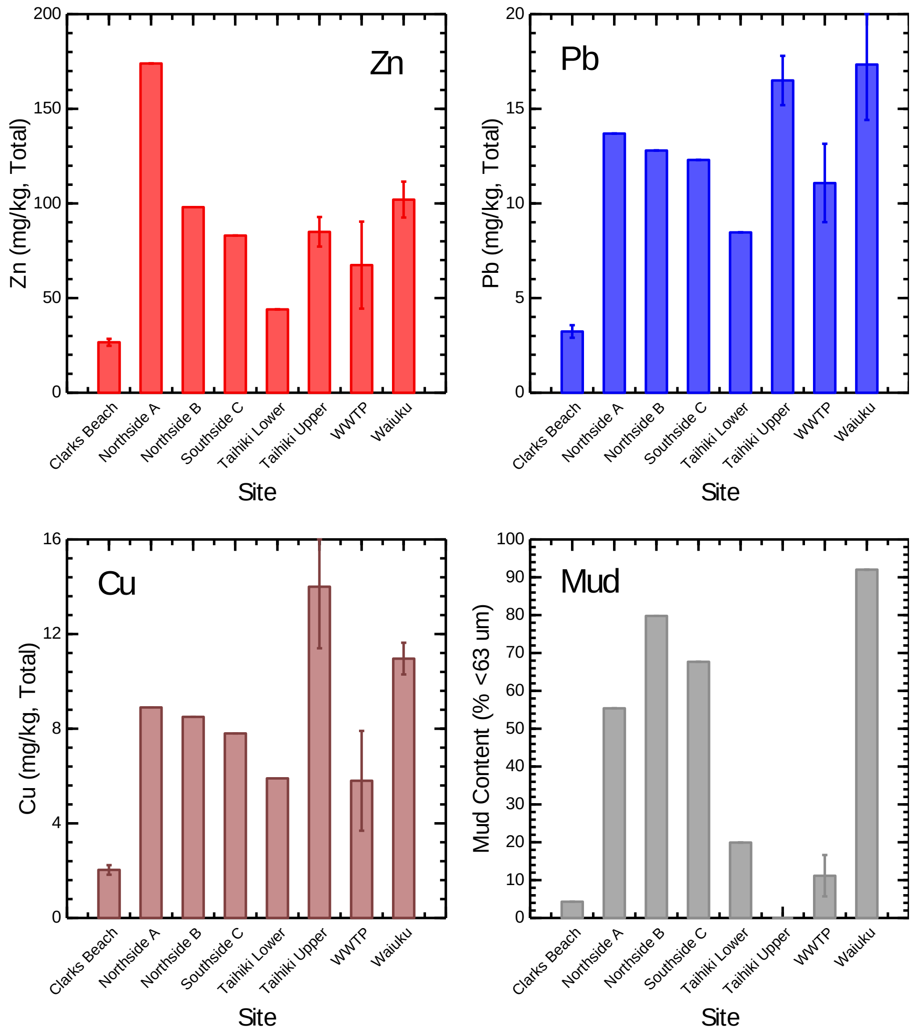

Figure 5-6 Total recoverable Cu, Pb, and Zn, and mud content, in Waiuku and Taihiki estuary sediments. Bars are means ±1 standard deviation. See table for site and sample details. No mud content data for Taihiki Upper.

The extractable metals' data provide a measure of the contamination in the fine sediment fraction. They show a smaller range of concentrations than the total metals, reflecting the narrower particle size range analysed. All concentrations were low.

The highest levels of extractable Cu, Pb, and Zn were measured at the urban Waiuku RSCMP site, and the rural Taihiki Upper site. The NZ Steel sites were lower, except perhaps at site A which had a slightly elevated Zn level.

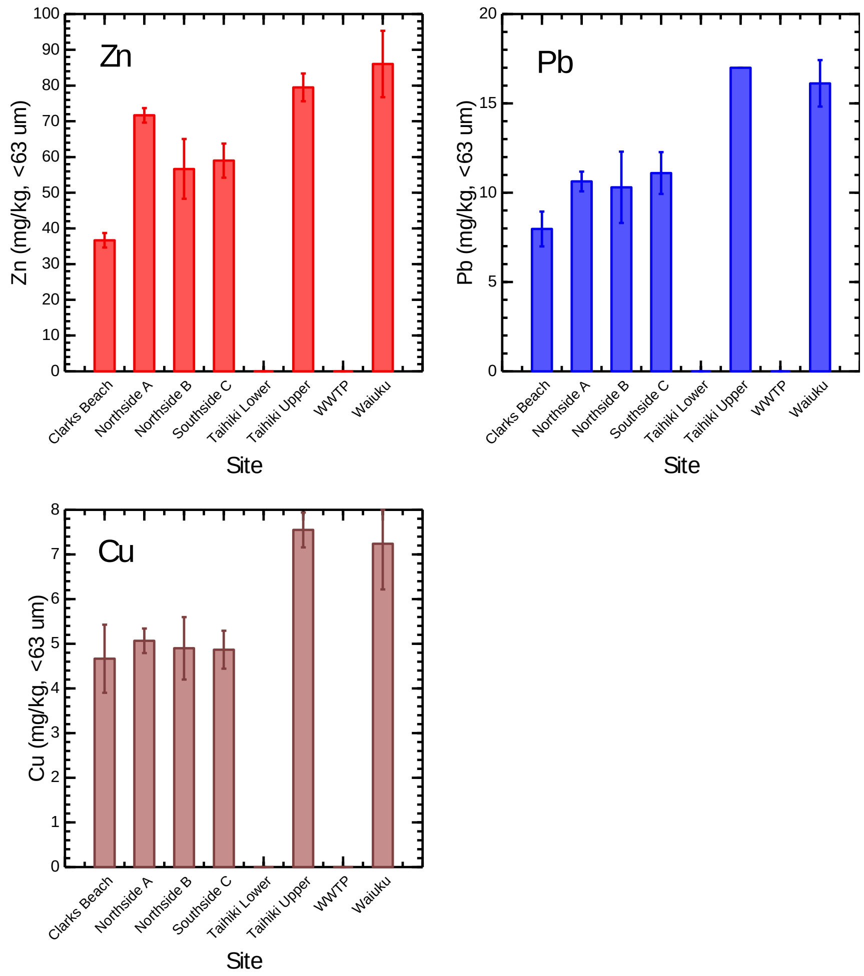

Figure 5-7 Concentrations of extractable metals (<63 µm fraction) in Waiuku and Taihiki estuary sediments. Bars are means ±1 standard deviation. See Table 5-1 for site and sample details. Extractable metals not analysed at Taihiki Lower or the Waiuku WWTP sites.

5.3.1 Spatial distribution summary

The only strong spatial signal was observed for total Zn, which was markedly elevated relative to other sites at the NZ Steel Northside A site, close to the discharge point. Concentrations at the B and C sites were similar to those at other muddy Waiuku and Taihiki estuary sites.

More subtle metals' signals were observed for the upper estuary sites in the Waiuku and Taihiki estuaries, which showed slightly elevated Cu, Pb, and Zn levels. These are suggestive of the influences of urban runoff, although horticultural runoff may also be a factor in these catchments.

Marked effects of the Waiuku WWTP discharge on sediment quality were not apparent from the data. Effects from the NZ Steel discharges appear to be confined to an area close to the discharge.

5.4 Trends in metals' concentrations

Trends in metals' concentrations over time can be assessed from the NZ Steel outfall monitoring data between 2003 and 2011 (inclusive), and from comparison of 2002 and 2012 monitoring results for the Waiuku RSCMP site.

5.4.1 NZ Steel monitoring

Background information and summary information on the overall effect of the NZ Steel discharge is provided in section 9.0. Extractable metals and total recoverable metals were analysed at each of the 3 monitoring sites in 2003, 2005, 2007, 2009, and 2011. Three replicates per sampling occasion were analysed for extractable metals, and a single composite per sampling for total metals. The extractable metals therefore provide a more robust set of data for assessing trends.

Trend data at the Northside A and B, and Southside C sites are summarised in

Table 5-3, and selected data are shown in Figure 5-8. These results indicate decreasing trends in extractable metals' concentrations at all three sites, except for Cu at Northside A, which showed no change over time.

Total recoverable metals showed no significant changes over time, probably because of the lack of replication on each sampling occasion. Mud content did not vary significantly over time.

Table 5-3 Summary of trends in metals and mud content at NZ Steel outfall sediment quality monitoring sites between 2003 and 2011 (inclusive). Trend significance tested by Mann Kendall test, with Relative Sen Slope Estimators (RSSE, % of median per annum) used to present trend magnitude. See table footnote for explanation of trend indicator symbols. Values are RSSE (% per annum).

Metal	Monitoring Site		
	Northside A	Northside B	Southside C
Extractable metals (<63 um):			
Chromium	↓ -1.9	↓ -1.9	↓-3.3
Copper	— 0.0	↓ -1.6	↓ -3.4
Lead	↓ -1.4	↓ -2.5	↓ -3.6
Zinc	↓ -2.7	↓ -2.7	↓ -3.9
Total Recoverable metals:			
Cadmium	↓ -5.3	— 0.0	— 0.0
Chromium	↓ -0.3	↑ +0.2	↓ -0.2
Copper	↑ 1.7	↑ +0.5	— 0.0
Lead	↓ -0.6	↓ -0.9	↓ -0.7
Zinc	↓ -2.3	↑ +1.8	↑ +1.0
% mud	↑ +1.3	↓ -0.5	↓ -0.3

Trend magnitude and significance:

↓	significant decrease (p<0.05 and >1% per annum)
↓	decrease (0.05<p<0.1 and >1% per annum)
unshaded	trends not significant (p<0.1)
—	"zero" trend <0.01% per annum

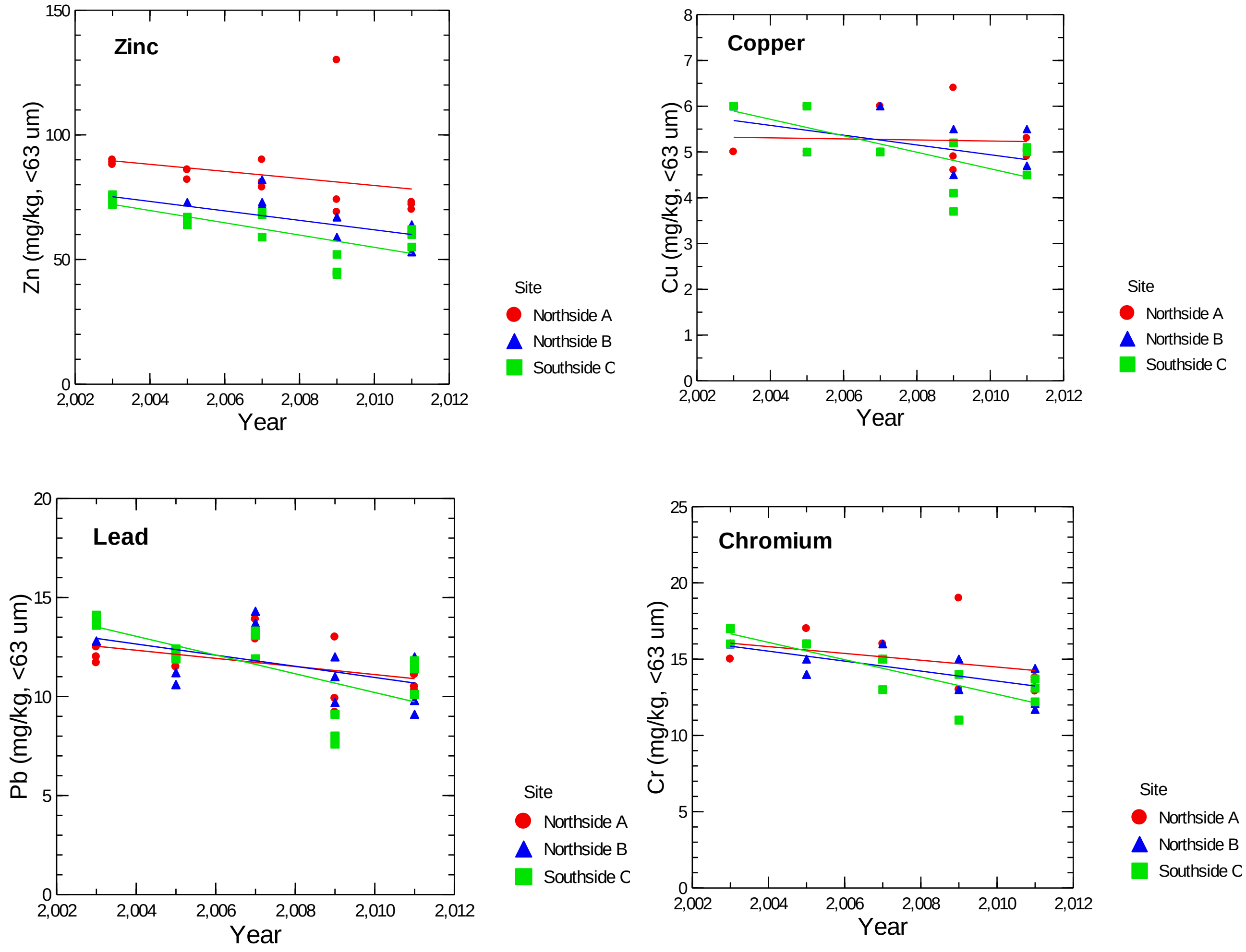

Figure 5-8 Trends in extractable metals' concentrations at NZ Steel sediment monitoring sites. Linear regression "line of best fit" shown to illustrate trends.

5.4.2 Waiuku RSCMP site

The Waiuku RSCMP monitoring site[5] has been sampled twice, in 2002 and in 2012. With only two sets of data, it is too early to assess trends. However, comparison of the results from 2002 and 2012 provides an indication of the changes that have occurred over this 10 year period.

Samples were analysed for Cu, Pb, and Zn (3 replicates, extractable and total recoverable metals) and texture (1 composite sample) in each of the two years. The metals' data are shown in Figure 5-9.

Zinc and copper concentrations were slightly higher in 2012 than in 2002. The differences were not significant (t-test, $p<0.05$) for extractable metals, but were so for total recoverable Cu (11 mg/kg compared with 9.4 mg/kg; $p=0.018$). Total Zn was also higher in 2012 (102 mg/kg cf 93 mg/kg) but

1.0

[5] The monitoring site sampled in 2012 was approximately 130 m upstream of the 2002 site.

this difference was not quite significant (p=0.091). Mud content was very similar in each year (91% and 92%), as were Pb concentrations.

The "increases" in Cu and Zn equated to a "trend" of approximately 1% per annum over the 10 year period, which is considered at the lower margin of detectability for sediment chemistry monitoring (Mills et al. 2012; Mills & Williamson 2013). Differences of this size may well be associated with analytical variability, rather than real changes in the environment. However, the small increases in Zn and Cu are consistent with anticipated changes resulting from accumulation of contaminants from urban stormwater inputs. Future monitoring will provide a better indication of whether these are part of an on-going "trend", or whether variability is a key contributor to differences observed between years.

These results indicate that relatively small changes in metals' concentrations at this site have occurred over the past 10 years.

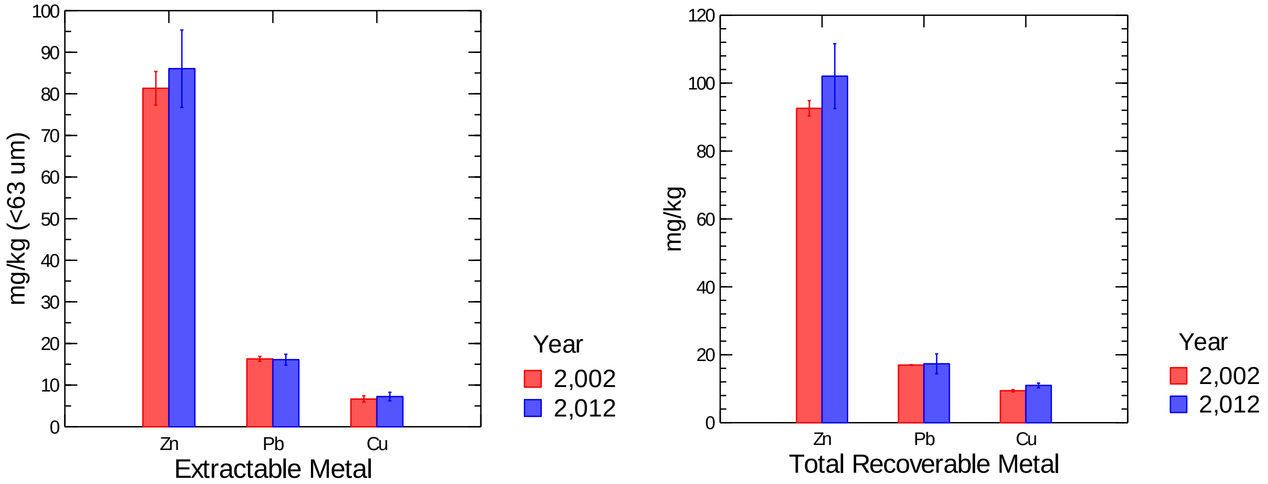

Figure 5-9 Concentrations of extractable and total recoverable Cu, Pb, and Zn in sediments at the Waiuku RSCMP monitoring site sampled in 2002 and 2012. Bars are means ±1 standard deviation (n=3).

5.5 Emerging contaminants

"Emerging contaminants" or "chemicals of potential environmental concern" (CPEC) are a very broad class of chemicals found in many products of day-to-day use, which are often manufactured or consumed in high-volume. They include, among others, plastics, resins and plastic additives (plasticisers, flame retardants), pharmaceuticals and personal care products (e.g. disinfectants, antibiotics, fragrances, sunscreens, drugs, natural and synthetic hormones), detergents and other cleaning agents, various petroleum products, pesticides and biocides (e.g. weed killers, fumigants, wood preservatives, antifouling agents), and compounds derived from wastewater and drinking water treatment, landfill or incineration.

Sediments from 13 estuarine locations around Auckland were sampled in March 2008. Sites covered a range of land use influences. Most were urban sites exposed to a variety of contamination sources, including wastewater discharges, stormwater runoff, historical landfills, and marinas. A site in the headwaters of the Taihiki River estuary was also included (Figure 5-5). The primary influence on this site is agricultural catchment runoff.

CPECs were analysed in two separate studies:

1. The first analyses, reported by Stewart et al. (2009) included the following CPECs:
   - polybrominated diphenylether (PBDE) flame retardants
   - phthalate ester plasticisers ("phthalates")
   - biocides, including common antifoulants, herbicides (including glyphosate), and various pesticides (including dithiocarbamates, diazinon, and pyrethroids)
   - triclosan (disinfectant)
   - oestrogens, and
   - nonylphenols.
2. The second set of analyses, reported by Stewart (2013) were 46 pharmaceuticals (an EU suite of target compounds), 33 of which are listed in the NZ Pharmac 2007 schedule (and are therefore directly relevant to the NZ environment).

The CPEC data indicated that residues of some emerging contaminants are found, at widely varying concentrations, in Auckland's estuarine sediments. A preliminary examination of the spatial distribution of these chemicals suggests that sites potentially influenced by treated wastewater discharge or wastewater overflows and possibly historical landfills, may have higher concentrations of most CPECs.

The Taihiki Estuary site generally had among the lowest CPEC concentrations of the sites surveyed. The concentrations of only the antibiotics (4^{th} highest of the 13 sites), antacids (5^{th} highest), and diuretics (11^{th} highest) ranked above the lowest of the site rankings. PBDE flame retardants were detected in low concentrations (7.8 ng/g, 6^{th} highest of the sites) – however, PBDE analysis was very sensitive, resulting in detection of residues at all sites, at concentrations ranging from 0.08 – 573 ng/g.

Overall, the initial CPEC survey data suggest that concentrations of most compounds at Taihiki were very low. However, Stewart et al. (2009) pointed out that the failure to detect many of the CPECs in their initial study does not mean that there is no cause for concern, as the detection limits were often higher than concentrations reported elsewhere in the international literature. Therefore, future studies utilising improved analytical methods are still warranted to improve the quality and coverage of the CPEC database.

5.6 Summary and information gaps

Sediment quality has been assessed at three locations in the Waiuku Estuary:

- In the upper urban reaches, at the Waiuku RSCMP monitoring site;
- In the 25–250 m reach around the Waiuku WWTP discharge; and
- At three sites in the vicinity of the two NZ Steel discharge outfalls.

In the neighbouring Taihiki Estuary, data has been collected from two locations:

- One site in the lower reaches of the estuary, which was used as a control site for comparison with the Waiuku WWTP discharge investigation sites; and
- One site in the upper reaches of the estuary, which was sampled for emerging contaminants and metals.

One set of metals' data has been collected from the Clarks Beach RSCMP site. This is located outside of the Waiuku Estuary mouth, in the Manukau Harbour.

The NZ Steel monitoring has provided the most comprehensive set of data, having measured metals' concentrations biennially between 2003 and 2011, using consistent sampling and analysis protocols. Other data have been from "one off" investigations or (from the RSCMP site) the early stages of longer term monitoring. As mentioned previously (section 5.1), there is also a large amount of historical data reviewed in the Williamson et al. (1992) report.

Concentrations of metals and (at one site) organic contaminants in sediments from the Waiuku and Taihiki estuaries were, with only one exception (NZ Steel Northside A), in the ERC-Green range. This indicates that these contaminants are unlikely to cause adverse effects on benthic fauna at the sites sampled. However, Auckland Council assessment of benthic health at the Waiuku RSCMP site in 2012 gave a grading of "unhealthy with low resilience", the poorest grade. The poor benthic health at this site is not consistent with the relatively low (ERC-Green) concentrations of sediment contaminants, suggesting other factors (particularly sediment muddiness) are also influencing benthic health. In contrast, the benthic health at Clarks Beach (Manukau Harbour site) was rated as "good" (the second highest rating).

At one site, the NZ Steel Northside outfall "A" site (the closest site to the discharge), Zn was ERC-Red. This indicates localised contamination at concentrations high enough to cause adverse ecological effects. Benthic health at the NZ Steel Northside A site has been assessed as poor, which is consistent with the elevated Zn concentration.

Trend data are limited to biennial NZ Steel consent monitoring between 2003 and 2011, and two samplings (in 2002 and 2012) from the Waiuku RSCMP site. The NZ Steel data indicate that sediment metals' concentrations have decreased in the vicinity of the outfalls. The Waiuku RSCMP monitoring data are insufficient to measure trends, but suggest that changes over the past decade have been relatively small.

Overall, the sediment quality in the Waiuku Estuary is well characterised. The long-term monitoring site in the upper estuary should provide any "early warning" signals associated with contaminant accumulation that may arise from urban inputs from Waiuku township. Continued monitoring here at, say, 5-yearly intervals should be sufficient.

The largest point source of metals' contamination, NZ Steel, has a high quality monitoring programme that has collected sediment quality data since 2003. The data provide a clear picture of status and trends in the vicinity of the discharges. This monitoring should continue. One possible gap relates to PAH concentrations – oyster survey data from the late 1980s-early 1990s (see section 6.2) found high concentrations of PAH in oysters from The Needles, a site equivalent to the Southside outfall sediment "S5" monitoring site. It would be useful to know the level and extent of

PAH contamination in the sediments around the NZ Steel outfalls and, if elevated, to have the source(s) of PAH identified (to assess potential treatment options, if required).

Investigations of the potential effects of the Waiuku WWTP discharge included a one-off study of sediment quality. The results indicated little effect. Based on these findings, further investigations are probably not warranted.

The zone outside the mouth of the estuary consists of broad, exposed, sand flats, which would not be expected to accumulate contaminants. The 2002 data from the Clarks Beach RSCMP site support this, showing low levels of metals and a coarse sediment texture. Low frequency monitoring (say every 10–15 years) is sufficient to confirm that no unexpected changes have occurred here.

Extension of the emerging contaminant database to include the Waiuku Estuary is one area that could be considered in the future. However, based on the data collected around the region to date the levels of these contaminants in the Waiuku Estuary are likely to be low. Inclusion of this area for future emerging contaminant work would therefore seem to be of a low priority compared with more at risk receiving environments around Auckland.

In summary:

- Status: This is quite well characterised, with generally low contaminant levels. It is likely that muddiness and sediment deposition are having a significant impact on benthic ecology.
- Trends: There is limited information, but data indicate no concerns at present.
- Gaps and opportunities: No gaps requiring immediate attention. Continued sediment quality and benthic ecology monitoring will provide trend data over the next 10–20 years. It would be useful to know the level and extent of PAH contamination in the sediments around the NZ Steel outfalls, and to identify sources and assess source control options if levels are sufficiently elevated to warrant it. A better understanding of estuary hydrodynamics to assess the fate and consequence of both diffuse and point-source discharges into the estuary would also be helpful.

6.0 Shellfish quality

6.1 Information sources

Shellfish quality information for the Waiuku Estuary is available from:

- The Auckland Regional Water Board/Auckland Regional Council "Manukau Harbour Shellfish Quality Survey" data from 1987–1991 (ARWB 1988, ARWB 1990, ARC 1992, ARC 1993). This programme was part of the Manukau Harbour Action Plan, and had the objective of characterising the distribution of pollutants in the Manukau Harbour using sentinel shellfish (Pacific oysters; *Crassostrea gigas*) as biomonitors. Three sites in the Waiuku Estuary were monitored, with samples analysed for metals, organic contaminants, and microorganisms. After 1991, the programme was reviewed, and the Waiuku Estuary sites were removed from the on-going Manukau Harbour shellfish contaminant monitoring programme[6] as the area was covered by shellfish monitoring for NZ Steel (see below).
- The NZ Steel discharge consent monitoring programme. Metals and biological condition of oysters have been monitored since 1985 at five sites in the Waiuku Estuary, and one "control site" in the Taihiki Estuary. Results are detailed in annual consent compliance reports (Bioresearches 2002–2012).
- Analysis of faecal coliforms and in oysters from above and below the Waiuku WWTP discharge in 2000 (Bioresearches 2000) and 2007 (Bioresearches 2007b).

Although dated, the early Manukau Harbour Shellfish Quality Survey data (1987–1991) provide valuable data on organic contaminants (polycyclic aromatic hydrocarbons, organochlorine pesticides, and polychlorinated biphenyls), as well as metals, in the Waiuku Estuary, and how these concentrations compare with sites in the wider Manukau Harbour. More recent monitoring programmes do not include organic contaminants at Waiuku Estuary sites.

The NZ Steel data can be compared with those from the Auckland Council Shellfish Contaminant Monitoring Programme (SCMP) to assess relative concentrations and to compare trends over time. The SCMP results have recently been reviewed (Stewart et al. 2013). The data provided in this document has been used for comparisons with the NZ Steel data.

6.2 ARC Manukau Harbour Programme 1987–1991

There were 11 routinely sampled sites in the original Manukau Harbour Shellfish Quality Survey programme, which were monitored from 1987–1991 (ARWB 1988, ARWB 1990, ARC 1992, ARC 1993).

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[6] The Manukau Harbour oyster contaminant monitoring programme is now part of the Auckland Council Regional Shellfish Contaminant Monitoring Programme (SCMP). Oysters from four sites are monitored – Granny's Bay, Hingaia, Pahurehure, and Cornwallis. See Stewart et al. (2013) for the most recent and comprehensive review.

Three sites in the Waiuku Estuary were monitored (Figure 6-1). In order of increasing distance down the estuary, these were:

- Waiuku Yacht Club, which according to ARWB (1990) was located on a large mud-flat between the camping ground and the point at the end of Racecourse Rd. Influences here are mainly stormwater runoff from Waiuku township. This site was only sampled once, in November 1988. Insufficient oysters were available for sampling after this.
- The Needles – this site is located downstream of the Waiuku WWTP discharge, and in the immediate vicinity of the NZ Steel Southside outfall (the site is essentially in the same location as the NZ Steel monitoring site "S5").
- Kahawai Point, a popular recreational area, approximately 6 km downstream from the Needles site.

The closest Manukau Harbour site to the mouth of the Waiuku Estuary is Awhitu, located in the Regional Park approximately 4 km north of the estuary mouth. It is subject to rural runoff, but is remote from other contaminant sources.

Figure 6-1 Location of regional shellfish (oyster) contaminant monitoring sites in the Manukau Harbour. Tan sites are those monitored for the entire programme (1987 to present), grey sites monitored in 1987–1991, Waiuku Yacht Club site monitored once in 1988. The Mill Bay site was first sampled in 2009.

Five replicate samples were taken from each site. Each replicate consisted of 36 individual oysters. These 36 individuals were divided into 3 groups for analysis of organic contaminants, metals, and pathogenic microorganisms (faecal coliforms, enterococci, and *Vibrio parahaemolyticus*).

The following sections summarise how the contaminant data from the Waiuku Estuary sites compare with those from the wider Manukau Harbour. The 1991 monitoring data (ARC 1993) have been used as the basis for the summary and for plotting. These results showed the same general patterns as the 1987–1990 results.

6.2.1 Metals

The spatial patterns in the concentrations of selected metals (arsenic, copper, and zinc) are shown in Figure 6-2.

Metals' concentrations at Awhitu were amongst the lowest of all the Manukau Harbour sites, with the notable exception of arsenic (As). The reason for higher levels of As at "cleaner" sites remote from, for example, urban-sourced contamination, is unknown (catchment geology is a possibility), but has also been observed for estuarine sediments (Mills et al. 2012). Arsenic at Kahawai Point was also distinctly elevated.

Concentrations of metals at the Waiuku Estuary sites (Kahawai Point and the Needles) were generally low-moderate compared with the other Manukau Harbour sites (as shown for Cu). The exception was for zinc (Zn), which was present at similar levels to more urban sites in the main body of the harbour (e.g. Pahurehure, Hingaia, and Granny's Bay). This moderately elevated Zn level in the Waiuku Estuary is attributable to the nearby NZ Steel discharge.

The 1988 sampling from the Yacht Club site also found low levels of metals (ARWB 1990).

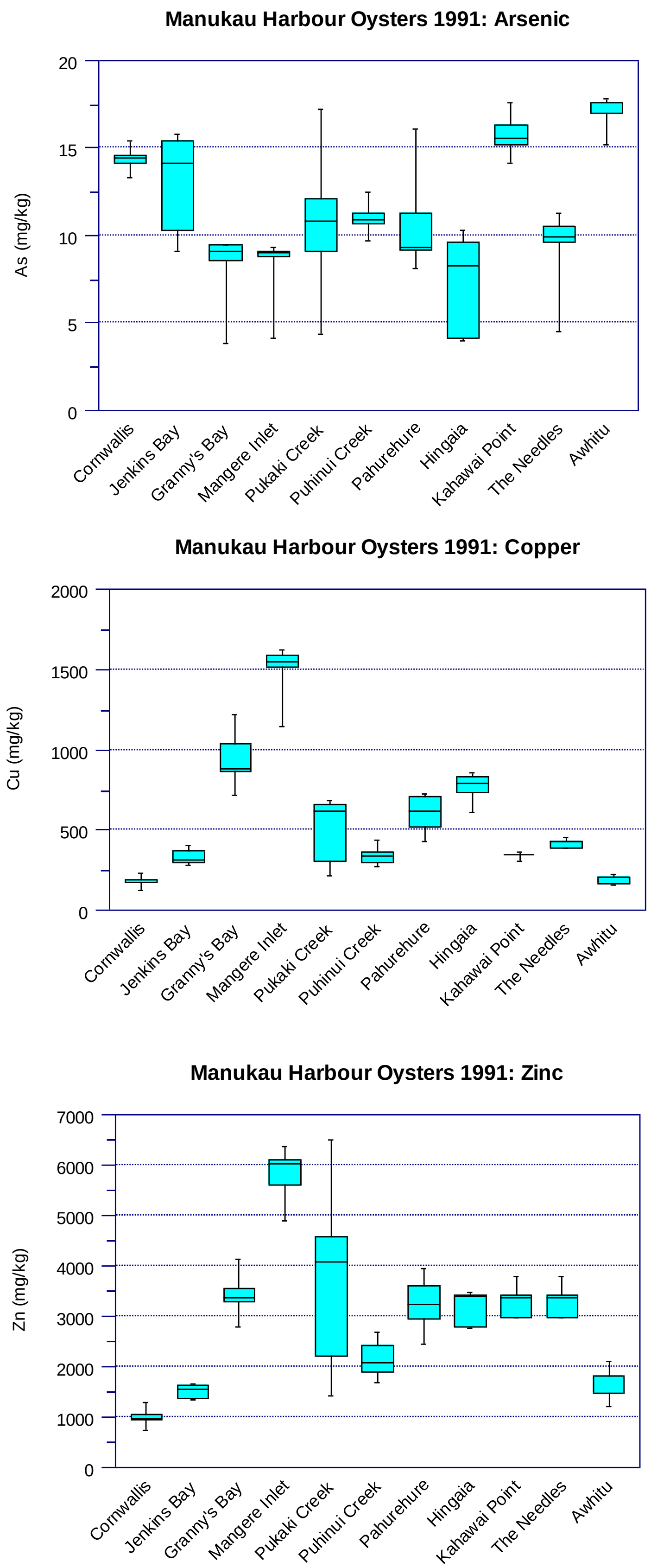

Figure 6-2 Arsenic, copper, and zinc concentrations in oysters from the Manukau Harbour. Data are from 1991 (ARC 1993).

6.2.2 Organic contaminants

Oysters were analysed for the major groups of persistent organic pollutants: polycyclic aromatic hydrocarbons (PAH), organochlorine pesticides (OCP; including DDTs, dieldrin, chlordanes), and polychlorinated biphenyls (PCBs). The OCPs and PCBs are "legacy" contaminants, being no longer in use in NZ. They continue to enter the aquatic environment via runoff from contaminated land, including (for OCPs) agricultural and horticultural land (and historical ex-horticultural land). However, concentrations are likely to decline over time as the historical sources are depleted. The PAH are sourced from combustion of fossil fuels, coal and oil, and roading materials, and therefore continue to be discharged into marine environments, principally via stormwater.

Awhitu had the lowest concentrations of organic contaminants in the Manukau Harbour surveys. Kahawai Point and The Needles were low-moderate compared with the wider Manukau Harbour sites for all organics, with the exception of PAH concentrations, which were markedly elevated at The Needles (Figure 6-3). This is probably attributable to the NZ Steel, which has a large stockpile of coal on site (adjacent to the Needles monitoring site), and uses this coal to fuel the steel production furnaces. The 1988 sampling from the Yacht Club site found low-moderate levels of all organic contaminants except DDTs, which were slightly elevated (ARWB 1990).

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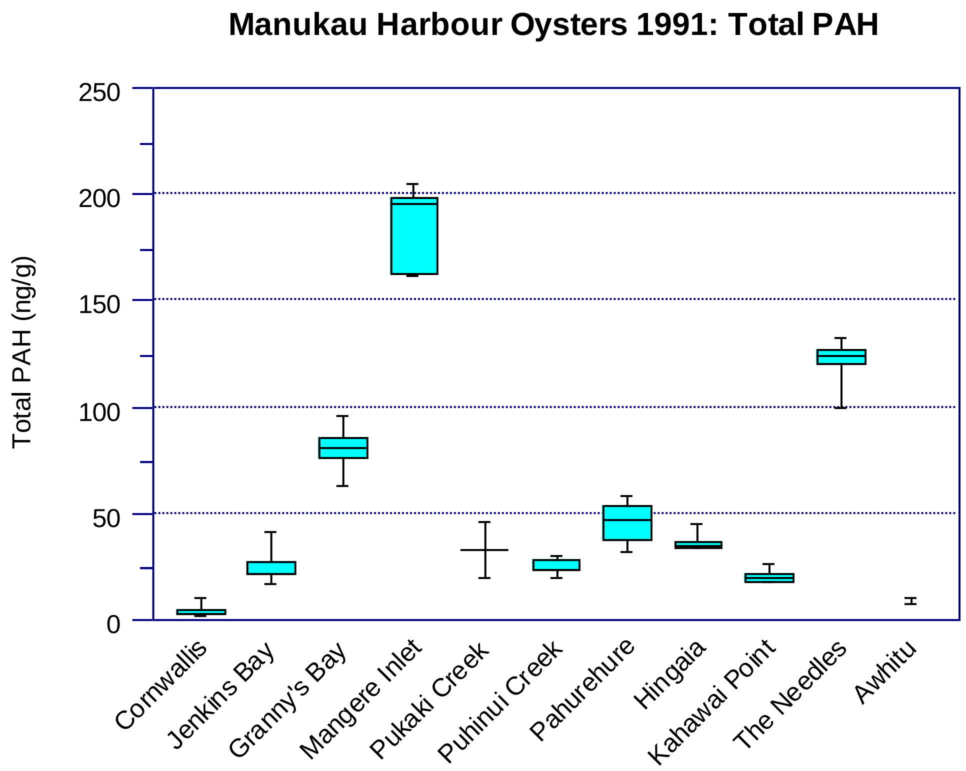


Figure 6-3 PAH concentrations in oysters in the Manukau Harbour. Data are from the 1991 survey (ARC 1993).

6.2.3 Microbial contamination

Faecal coliforms (FC) and enterococci are indicators of faecal contamination, whereas *Vibrio parahaemolyticus* is an opportunistic pathogen that can cause vomiting and diarrhoea.

No Waiuku Estuary oysters had detectable enterococci or *Vibrio* in the 1991 survey. Faecal coliforms were detected at low levels in 2 of the 5 replicates from Kahawai Point, and at higher levels in all 5 replicates from The Needles. The median FC count at The Needles was 26 MPN/100 g, which while fairly low, was the 4th highest of the 11 Manukau Harbour sites in the 1991 survey (Figure 6-4). The 1990 survey (ARC 1992) found no detectable FCs (<20 MPN/100 g) at Kahawai Point or The Needles. In 1988 and 1989, oysters from Awhitu and Kahawai Point had lowest FC levels. FCs were detected at The Needles in 1989 (ARWB 1990; the data for 1988 were not given in the report).

Microbial levels in the environment can be highly variable, particularly in response to rainfall and associated runoff events. The sampling undertaken in the Manukau shellfish quality surveys was done during dry weather conditions, so this should not have been a major influence.

The data, while variable, suggested that microbial levels at Awhitu and Kahawai Point at that time were low, while those further up the estuary at The Needles were (on occasion at least) higher. This is consistent with the greater influence from contaminant sources (wastewater treatment plant discharge, urban runoff, and rural catchment inflows) nearer to the estuary headwaters.

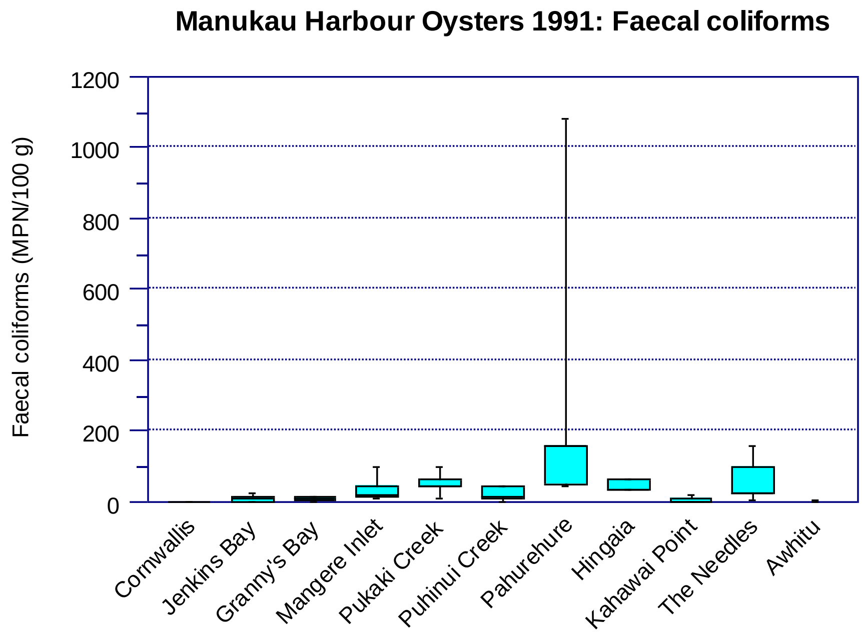


Figure 6-4 Faecal coliforms in oysters in the Manukau Harbour. Data are from the 1991 survey (ARC 1993).

6.2.4 Summary of 1987–1991 Manukau Harbour shellfish quality surveys

The Manukau Harbour surveys showed that the concentrations of metals, organic contaminants, and pathogenic microorganisms in oysters from the Waiuku Estuary were generally low compared with the more heavily urbanised harbour locations. The Awhitu site generally had the lowest contaminant levels of any of the harbour sites.

The only contaminants to stand out in the Waiuku Estuary were PAHs, which were markedly elevated at The Needles. Zinc was slightly elevated at The Needles and Kahawai Point, comparable with the more urbanised/industrial harbour sites such as Hingaia and Pahurehure.

It is considered likely that discharges and runoff from the NZ Steel site are major contributors to these elevated PAH and Zn levels.

6.3 NZ Steel monitoring

6.3.1 Outline of monitoring

Background information and summary information on the overall effect of the NZ Steel discharge is provided in section 9.0. A component of the NZ Steel discharge consents monitoring programme requires monitoring of oysters within and adjacent to the mixing zones of the Northside and Southside discharges. Sampling for metals and condition analyses are undertaken every year and reported in the consent monitoring reports (see Bioresearches 2012 and references therein). Oyster densities are also assessed.

Five sites are sampled (Figure 6-5):

- Site N6 (and N6a) approximately 50 m from Northside outfall
- Site N5 approximately 350 m south of Northside outfall
- Site N10 approximately 500 m north of Northside outfall
- Site S3 approximately 20 m from Southside outfall
- Site S5 (and S5a) approximately 350 m south of Southside outfall

Sites N6, N5, and S3 are within the mixing zones of the Northside and Southside outfalls respectively. Sites N10 and S5 are on the mixing zone boundaries (Simon West, Bioresearches, pers. comm.).

A “control” site in the lower Taihiki Estuary is also monitored.

Each year, the monitoring data are reported and commentary made on changes in Zn and Cu concentrations (including compliance with moving average wet weight concentration criteria), and changes in oyster size, condition, and density.

A summary of key features of the monitoring data are given below. Comparisons of the NZ Steel monitoring data with Manukau Harbour Shellfish Contaminant Monitoring Programme (SCMP) data are also made to put the NZ Steel information into a broader spatial context. For these comparisons, a sub-set of the data, covering the period 2009–2011 only (the period for which the SCMP data were summarised in Stewart et al. 2013) were used.

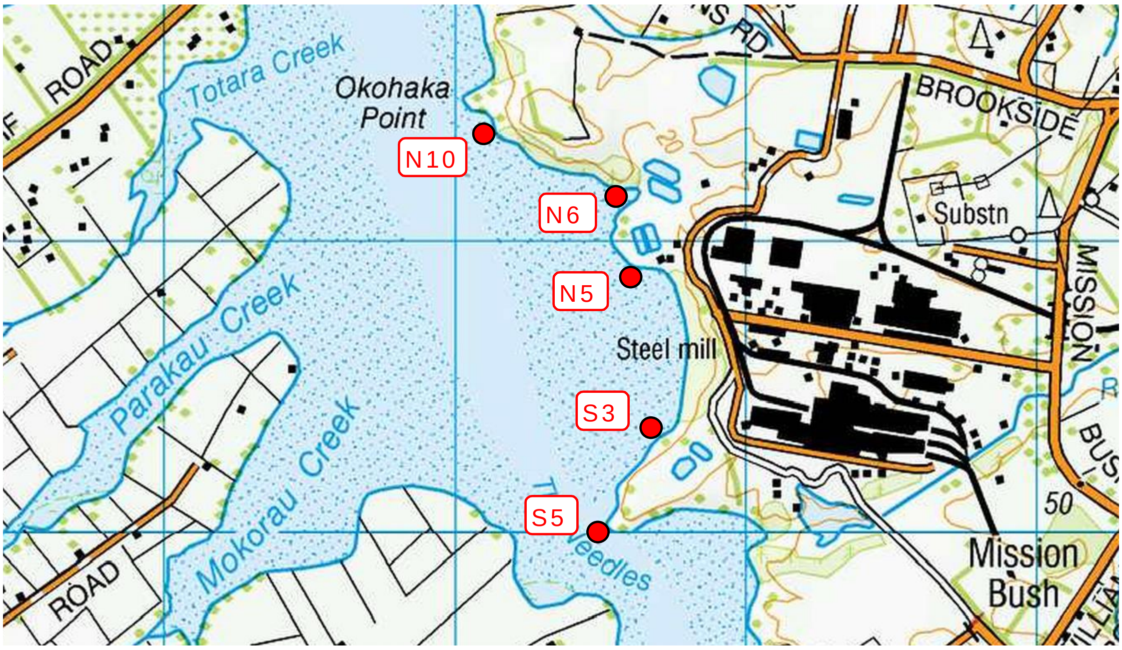


Figure 6-5 NZ Steel oyster monitoring site locations

6.3.2 Changes in oyster density over time

There have been some major changes in oyster density since monitoring began in 1985. These are detailed in the most recent survey monitoring report (Bioresearches 2012), and are as follows:

- The density of oysters at Southside 5 declined steadily from 1987, most likely as a result of habitat change caused by colonisation and proliferation of mangroves seawards of the site.
- Densities at Southside 3 have fluctuated over the 26 year period, with the density in 2011 being the lowest recorded.
- At Northside 5 the density of oysters peaked in May 1990 and decreased to a low in May 1995, recovered slightly and then decreased to the current and lowest density.
- The density of oysters at Northside 6 has declined steadily since 1988. The lowest density was recorded in 2009, after which the site was moved.
- The density of oysters at Northside 10 declined between 1992 and 1995 and had recovered to densities similar to pre 1993 by 1997. Since 1997 the density of oysters at this station fluctuated but remained much the same, until 2011 when the density decreased markedly to a new minimum. Numbers recovered slightly in 2012.

The density of oysters at the Taihiki Control has been variable, with a maximum in 1987 of 95 oysters per 0.25 square metres and a steady decrease in density to the 1993 minimum of 6 oysters per 0.25 square metres. Density remained low with a maximum of 18 per 0.25 square metres between 1993 and 1999. The density of oysters had increased to 33 per square metre in 2000, the highest recorded since 1991. Since 2005 the density has decreased to almost zero.

According to Bioresearches (2012), mud deposition, much of it from the adjacent farm land, appears to have been a major contributing factor to the decrease in density. In addition, oyster populations in the Manukau Harbour and other areas of northern New Zealand suffered from the effects of a naturally introduced oyster virus between 2010 and 2011. This has resulted in significant mortality, contributing to a reduction in the density of oyster populations. In 2012 the density was still low at the Taihiki Control Station.

Overall, therefore, oyster densities have generally decreased over time at the sites monitored in the NZ Steel programme, including the Taihiki control site. Sediment deposition, mangrove encroachment, and the oyster virus have been implicated as causative factors in the observed declines.

6.3.3 Oyster condition – spatial patterns

The condition of the oysters in the NZ Steel monitoring are compared with the Auckland Council Manukau Harbour SCMP data in Figure 6-6. The data cover the period 2009–2011 only (the period for which the SCMP data were summarised in Stewart et al. 2013).

This comparison indicates that the oysters at the NZ Steel sites vary in condition, with site S3 being generally lowest, and N10 the best. The Taihiki control site has the highest median condition. Condition appears to improve with distance from the Northside outfall (N6 to N10, and to a lesser degree, N6 to N5), and also slightly for the Southside outfall (S3 to S5).

Compared with the Manukau Harbour SCMP sites, all NZ Steel sites are better than the “worst” Manukau site (Granny’s Bay), and apart from S3 are comparable or better than the “best” SCMP site (Cornwallis).

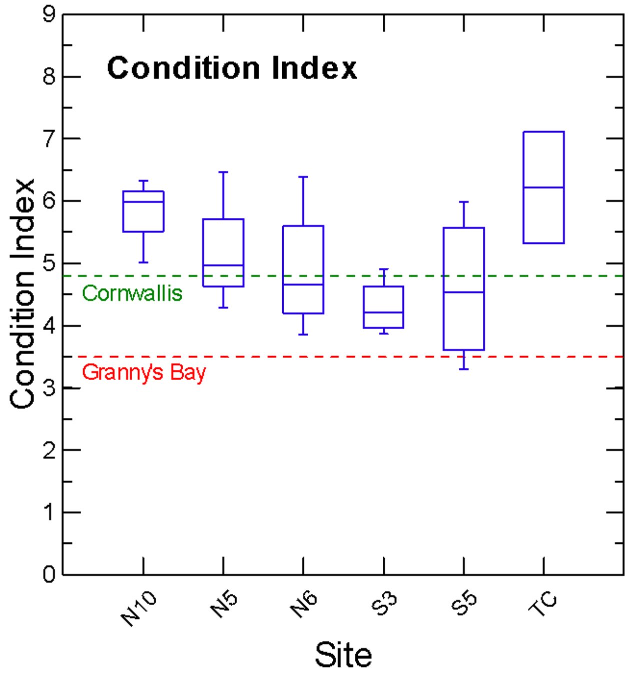


Figure 6-6 Oyster condition at NZ Steel monitoring sites compared with the worst (Granny’s Bay) and best (Cornwallis) sites in the AC Manukau Harbour shellfish contaminant monitoring programme (SCMP). Data are for the 2009–11 period. SCMP condition index values are estimates from visual inspection of Figure 4-1 of Stewart et al. (2013).

6.3.4 Trends in oyster condition

Oyster condition varied considerably from year to year. Trend plots of annual mean condition indices for all sites for the period 1985 to 2011 are shown in Figure 6-7.

Trend analysis (using the Mann Kendall trend test) showed that the overall trend in condition has been a decrease (between -0.2% and -1.4% per year), although these changes are only significant at sites N10 and N5 ($p \leq 0.05$). Mann Kendall trend test results are shown Figure 6-12.

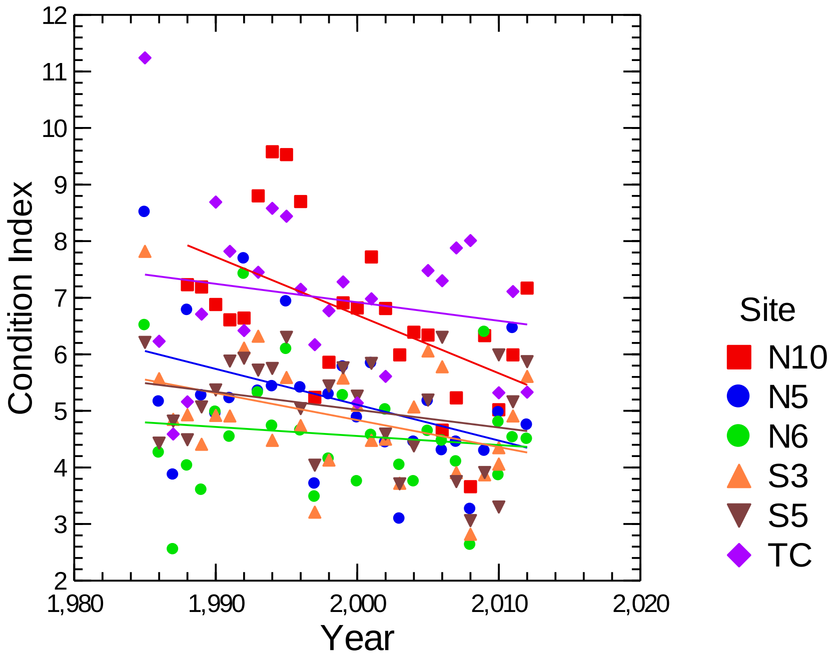


Figure 6-7 Trends in condition at NZ Steel monitoring sites. "TC" is the Taihiki control site.

6.3.5 Spatial patterns in metals

All sites around the NZ Steel outfalls had higher Zn and Cu than the Taihiki Estuary control site.

Zinc concentrations show a decreasing concentration gradient with distance from the Northside outfall (N6 to N10 and N5). Zn is markedly higher at site N6 (and from 2010 at N6a, which is included in the plots in Figure 6-8 as N6). Site N5 concentrations are lower, and Site N10 is the lowest of the NZ Steel monitoring sites.

The Southside outfall is not having as great an effect as the Northside outfall, with oysters at S3 having lower Zn concentrations than at N6.

Copper effects are not so great as those observed for Zn. Copper concentrations were generally similar at N5, N6, S3 (possibly the highest), and S5, which were all higher than at N10.

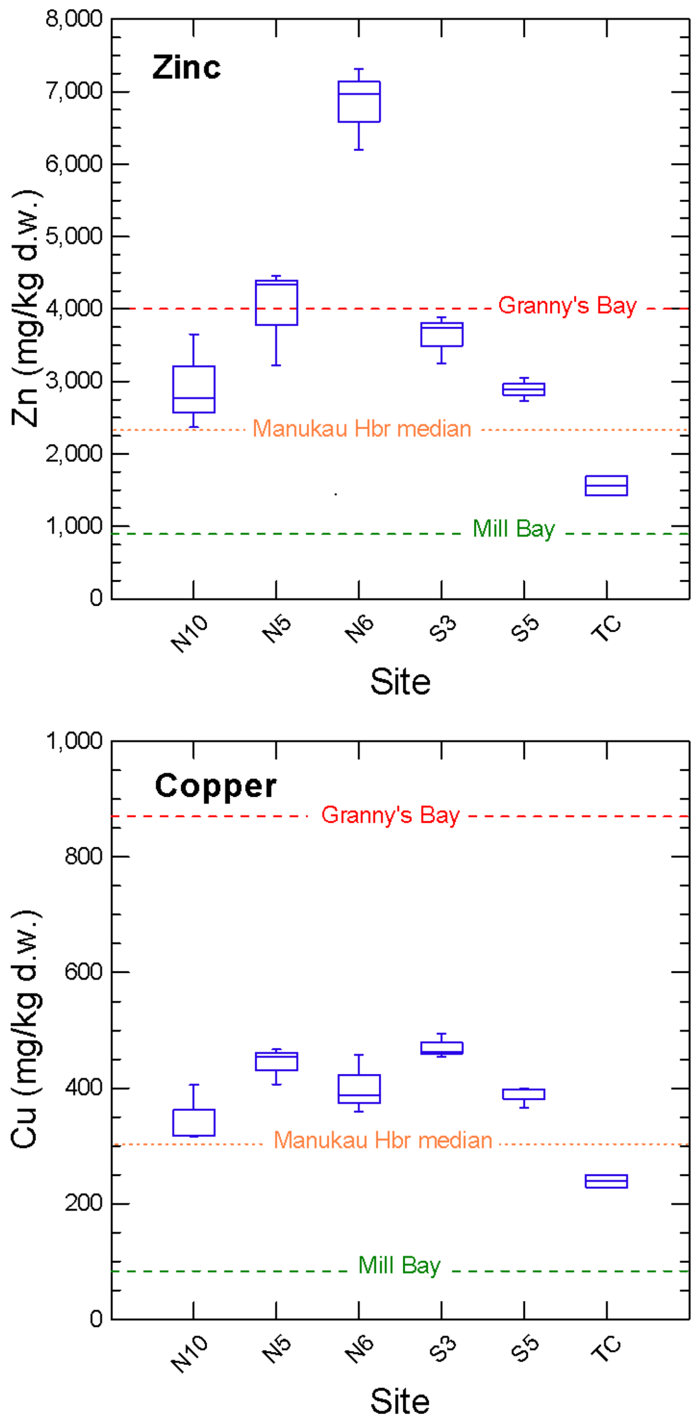


Figure 6-8 Copper and zinc concentrations in oysters at NZ Steel monitoring sites compared with the worst (Granny's Bay) and best (Mill Bay) sites in the AC Manukau Harbour shellfish contaminant monitoring programme (SCMP). Data are for the 2009–11 period. SCMP values are from Table 6-1 of Stewart et al. (2013).

Compared with Manukau Harbour SCMP data, Zn concentrations at N6 were markedly higher than the highest SCMP site (Granny's Bay). Sites N5 and S3 were comparable with Granny's Bay, and all sites were above the SCMP "Manukau median". The Taihiki control site had Zn levels that were higher than those measured at Mill Bay, the lowest site in the SCMP.

Copper concentrations at the NZ Steel sites were higher than the SCMP “Manukau median” level, but were much lower than the highest concentrations (Granny’s Bay).

Zinc had higher enrichment factors (relative to concentrations at the control site) than Cu (Figure 6-9). Enrichment factors for Zn were approximately 2 to 5 times the Taihiki Estuary control, and approximately 1.5 to 2.6 for Cu; i.e. Zn concentrations were up to 5 times higher due to the outfall (Northside) and Cu up to 2.6 times higher. Site N6, closest to the Northside outfall, was clearly enriched with Zn (relative to Cu), as shown in Figure 6-10.

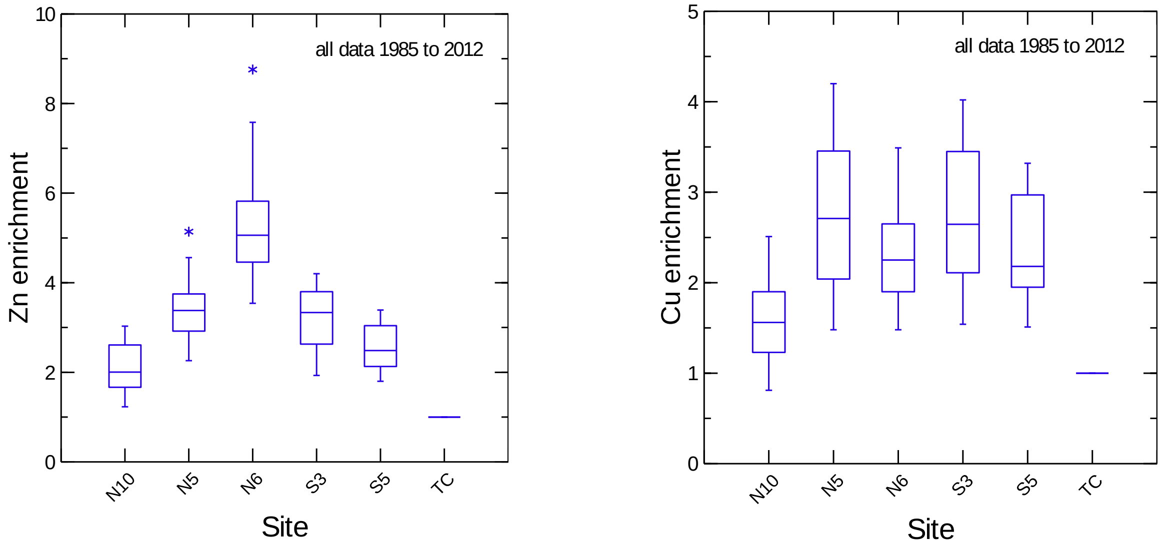


Figure 6-9 Zinc and copper enrichment at NZ Steel monitoring sites relative to the Taihiki control site.

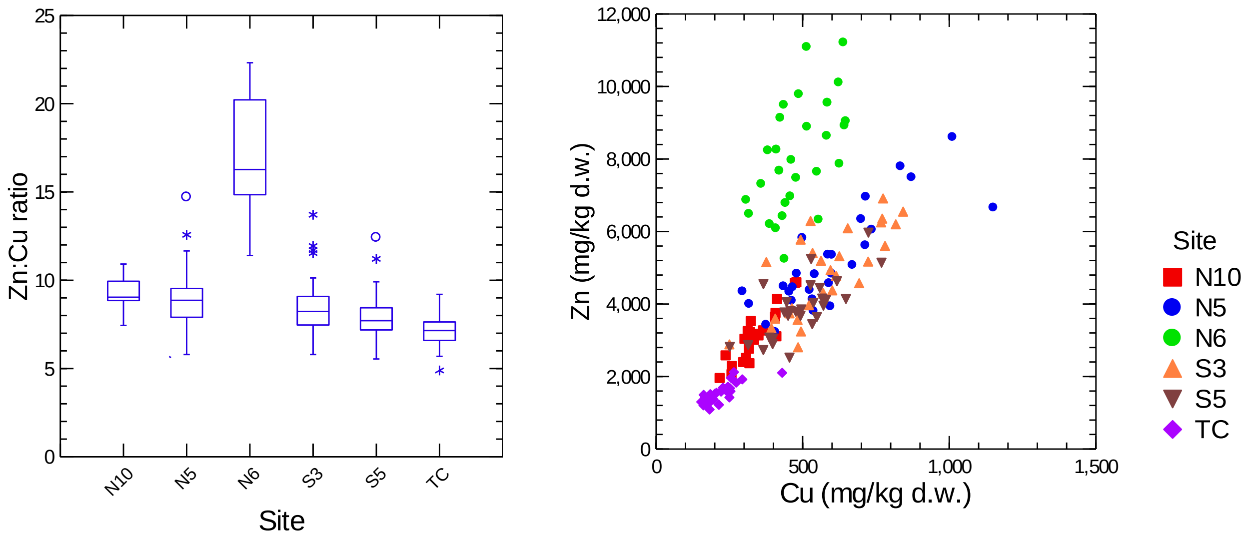


Figure 6-10 Zinc to copper ratios in oysters at NZ Steel monitoring sites, showing the distinctly different ratios for site N6.

Overall, the NZ Steel discharges are having a clear effect on oyster Zn and Cu concentrations. The greatest effect is for Zn near the Northside outfall. The effects are localised, but Zn concentrations at site N10 (which is 500 m from the outfall) are still approximately double those in Taihiki control site oysters. Zn concentrations at the site closest to the Northside outfall (N6) are higher than any sites monitored in the Manukau Harbour SCMP, and at N5 (ca. 350 m south of the outfall) they are as high as the highest SCMP site (Granny's Bay).

6.3.6 Trends over time in metals

Concentrations of Zn over the entire monitoring record (1985 to 2012) are decreasing at the NZ Steel sites, although the trends are only significant at sites S3 and S5 (Mann Kendall trend test, $p<0.05$). Trend plots are shown in Figure 6-11, and the trends summarised for two periods (1985–2012, and 1999–2011, the latter to enable direct comparison with Auckland Council SCMP data reported by Stewart et al. 2013) in Figure 6-12.

Concentrations of Cu decreased by -0.2% to -0.8% per year over the full duration of monitoring (1985–2012), the largest decrease being for the Taihiki control site. Between 1999 and 2011, Cu decreased by between -0.1% and -3.3% per year (at S5). Generally therefore, even if not statistically significant, Cu concentrations appear to be decreasing slowly over time.

Zinc concentrations have decreased by -0.6% (at Taihiki) to -1.8% per year (at S3) over the 1985–2012 period. For the 1999–2011 period, trends ranged from -2.3% per year (at S5) to +0.4% per year (at N6) – none of these changes for the 1999–2011 period were significant.

While somewhat variable, and with differences observed between assessment periods, these trend data indicate that Cu and Zn concentrations in oysters are not increasing over time.

A comparison of trends in the NZ Steel oysters and Manukau Harbour SCMP results is given in Table 6-1. This comparison shows that few of the trends in either programme were statistically significant. Over the long term data record (1985/7–2011), the two monitoring programmes have recorded similar results – trends in Cu were decreases, as were most Zn results (the exception being a non-significant or small increase at Cornwallis in the SCMP).

Over the shorter data period (1999-2011), the comparisons were mixed. For Cu, increases were recorded at 2 sites in the SCMP, while all the NZ Steel trends were decreases. For Zn, increases were recorded at all SCMP sites, while a mix of increases (2 sites) and decreases (4 sites) were recorded at the NZ Steel sites (none of which were significant). Mixed results might be expected to occur more frequently for a shorter data record, because the effects of episodic events would make a greater difference to the overall trend.

Overall, the trend results suggest that changes over time have been relatively small, and data variability is high. At the NZ Steel sites, trends have generally been small decreases (although not necessarily statistically significant).

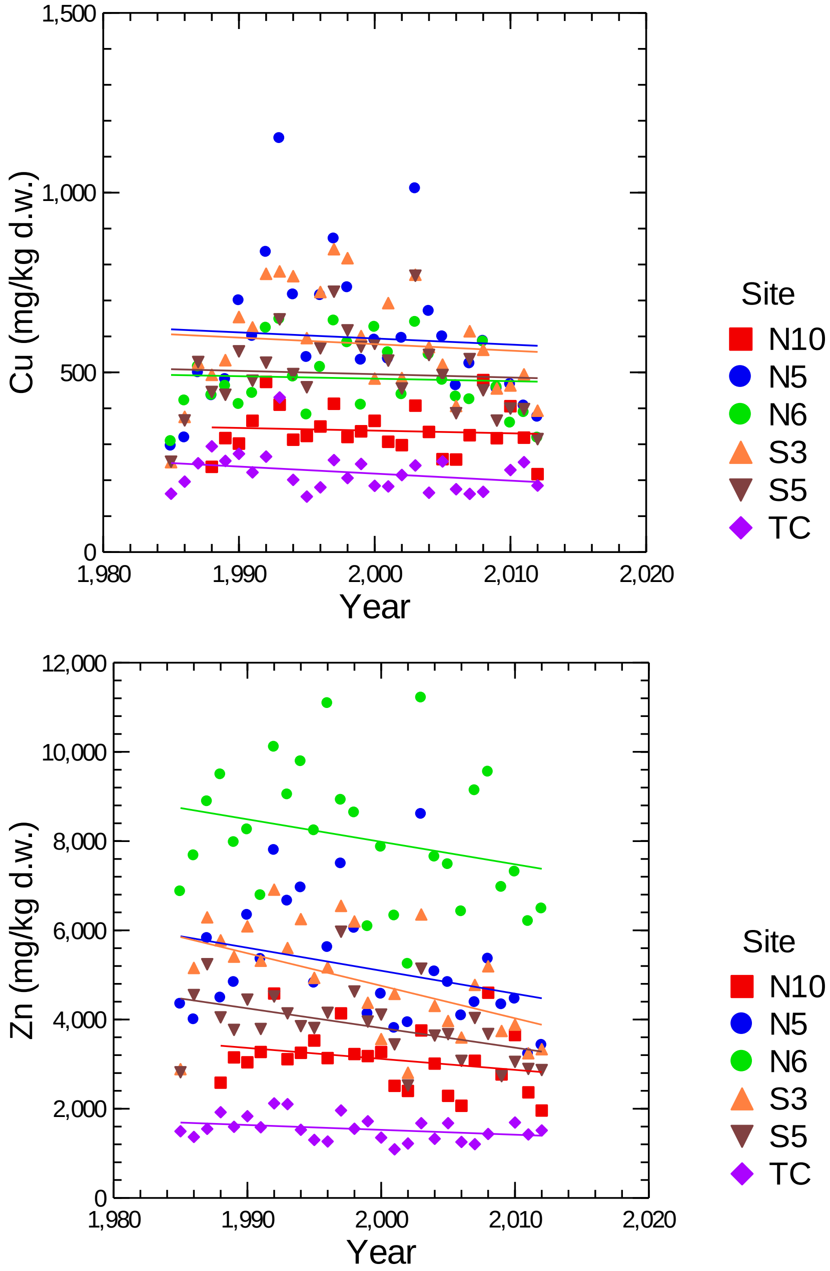
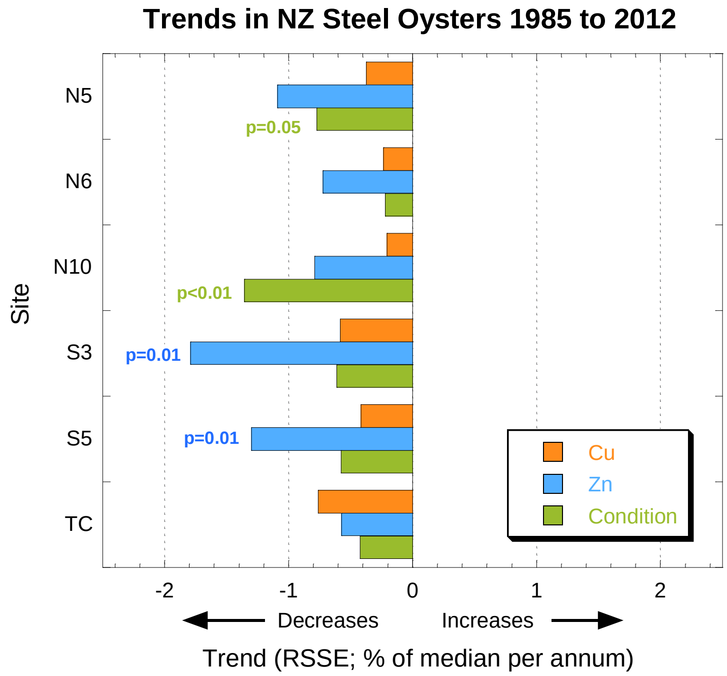


Figure 6-11 Trends in copper and zinc concentrations in oysters at NZ Steel monitoring sites between 1985 and 2011. Data are annual means, as tabulated in Bioresearches (2012).



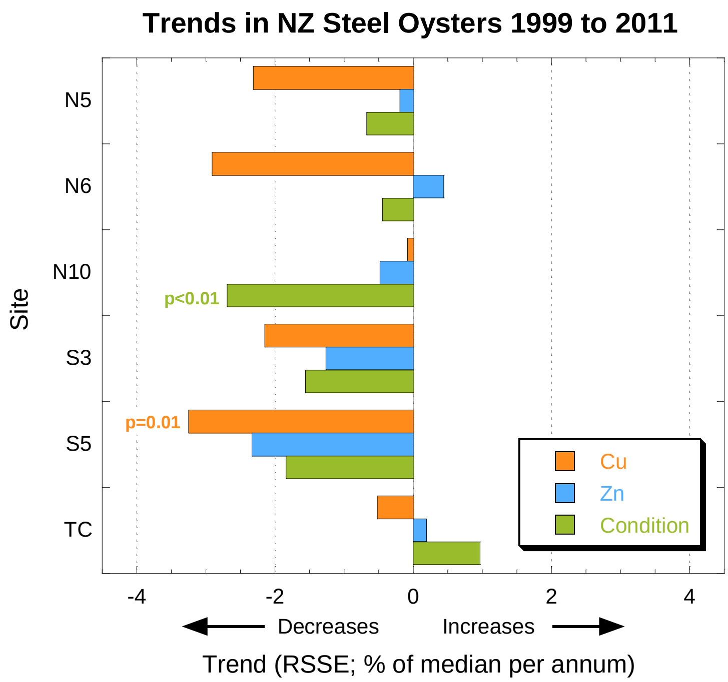


Figure 6-12 Trends, expressed as “Relative Sen Slope Estimators” (RSSE, % of median values per year), for Cu, Zn, and condition in oysters at NZ Steel monitoring sites. “TC” is Taihiki control site. Trend significance is shown above the bars (no values indicate trends are not significant; $p>0.05$).

Table 6-1 Comparison of trends in copper and zinc in oysters at NZ Steel and Manukau Harbour SCMP sites. SCMP trend results were taken from Tables 6-2 and 6-3 of Stewart et al. (2013).

Programme	Site	Copper		Zinc	
		1985/7 – 2011/12	1999-2011	1985/7 – 2011/12	1999-2011
Manukau Hbr SCMP	Grannys Bay	↓	↑	↓	↑
	Pahurehure	↓	↑	↓	↑
	Hingaia	↓	↓	↓	↑
	Cornwallis	↓	↓	↑	↑
NZ Steel	N5	↓	↓	↓	↓
	N6	↓	↓	↓	↑
	N10	↓	↓	↓	↓
	S3	↓	↓	↓	↓
	S5	↓	↓	↓	↓
	TC	↓	↓	↓	↑

↑	significant increase (p<0.05 and >1% per annum)
↓	significant decrease (p<0.05 and >1% per annum)
unshaded	trends not significant (p<0.05) OR not "meaningful" (<1% per annum)

6.4 Shellfish microbiological quality

6.4.1 Manukau Harbour shellfish quality surveys 1987–1991

Shellfish microbiological quality was monitored in the Manukau Harbour Shellfish Quality Survey between 1987 and 1991. A summary of findings was given in section 6.2.3. Generally, the levels of microbial pathogens at Awhitu and Kahawai Point were very low, while those further up the estuary at The Needles were (on occasion) higher; for example in the November 1991 survey, the median faecal coliform concentrations in oysters from the Needles was 26 MPN/100 g (individual samples 4–158 MPN/100 g), compared with Awhitu and Kahawai Point which had medians of zero (range for individual samples of 0–19 MPN/100 g). This is consistent with the greater influence from contaminant sources (wastewater treatment plant discharge, urban runoff, and rural catchment inflows) nearer to the estuary headwaters.

6.4.2 Waiuku WWTP surveys in 2000 and 2007

Background information and summary information on the overall effect of the Waiuku WWTP is provided in section 10.1. In February 2000, Pacific oysters from a site 500 m upstream of the discharge (adjacent to the southern end of the treatment plant property) and 1000 m downstream (at the Needles) were taken and analysed for faecal coliforms (Bioresearches 2000). Five replicates, each comprising 12 individuals were sampled, the MoH (1995) protocol. Results are summarised in Table 6-2.

Table 6-2 Faecal coliforms (cfu/100 g) in oysters from the Waiuku Estuary, taken 500 m upstream and 1000 m downstream (The Needles) of the Waiuku WWTP discharge in February 2000 (data taken from Bioresearches 2000).

	Replicate					
Site	1	2	3	4	5	Median
Upstream 500 m	170	300	170	300	110	170
Downstream 1000 m (at Needles)	40	20	80	80	70	70

The MoH (1995) criteria operative at that time[7] classed raw shellfish as being acceptable for human consumption if the faecal coliforms count was <230 cfu/100 g[8]. If more than 2 of the 5 replicate samples exceeded 230 cfu/100 g, then shellfish from that site were considered unacceptable for human consumption. No samples were considered acceptable if any replicate exceeded 330 cfu/100 g.

Base on the MoH (1995) criteria, the oysters from the Needles (1000 m downstream of the discharge) were acceptable, but those from the upstream site were probably marginal (2 replicates >230 cfu/100 g, but no single sample >330 cfu/100 g).

At the time of sampling, the discharge of treated effluent did not appear to adversely affect the bacteriological quality of the oysters at The Needles. The results from the upstream site suggest microbiological quality in the upper estuary is likely to be marginal for shellfish gathering purposes. This is consistent with limited microbiological water quality data collected to date in the Auckland Council saline water quality monitoring programme, as summarised in section 4.4.2 (the Waiuku Town Basin site is in the same general location as the upstream oyster sampling site).

Bioresearches (2007b) reported the results of a survey conducted in March 2007, in which oysters were sampled from upstream of the discharge, below the discharge (at the Needles, Okohaka Point, and Kahawai Point), and in the Taihiki Estuary (Figure 6-13). The sampling was undertaken after a period of heavy rainfall, and this may have affected the results (due to catchment runoff).

1.0

[7] Shellfish suitability for human consumption is now assessed using *E. coli* (FSANZ 2002).

[8] Note that no units are specified in the MoH (1995) criteria (given as bacterial “numbers” per 100 g). Survey data has been given in units of MPN/100 g (Bioresearches 2000) and cfu/100 g (Bioresearches 2007b). The comparability of results expressed in these different units is not clear. This uncertainty applies to microbiological surveys generally, not just these examples.

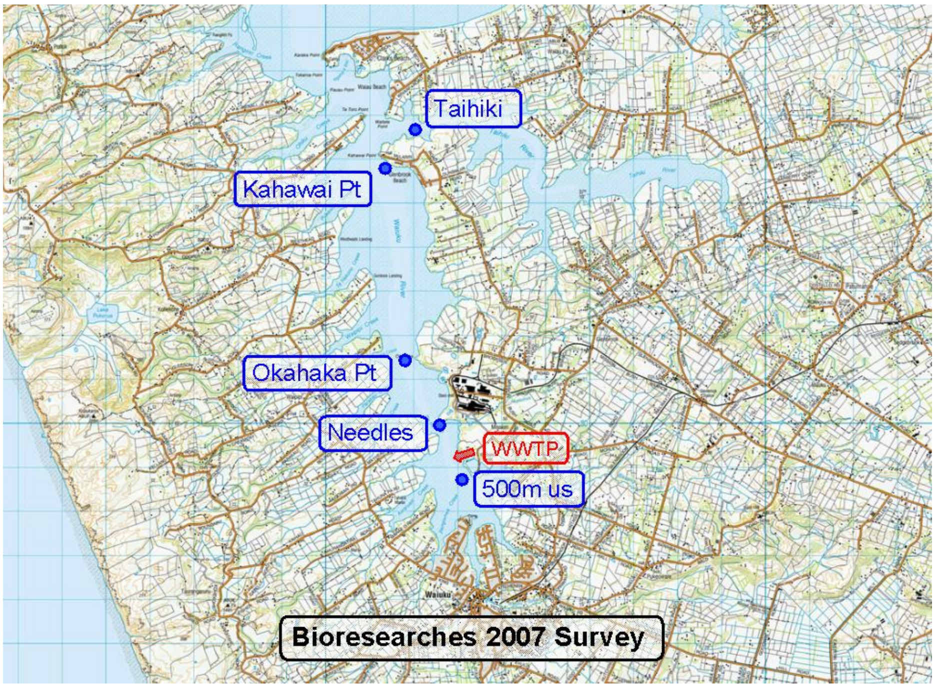


Figure 6-13 Sampling locations for Bioresearches (2007b) shellfish microbiological quality survey.

Faecal coliform numbers in all shellfish samples were elevated, including those from the Taihiki River (Table 6-3). The highest median faecal coliform count from shellfish occurred in the shellfish samples from the Needles, which was the closest sampling station northward of the discharge point (approximately 1000 m). Faecal coliform numbers in shellfish from both Okohaka Point and from Kahawai Point were also elevated above those found in shellfish from the upstream sampling station and the Taihiki River sampling station.

Bioresearches (2007b) concluded that while the rainfall prior to sampling may have resulted in increased bacteriological contamination of oysters throughout the Waiuku Estuary, the wastewater treatment plant discharge may also have been adversely affecting bacterial numbers in nearby natural shellfish populations. Based on comparisons of the MoH (1995) criteria for faecal coliform bacteria in unprocessed shellfish, none of the sampling stations would have been considered safe for human consumption at the time of sampling.

Table 6-3 Faecal coliforms (MPN/100 g) in oysters from the Waiuku Estuary upstream and downstream of the Waiuku WWTP discharge, and in the Taihiki Estuary (data taken from Bioresearches 2007b).

		Replicate					
Site	Distance (km)	A	B	C	D	E	Median
Upstream	0.5 u/s	800	800	800	1100	1300	800
Needles	1	8000	8000	8000	8000	13000	8000
Okohaka Point	2.5	230	1300	300	1700	1700	1300
Kahawai Point	7	1700	2200	1300	1300	8000	1700
Taihiki Estuary	n/a	220	300	500	300	230	300

6.5 Shellfish quality summary

Shellfish (Pacific oysters) quality has been monitored in the Waiuku Estuary since the mid-1980s in two programmes, and smaller "one off" investigations associated with the Waiuku WWTP discharge:

- The Manukau Harbour Shellfish Quality Survey, at 3 sites for 5 years. Heavy metals, persistent organic contaminants, and three indicator bacteria were measured on samples taken on one occasion each year;
- The NZ Steel Northside and Southside outfalls monitoring programme. Five sites within and outside the discharges' mixing zones, and one control site in the Taihiki Estuary, were sampled annually since 1985. Oyster density, length, condition, Cu, and Zn were measured.
- Sampling for faecal coliforms in oysters above and below the Waiuku WWTP discharge point in two surveys conducted in 2000 and 2007, to assess receiving water environmental effects.

These programmes have provided information on chemical contaminant concentrations (metals, organic contaminants), trends (for metals and condition), and microbiological quality.

In summary:

- Status: Fairly well characterised in terms of chemical contaminant levels. Organic contaminant concentrations are generally low, except for PAH at one site (Needles) close to the NZ Steel site. Metals' concentrations are low-to-moderate compared with wider Manukau Harbour, except for Zn around the NZ Steel outfalls (especially the Northside outfall). Microbiological status is not as well defined – there are no routine monitoring data, the very limited data are not definitive, but indicate general microbiological quality in upper estuary is probably poor and that the Waiuku WWTP might have some impact on shellfish microbiological quality.
- Trends: Very good data exist from NZ Steel discharge consent monitoring for Cu and Zn (and shellfish condition). No major changes are apparent from the data, although concentrations are possibly decreasing slowly over time. No trend data exist for organic contaminants, although it is likely that concentrations of legacy pesticides and PCBs will be decreasing.
- Gaps and opportunities: Microbiological status and health risks for human consumers of shellfish, especially within the estuary. Incremental health risks (over and above the general background contamination from diffuse sources) associated with the Waiuku WWTP discharge. Update data for PAH in oysters at Needles (or equivalent NZ Steel monitoring site). Sedimentation rates and effects of sedimentation and mangrove encroachment on shellfish abundance, densities, and condition (not just Pacific oysters, but other species as well). A better understanding of estuary hydrodynamics would be useful to help assess the fate and consequence of both diffuse and point-source discharges into the estuary.

7.0 Aquatic ecology

7.1 Information sources

The ecology of the Waiuku Estuary seems to be understood in general terms, and its characteristics qualitatively described in various resource consent documents (e.g. Tonkin and Taylor 2012), management plans (e.g. Fraser Thomas 2008; Tonkin & Taylor 2006), and broader information reviews (e.g. the very comprehensive Manukau Harbour review by Kelly 2009).

No detailed technical investigation reports or reviews (of the type conducted in many other estuaries in the Auckland region, e.g. Puhoi, Waiwera, Upper Waitemata Harbour, Whangateau, Mahurangi etc) for the Waiuku Estuary were found for this review. It is possible that the ecological review conducted by Wildlands (2005) for the Waiuku Coastal Compartment Plan (Tonkin & Taylor 2006) contains detailed ecological information, but this document was not able to be sourced at the time of reporting. The following ecological summary is therefore limited to a broad overview.

Extremely detailed, long term ecological monitoring data exists for the Manukau Harbour, including a site off Clarks Beach – site “CB” is one of the key “anchor” sites in the Manukau Harbour ecology programme. Monitoring data has been thoroughly reviewed and interpreted in terms of trends over time, relationships between ecological characteristics and key environmental variables/influences (e.g. the Mangere sewage treatment plant discharges and upgrades, and natural variables such as longer term climate changes such as the El Nino Southern Oscillation). A summary of key findings is given in Kelly (2009, and references therein). The CB site information is not considered directly relevant to this Waiuku Estuary review because of the very different ecological and physical character of the Clarks Beach ecology site, which is situated on expansive intertidal sand flats rather than in an enclosed, channelized, often muddy, side arm estuary.

7.2 Benthic ecology

Benthic biological communities are dominated by mud snails (*Amphibola crenata*) within mangrove areas, large numbers of cockles (*Austrovenus stutchburyi*) in sandy mid-tide habitats, and abundant crabs and shrimps lower on the shoreline. Pacific oysters (*Crassostrea gigas*) are well established with numerous localised clumps present along the coastline. In this sense, the Waiuku Estuary is typical of many muddy tidal estuaries in the Auckland region.

Benthic ecology sampling and analysis, using the Auckland Council monitoring protocol, has been undertaken at the Waiuku RSCMP site (along with the sediment chemistry sampling, in November 2012 – see section 5.1.3), and also at the most impacted NZ Steel mill Northside sediment sampling site, with the latest sampling in 2011 (see section 5.1.1).

The ecological data from these sites has been entered into the Auckland Council Benthic Health Model (BHM) to produce “scores” or “grades” that provide an overall assessment of ecological health. The BHM incorporates two scores – one that relates to the effects of metal contaminants (the “CAPmetal” score) and (a more recent addition) one that relates to the effects of sediment muddiness (the “CAPmud” score). There are 5 groups, ranging from Group1 which is ecologically healthy, to Group 5, which has the most heavily impacted and degraded fauna.

The Waiuku RSCMP site sampled in 2012 had a CAPmetal score of 0.080, which put it into "Group 4", which indicates a degraded faunal composition. The CAPmud score was 0.128, which put it into the mud Group 5, the most impacted range. The overall rating for the site was "unhealthy with low resilience", the poorest ecological grade. The metals' concentrations at the Waiuku site are not particularly elevated (falling into the ERC-Green range – see section 5.2), but the site is very muddy (92% <63 µm). Presumably the very poor ecological health at this site is therefore strongly related to muddiness and the associated impacts of increased sedimentation.

The NZ Steel, Northside A (NA) site sampled in 2011, obtained a CAPmetal score of 0.106, which was ranked as 4, which is indicative of degraded ecological condition (Bioresearches 2011). The CAPmud analysis was not available at the time of the NZ Steel assessment in 2011.

In contrast to these impacted muddy sites, the Clarks Beach site in the main body of the Manukau Harbour has the highest benthic biodiversity (38 species) of the sites monitored in the harbour ecological programme. The benthic health grading for this site in 2012 was "good", which is the second best ecological health rating (CAPmetals score -0.089, group 2, and CAPmud score 0.100, group 2).

7.3 Fish

Surveys of fish use of intertidal to low tide sand and mudflats conducted by NIWA and summarised in Kelly (2009) indicated that southern side-branches of the Manukau Harbour tended to have more fish species per site than central or northern parts of the harbour. Fish diversity was greatest in the Waiuku River estuary (8 to 12 species), with the highest number of species being obtained from the upper reaches of the Taihiki Estuary.

Similarly, greater numbers of fish were caught in side-branches of the harbour. Waiuku River (including Taihiki Creek) had the highest counts of anchovy, exquisite goby, garfish, mottled triplefin, grey mullet, estuarine triplefin, red gurnard, smelt, and speckled sole.

The Waiuku and Taihiki estuaries are therefore highly valuable habitats for the overall health of fish stocks in Manukau.

7.4 Mangroves

One of the most widely distributed and conspicuous coastal plants in Manukau Harbour is the mangrove *Avicennia marina*. Mangrove proliferation is a relatively recent phenomenon, and has polarised public opinion on their ecological value relative to negative impacts on human uses of affected coastlines. A review by Morrisey et al. (2007) provides an objective assessment of the causes of mangrove expansion, their ecological effects, and management issues associated with their control.

Kelly (2009) provided quantitative information on the extent of mangrove expansion between 1976 and 2006 in the Manukau Harbour, including the Waiuku Estuary. The following discussion and data are excerpts from this report:

Maps produced from 2006 aerial photographs indicated that mangrove cover was most extensive in muddy, sheltered side-branches of the harbour. Few mangroves occurred in the exposed main *body of the Manukau Harbour, and when they did, they invariably occurred in the lee of a physical barrier. Mangrove cover also tended to be more sparse in the wider main channels of Waiuku Creek and Pahurehure Inlet. The total area covered by mangrove forests in 2006 was estimated to be approximately 1100 ha. Waiuku Creek and Pahurehure Inlet had the greatest areas of mangrove cover, reflecting their physical size. Mangrove cover in Manukau Harbour has increased markedly over the past 50 years, with the most substantial increases occurring in the past 30 years – cover in Waiuku and Taihiki Creeks increased from approximately 60 to approximately 274 ha. Overall, since 1976, total mangrove cover in Manukau Harbour has increased from approximately 447 ha to approximately 1100 ha.*

Table 7-1 provides data on mangrove areas in 1976 and 2006 in various areas of the Manukau harbour, including Waiuku/Taihiki estuaries and Awhitu Peninsula (north of the Waiuku Estuary mouth). These data highlight the very large increase in the Waiuku/Taihiki estuaries (357%). It should be noted that the data provided in Table 7-1 are only estimates and that different methods were used to determine the areas in 1976 and 2006. As such the mangrove areas and any associated increases outlined in Table 7-1 should only be viewed as indicative rather than highly accurate or absolute.

Table 7-1 Estimated area covered by mangroves in 1976 and 2006 (tabulated and % changes calculated from data given in Kelly 2009).

	Mangrove Area (ha)		Increase	
Location	1976	2006	ha	%
Big and Little Muddy Creeks	50	57	7	14
Puhinui	30	40	10	33
Other	4	20	16	400
Pukaki	88	136	48	55
Awhitu Peninsula (north of Clarks Beach)	41	91	50	122
Clarks Creek	52	113	61	117
Mangere Inlet	9	97	88	978
Pahurehure	113	272	159	141
Waiuku Creek (including Taihiki)	60	274	214	357
Total	447	1100	653	146

A summary of the mangrove situation in the upper arms of Waiuku Estuary was provided by Fraser Thomas (2008), summarising the ecological review by Wildlands (2005):

Intertidal mangrove scrub and forest is now a dominant ecological community in the upper estuary arms of the Waiuku Inlet. Examination of a series of aerial photographs of the study site taken at different dates from 1969 to 2005 by Wildlands Consultants (2005), show that mangrove colonisation has been a relatively recent occurrence in the upper reaches of the Waiuku estuary. The examination of aerial photographs by Wildlands revealed that there was no evidence of mangroves within the (upper estuary) area in aerial photographs between 1969 and 1975. They did note a stand about 2 km north of the Glenbrook steel mill. They noted that by 1980, scattered *mangrove individuals and small patches of mangroves were evident in the heads of inlets on the western side of the estuary.*

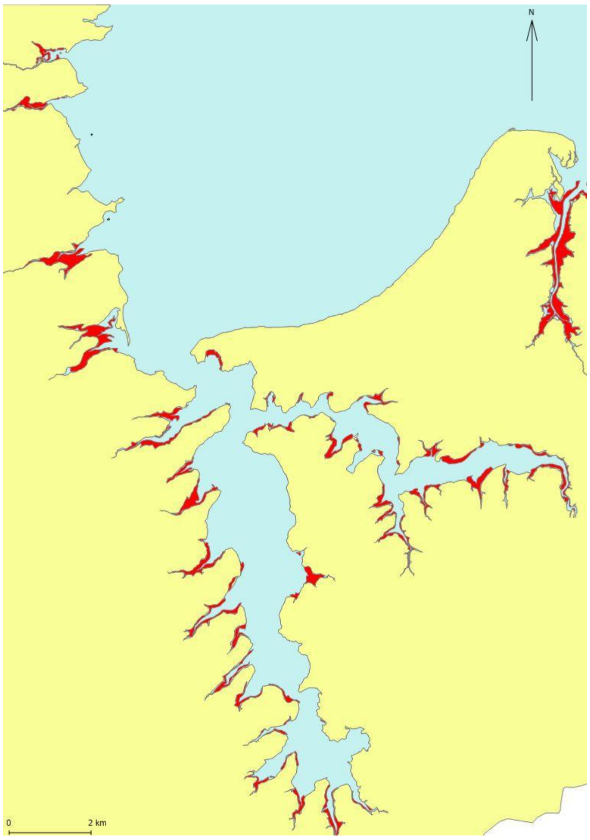
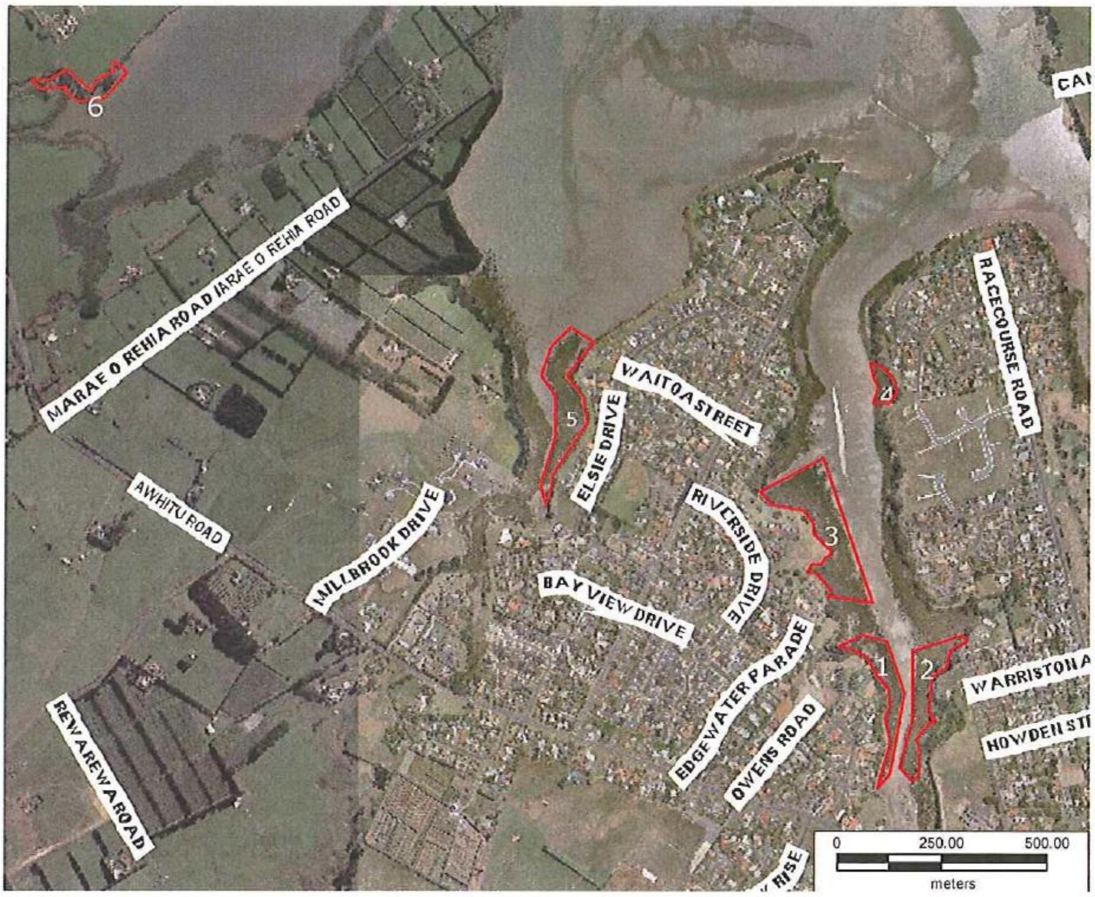


Figure 7-1 Mangrove distribution (in red) in the south west Manukau Harbour from ARC 2006 aerial photos. The Waiuku estuary is the main body running north-south, with the Taihiki estuary branching to the east (figure reproduced from Kelly 2009, Figure 45).

One of the Coastal Compartment Management Plan's visions is to "Manage mangroves using environmentally appropriate and sustainable methods in selected areas where their encroachment has adverse environmental effects".

Consents for mangrove removal from 9.1 ha were granted in 2010 (Auckland Council consent number 37547, removal of coastal vegetation). The areas were adjacent to esplanade reserves at View Rd, Meachen Terrace, Riverside Drive, Harbourcrest Drive, Elsie Drive, Waiuku and Tahuna Pa, and Tahana Pa Rd. Locations are shown in Figure 7-2.

Removals are currently on hold whilst the extent and monitoring of the removal areas is clarified.



MANGROVE REMOVAL SITES

Site 1 – 16540.58m2

Site 2 – 13026.24m2

Site 3 – 28250.28m2

Site 4 – 3315.09m2

Site 5 – 21351.62m2

Site 6 – 8439.77m2

Total – 90,923.58m2

% of total area of mangroves within Waiuku Estuary – 13%

Figure 1 Mangrove removal sites

Figure 7-2 Areas in the upper Waiuku Estuary consented for mangrove removal (Auckland Council Consent 37547 Decision Report, April 2010).

7.5 Summary

In summary:

- Status: The aquatic ecology of the estuary is understood in general terms, being similar in many respects to many other intertidal harbour side arm estuaries around Auckland. There seems to be little detailed quantitative data on benthic ecology, although this information may be available (the Wildlands (2005) review may shed light on this). The quantitative benthic ecology data indicates poor ecological health (at two muddy sites). There is probably good information on fish (in NIWA records), and the mangrove situation is well documented.
- Trends: No known information, apart from the increases in mangrove and pacific oyster cover.
- Gaps and opportunities: Broader spatial coverage of quantitative benthic ecology (including habitats), especially in less muddy/impacted areas susceptible to change from on-going sedimentation – these may be useful to use to track trends, especially as ICMPs or other management tools are instituted. A better understanding of estuary hydrodynamics would be useful to assess the fate and consequence of both diffuse and point-source discharges into the estuary.

8.0 Sedimentation

No quantitative data on sedimentation rates in the estuary were found for this review. According to Tonkin and Taylor (2008), the Waiuku Estuary is experiencing an aging process which includes some natural infilling and sedimentation. Changes in catchment development and land use affect the natural aging process, increasing rates of sedimentation. Anecdotal evidence (Tonkin & Taylor 2008) suggests that the sedimentation of the upper Waiuku Estuary increased rapidly following the reclamation of land by the Waiuku Borough around the 1970s.

In the sheltered inlets sedimentation is probably occurring at a greater rate than in the exposed main basin, where mobilisation and redistribution of sediments occur.

Improvements in land management can reduce the rate of sedimentation by reducing sediment loads to the estuary. One of the key tools for addressing sedimentation rates will be the further development and implementation of Integrated Catchment Management Plans (ICMPs). These can identify sediment sources and determine how to manage them. A draft ICMP for the Waiuku catchment was produced by Fraser Thomas (2008), which was finalised in August 2010. However the final ICMP report was unavailable at the time of carrying out this review.

Auckland Council have commissioned NIWA to undertake Catchment Land Use for Environmental Sustainability (CLUES) modelling as part of its National Policy Statement on Freshwater Management (NPSFM, 2011) Implementation Programme. The work undertaken to date includes preliminary model results for the region for three land use scenarios. The modelling will predict sediment and nutrient annual yields and loads, and nutrient concentrations from rural land uses across the Auckland region for default land use for the year 2002, land use for the year 2008, and Pre-European land use (1770). The report has yet to be finalised, but a set of preliminary load estimates for TSS have been produced, and are summarised in Table 8-1.

For the Waitangi Stream catchment, the TSS specific yield (the amount of sediment lost from a given area of catchment per year; usually expressed as tonnes per square kilometre of catchment area per year) is relatively low compared with the other catchments modelled. At 0.39 t/ha/year, Waitangi ranks as 3rd lowest, slightly higher than Rangitopuni (0.3 t/ha/year) and similar to Kaipara (0.4 t/ha/year). Because of the relatively small catchment area (1808 ha, from the yield and load data given in Table 8-1), the predicted annual sediment load is relatively small (0.705 kt/year).

How this sediment load translates into sediment accumulation in the estuary is currently unknown.

Table 8-1 TSS loads and yields for river catchments calculated using the three land use scenarios (from notes supplied to Auckland Council from Annette Davies, NIWA, 17th June 2013).

Catchment	Pre-Euro 1770		Default 2002		Updated 2008	
	Load (kt/y)	Yield (t/ha/y)	Load (kt/y)	Yield (t/ha/y)	Load (kt/y)	Yield (t/ha/y)
Whangateau estuary	3.6	1.1	7.2	2.2	6.5	2.0
Mahurangi River	1.9	0.3	4.4	0.8	4.5	0.8
Hoteo River	21.2	0.5	44.0	1.1	43.4	1.1
Kaipara River	3.6	0.1	12.3	0.5	11.9	0.4
Rangitopuni River	1.1	0.1	3.2	0.3	3.2	0.3
Brighams Creek	0.2	0.1	0.7	0.3	1.1	0.5
Papakura Stream	0.9	0.2	2.8	0.7	2.8	0.7
Wairoa River	9.5	0.4	22.2	0.9	22.0	0.9
Hingaia stream	1.9	0.3	6.8	1.2	6.6	1.2
Whangamaire River	0.1	0.1	0.5	0.2	0.5	0.2
Waitangi Stream					0.705	0.39

Summary

- Status: Sedimentation has obviously occurred at accelerated rates in sheltered inlets. However, no quantitative data was found for this review.
- Trends: No known data.
- Gaps and opportunities: Quantitative understanding of sedimentation rates throughout the estuary. Quantification of catchment loads (underway for the Waitangi Stream sub-catchment), identification of key sediment sources within the catchment, and development of sediment runoff management strategies. Identification of estuarine areas susceptible to future sedimentation. Monitoring system for tracking sedimentation (and ecological effects) at key sites (important if ICMP or other management tools are put in place). Modelling to determine the fate and deposition of sediments in the estuary from the wider Waiuku catchment to prioritize areas for ecological assessment and to determine effectiveness of any catchment based management action.

9.0 Summary of effects of the NZ Steel discharges

The effects of the NZ Steel Northside and Southside discharges on estuary sediment and shellfish quality were discussed in sections 5.0 and 6.3 respectively.

9.1 Receiving water quality

Water quality effects in the receiving waters are not (to our knowledge) routinely monitored, although the discharges themselves are monitored for TSS, turbidity, metals (Zn, Cu, Cr, Pb, Fe, Ni) and oil and grease. A “Discharge Self Monitoring Report” for the period November 2012 to February 2013 supplied by NZ Steel to Auckland Council showed all parameters were within compliance limits.

9.2 Estuarine sediment quality

Sediment quality in the immediate vicinity of the discharges is slightly impacted, with elevated levels of total Zn (but not extractable Zn in the <63 µm fraction) at the site closest to the Northside outfall (Northside A). The concentrations of metals at the other monitoring sites were similar or lower than those measured at the Waiuku RSCMP site in the upper urban reaches of the estuary, and at the head of the Taihiki Estuary. The Northside A site sediment had a poor benthic ecological health grade (from the BHM). Since 2003, when sediment quality monitoring began, the concentrations of metals in the sediments near the NZ Steel outfalls have decreased.

Overall, the sediment data indicate that impacts from the outfalls are relatively minor and limited to elevated total Zn at one site close (50 m) to the Northside outfall. There is evidence of decreasing metals’ concentrations over time.

9.3 Shellfish quality

The NZ Steel discharges are having a clear effect on Zn and Cu concentrations in oysters. The greatest effect is for Zn at site N6, closet to the Northside outfall. The effects are localised, but Zn concentrations at site N10 (which is 500 m from the outfall) are still approximately double those in Taihiki control site oysters. Zn concentrations at the site closest to the Northside outfall (N6) are higher than any sites monitored in the Manukau Harbour SCMP, and at N5 (ca. 350 m south of the outfall) they are as high as the highest SCMP site (Granny’s Bay).

Oysters at the NZ Steel sites vary in condition, with site S3 being generally lowest, and N10 the best. The Taihiki control site had the highest median condition. Condition appears to improve with distance from the Northside outfall (N6 to N10, and to a lesser degree, N6 to N5), and also slightly for the Southside outfall (S3 to S5). Compared with the Manukau Harbour SCMP sites, all NZ Steel sites have better condition than the “worst” Manukau site (Granny’s Bay), and apart from S3 are comparable or better than the “best” SCMP site (Cornwallis).

Shellfish condition and Zn concentrations have generally decreased over time, but the data are variable and trends are mostly not statistically significant.

Oyster densities have dropped markedly at some sites, requiring relocation of some sites in 2010. The reductions are thought to be due to sedimentation and possibly the effects of the oyster virus.

9.4 Summary

NZ Steel discharges have a marked effect on the concentrations of Zn, and to a lesser degree Cu, in oysters in the estuary, with higher than expected concentrations recorded at 500 m from the Northside outfall (the furthest site monitored). Effects on sediments are far less pronounced and localised, possibly indicating the discharged Zn being in soluble form, and therefore readily bioavailable but not as susceptible to deposition in the sediments. Effects on receiving water metals' concentrations are not directly monitored, but the discharges are (from limited recent data) within consent compliance limits.

10.0 Summary of effects of WWTP discharges

10.1 Waiuku WWTP discharge to Waiuku Estuary

The effects of the Waiuku WWTP discharge on estuary water, sediment and shellfish quality are discussed in more detail in sections 4.0, 5.0 and 6.0 respectively.

10.1.1 Background

The Waiuku WWTP services Waiuku township and domestic flow from the NZ Steel mill. It discharges tertiary treated wastewater into the estuary approximately 3km to the north of the town centre.

The existing discharge permit for the Waiuku WWTP expired on 31st December 2000. In June 2000, an application was lodged to renew this consent, but the new consent has yet to be issued. Our understanding is that it is currently in the final stages of processing. Because of this, the final details of the new consent, or recent treatment plant performance, are uncertain and we have therefore largely relied on the consent supporting information report produced in 2009 for general information (AWT 2009). A comprehensive Assessment of Environmental Effects (AEE) was prepared by Wood (2012) and information from this has also been drawn.

The treatment system comprises two ponds, a primary facultative oxidation pond and a maturation pond, followed by a rock (slag) filter and a UV disinfection system. Treated effluent is retained in a tidal storage pond until it can be discharged into the Waiuku Estuary, only during the first three hours of an ebb tide, via a buried 450 mm piped outlet with no diffuser. Details of the system are provided in AWT (2009).

According to AWT (2009) and Wood (2012), the plant has, historically, been non-compliant with the existing consent conditions for Biological Oxygen Demand (BOD_5), Total Suspended Solids (TSS), ammonia (NH_4-N), and enterococci. Following a review in June 2006, ammonia, total inorganic nitrogen (TIN), and total phosphorus (TP) have been showing consistent improvement, while the BOD and TSS have shown some deterioration.

In reviewing the plant's effluent quality, AWT (2009) concluded that the Waiuku WWTP oxidation ponds were achieving better than the typical 95%-ile quality for such treatment systems for all parameters except nitrate. The plant was considered to be effectively converting ammonia to nitrate, which indicated good plant operation. Because ammonia toxicity is an issue for aquatic life in receiving waters, reduction of ammonia (at the expense of increasing nitrate) was seen as advantageous.

The UV system has reportedly failed to provide adequate microbiological treatment to meet consent conditions, but the reason (in 2009) was not known. Median enterococci numbers for October 2008 to September 2009 were 15 cfu per 100 mL (95%-ile 320 cfu per 100 mL; Table 2-3, AWT 2009). AWT (2009) considered it possible that dissolved iron from the slag filters, high suspended solids, or colour was preventing the system operating as expected. An updated summary of discharge quality (Kennedy 2012, Wood 2012) indicates this may have improved, with a median enterococci of 3 MPN (or cfu)/100 mL (92%ile 125 MPN (or cfu)/100 mL) for the May

2010 to April 2011 period, and 9 per 100 mL (92%ile of 97 per 100 mL) for the April 2011 to May 2012 period.

In summary, the Waiuku WWTP is considered to be operating as expected for this type of plant, with the possible exception of the UV system.

10.1.2 Effects on receiving water quality

Effects of the discharge on estuarine receiving water quality were discussed in section 4.6. The broad-scale effects of the Waiuku WWTP discharge on estuary water quality were assessed in two separate surveys conducted by Bioresearches (2000, 2007b). The results showed increases in the concentrations of nutrients, indicator bacteria, and ammonia attributable to the discharge. Ammonia levels found were considered unlikely to reach those considered toxic to aquatic life after initial mixing, and dropped with distance downstream. Visual clarity and dissolved oxygen levels in receiving waters were largely unaffected. Effects had reduced to background levels by about 1000 m below the discharge.

The Bioresearches surveys indicated that microbiological inputs may render the estuary waters downstream of the discharge unsuitable for contact recreation and shellfish gathering. Based on updated microbiological data for the discharge, Kennedy (2012) and van Duivenboden (2013) concluded that the discharge was unlikely to increase the levels of enterococci in estuary waters outside the mixing zone, and it was unlikely to result in exceedance of MfE (2003) contact recreational water quality guidelines. However, the potential for increased health risk to shellfish consumers from the pathogens in the wastewater discharge was noted, and identified as requiring further investigation. A quantitative microbial risk assessment, including the health risks associated with viral infection, would be required to reliably assess this.

The contribution from the discharge to overall estuarine nutrient enrichment from the discharge has not, to our knowledge, been analysed in any detail. In a letter to Auckland Council reviewing various aspects of the discharge's potential effects, Rob van Duivenboden (Resource Management Professional Ltd) considered the nutrient enrichment issue. He estimated that the nitrogen flux from the plant was about 0.23 g/second, compared with the only studied inflow, the Waitangi Stream, which was delivering 4.5 g/s (on average). Since there are two other significant stream inflows to the estuary, both from urban/rural catchments, the Waiuku WWTP contributor to the estuary nutrient load was considered of concern, but only as a moderate source contributor. He also noted that there are no observed significant adverse effects of eutrophication known at this time, and considered the potential effects from nutrients over the proposed term of the consent (5 years) to be small.

Overall, the effects of the discharge on estuarine water quality appear to be relatively minor but some uncertainty remains. The key outstanding uncertainty is the potential incremental health risks for recreational users, primarily via shellfish consumption, associated with pathogenic microorganisms in the discharge. Some uncertainty also remains around the effect of the discharge under different discharge, tidal and antecedent weather conditions. Effects on estuarine sediment quality

The effects of the discharge on sediment quality were summarised in section 5.0. Sediment quality was included in an investigation conducted in 2007, reported by Bioresearches (2007b). Sampling was conducted in February 2007 from 10 sites – 9 in the Waiuku Estuary from 25 m to 250 m from the outfall, and one site in the lower Taihiki River estuary (as a "control"). Sites were:

- 25 m, 50 m and 100 m upstream (southward) of the discharge point;
- 25 m, 50 m, 100 m and 250 m downstream (northward) of the discharge point;
- 25 m west and 25 m east of the discharge point; and
- 1 site in the middle of the lower Taihiki River estuary.

Samples were analysed for total recoverable Cu, Pb, and Zn, and sediment texture.

The results indicated little effect from the discharge. The metals' concentrations were, on average, lower than those measured upstream at the urban RSCMP monitoring site, and similar to those recorded at the lower Taihiki Estuary "control" site. Concentrations were in the ERC-Green range (i.e. unlikely to cause adverse effects on benthic organisms).

Based on these results, it appears that the discharge is having little effect on receiving water sediment quality.

10.1.3 Effects on shellfish microbiological quality

The effects of the discharge on shellfish microbiological quality were discussed in section 6.4.2.

In February 2000, Pacific oysters from a site 500 m upstream of the discharge (adjacent to the southern end of the treatment plant property) and 1000 m downstream (at the Needles) were taken and analysed for faecal coliforms (Bioresearches 2000). At the time of sampling, the discharge of treated effluent did not appear to adversely affect the bacteriological quality of the oysters at The Needles. The results from the upstream site suggested microbiological quality in the upper estuary is likely to be marginal for shellfish gathering purposes. This is consistent with limited microbiological water quality data collected to date in the Auckland Council saline water quality monitoring programme, as summarised in section 4.4.2 (the Waiuku Town Basin site is in the same general location as the upstream oyster sampling site).

Bioresearches (2007b) reported the results of a survey conducted in March 2007, in which oysters were sampled from upstream of the discharge, below the discharge (at the Needles, Okohaka Point, and Kahawai Point), and in the Taihiki Estuary. The sampling was undertaken after a period of heavy rainfall, and this may have affected the results (due to catchment runoff). Faecal coliform numbers in all shellfish samples were elevated, including those from the Taihiki River. The highest median faecal coliform count from shellfish occurred in the shellfish samples from the Needles, which was the closest sampling station northward of the discharge point (approximately 1000 m). Faecal coliform numbers in shellfish from both Okohaka Point and from Kahawai Point were also elevated above those found in shellfish from the upstream sampling station and the Taihiki River sampling station.

Bioresearches (2007b) concluded that while the rainfall prior to sampling may have resulted in increased bacteriological contamination of oysters throughout the Waiuku Estuary, the wastewater treatment plant discharge may also have been adversely affecting bacterial numbers in nearby natural shellfish populations. Based on comparisons of the MoH (1995) criteria for faecal coliform bacteria in unprocessed shellfish, none of the sampling stations would have been considered safe for human consumption at the time of sampling.

Overall, the effects of the discharge on shellfish microbiological quality are unclear. The very limited data are not definitive, but indicate general microbiological quality in upper estuary is probably poor, and that the Waiuku WWTP might have some impact on shellfish microbiological quality. The incremental health risks associated with the Waiuku WWTP discharge need to be quantified (for example using a Quantitative Microbial Risk Assessment, QMRA). Because the UV disinfection system has (at least historically) been underperforming, consideration of health risks associated with viral infection should be considered. The need for additional information on this aspect is supported by recent reviews (Kennedy 2012, van Duivenboden 2013, Wood 2012).

10.1.4 Monitoring

Unless there are major changes in effluent quality or quantities discharged, future receiving environment monitoring of the type already undertaken (e.g. water quality monitoring at a range of sites above and below the discharge) is highly likely to find what has already been recorded by Bioresearches (2000, 2007b), as has been summarised in this review. This type of monitoring is therefore likely to consolidate the existing information base, but is unlikely to provide much important new information (unless monitoring is undertaken during different discharge and antecedent weather conditions), or to address currently unanswered issues, which include:

- the fate of the wastewater in the estuary, including dilution and dispersion and retention. According to information in Wood (2012), the residence time of water in the Waiuku River has been estimated at approximately 4–5 days, with an overall residence time of water in the Waiuku River/Channel of 12–13 days. This shows that it takes a significant amount of time for the Waiuku Estuary to completely “flush”. A better understanding of estuary hydrodynamics is therefore required to assess present effects and predict effects of any future changes in discharge regime.
- risks to human health for contact recreation and shellfish consumption at key locations in the estuary;
- contribution from the discharge to the overall catchment loads of nutrients, TSS, and microbes.

More emphasis on modelling, rather than on-going routine monitoring in the estuary, would seem to be more useful in understanding the effects of the discharge and may help to define limits to manage overall effects on the receiving environment. Continued monitoring of the discharge is, however, considered to be essential as this provides the data required for predictive modelling. It also provides the data required to assess whether discharge quality (and quantity) has remained within specified limits, and hence whether significant changes in the receiving environment are likely to be occurring.

Although not related to monitoring, the lack of a diffuser at the outfall may be hampering the rate of dilution of the discharge and improved dilution may be obtained if a diffuser was attached. Better definition of the effluent mixing zone would also be worthwhile.

10.2 Clarks Beach WWTP discharge to Waiuku Estuary

There is information on the Clarks Beach WWTP system and discharge. We understand modelling work has been undertaken to predict effects in receiving waters, but this was not available to be included in this review.

This information should be reviewed to assess what effects (if any) this discharge is having.

11.0 Concluding remarks

The review has found a variety of information on the Waiuku Estuary; however there are still a number of gaps. Good information was found for water quality (more so for estuarine, but freshwater monitoring is underway) and sediment quality (in particular for heavy metals associated with the NZ Steel discharge). A smaller amount of information was found for shellfish quality, although the NZ Steel discharge monitoring has accumulated a great deal of chemical (metals) and condition data.

Key information gaps identified during this review include the following:

- Catchment loads and key sources (urban, rural, point, and diffuse) of nutrients, sediment, and microbes. These are key parameters affecting the quality of the estuary receiving waters, so an improved quantitative understanding of their sources, fate, and future trends is considered important. This should include an assessment of sedimentation rates in the estuary.
- Human health risks associated with microbial contamination in estuary waters and shellfish, in particular with regard to inputs from the two wastewater treatment plant discharges.
- Quantitative description of the behaviour and fate of effluent from the Waiuku and Clarks Beach WWTP discharges in the estuary.
- A better understanding of estuary hydrodynamics (including physical processes such as wind, waves, currents, tides and rainfall) to assess the fate and consequence of both diffuse and point-source discharges into the estuary.
- More detailed spatial coverage of ecological condition, and assessment of zones requiring ongoing monitoring for potential future impacts (in particular from sedimentation).
- Zn budget for the estuary, in order to assess the contribution from NZ Steel compared with other sources, and to estimate the proportions retained within, and exported from, the estuary.
- Effects of mangrove expansion and removal on sediment movement and deposition, and on estuarine ecology.

12.0 Acknowledgements

The author wishes to thank NZ Steel and Bioresearches for supply of NZ Steel monitoring data, Auckland Council consents department and Watercare Services Limited for supply of Waiuku WWTP data and information and Marcus Cameron and Jarrod Walker of Auckland Council for supply of data and information and reviews of earlier drafts. The author also wishes to acknowledge the input of two anonymous reviewers from Auckland Council's peer review panel and Andrew Benson for helpful suggestions.

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