State of the Environment Water Quality in the Whāngārei Harbour 2000 - 2010

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Executive summary

Northland Regional Council (the Council) monitors water quality at 16 sites in the Whāngārei Harbour on a bi-monthly basis, in order to record the state of the environment, identify environmental issues and monitor changes over time.

Of the 16 sites monitored, eight sites have been monitored for more than ten years, one site for five years and seven sites for three years. Currently, 12 chemical and physical water quality parameters are measured, including dissolved oxygen, water clarity, temperature, salinity, micro-bacteria and nutrients.

Analysis of the data collected over the last ten years indicates that sites with the best water quality are located close to the harbour entrance and sites with the worst water quality are located in the Hātea River and Mangapai River. Sites near the entrance of harbour are more heavily influenced by coastal water, while sites in the Hātea and Mangapai Rivers, are more influenced by freshwater input from rivers and streams. By ranking sites based on results from seven parameters, the site with the best water quality was located at Marsden Point and the site with the worst water quality was located in the Waiharohia Canal.

Of the parameters where default trigger values have been developed by ANZECC, the median value was within the recommended guideline for turbidity, dissolved oxygen (%) and enterococci at all sites. However, four sites had a median value that fell outside of the guideline value for faecal coliforms; all 16 sites had a median value that fell outside of the guideline value for dissolved reactive phosphorus; 10 sites had a median that fell outside of the guideline value for total phosphorus; 13 sites had a median value that fell outside of the guideline value for nitrate-nitrite nitrogen; and nine sites had a median value that fell outside of the guideline value for ammonium.

Trend analysis was conducted on all data collected over the last ten years using two different software packages. Trends identified include an increase (improvement) in water clarity at three sites; an increase (improvement) in dissolved oxygen at three sites, a decrease (improvement) in nutrients at three sites, an increase (decline) in turbidity at two sites and a decrease (improvement) in bacteria at two sites. This is the first time trend analysis has been conducted on data collected from the harbour and some sites and parameters have a limited dataset. It is recommended that the Whāngārei Harbour monitoring programme continue in its current format and that further trend analysis is undertaken once a larger dataset has been collected.

In general weak relationships were observed between the different water quality variables. Dissolved reactive phosphorus had strong positive correlations with total phosphorus and ammonium. As expected the concentration of dissolved oxygen and dissolved oxygen saturation also had a strong positive correlation with each other.

Negative correlations were found between salinity and dissolved oxygen (mg/l), turbidity, micro bacteria and nutrient concentrations, although these correlations were generally quite weak. This indicates that turbidity, levels of micro bacteria and concentrations of nutrients tend to decrease with distance from freshwater sources.

Recommendations include continuing bi-monthly sampling of coastal water quality at the same 16 sites in the Whāngārei Harbour to monitor state and trends over time and identify any emerging environmental issues. We also recommend that the Council:

- Reviews the available data again in five years time, when sufficient data has been collected for nutrient parameters to identify trends; and

- Reviews the management aims and objectives of the different zones and existing water quality standards in the Regional Coastal Plan for Northland.

1. Introduction

1.1 Background

Northland's coastal environment is a valuable resource. Maintaining coastal water quality at a good level is important to Northland's inhabitants, its economy and the many diverse forms of marine life that inhabit this environment. Good water quality is essential for healthy marine ecosystems, the development of the aquaculture industry and tourism in Northland.

Coastal water quality is affected by freshwater inputs from rivers and streams, urban and rural run off and direct discharges into the coast. As land use and urban development intensify coastal water quality is likely to come under increasing pressure.

The Northland Regional Council (the Council) carries out state of the environment monitoring of the region's coastal water quality to record the state of this resource, to identify environmental issues and to track changes in water quality over time. Although state of the environment monitoring can highlight emerging trends or changes in the environment, both positive and negative, additional investigation is sometimes required to identify the cause of any change. The Council currently conducts sate of the environment water quality programmes in Whāngārei Harbour, Bay of Islands and Kaipara Harbour.

The results from this programme provides resource planners, politicians and the public with information regarding the water quality of Whāngārei Harbour, and helps enable informed decision making relating to activities which impact water quality. Importantly the programme will help Council to assess the effectiveness of the Regional Coastal Plan for Northland and The Regional Water and Soil Plan for Northland and determine if these plans need to be reviewed and improved.

State of the environment monitoring is not designed to monitor individual sources of contamination. Consented discharges are monitored through compliance monitoring programmes. Non-consented discharges that may lead to adverse environmental impacts are investigated by Council as 'environmental incidents'.

The programme addresses the Council's responsibilities under the Resource Management Act (1991) in relation to sustainable management principals set out in Part II (Section 5) and directives to monitor the state of the environment as set out Part IV (section 35; 1 & 2a section 30; 1a). The programme also achieves the Regional Community Outcomes and Levels of Service for Environmental Monitoring set out in the Northland Community Plan (Northland Regional Council 2009).

This report presents the results from coastal water quality monitoring undertaken by the Council since January 2000 up to December 2010 at 16 sites in Whāngārei Harbour. The report also includes a comparison to current water quality standards in the Regional Coastal Plan, relevant Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) guideline values (Australian New Zealand Environment Conservation Council 2000) and Ministry for Environment (MfE) Microbiological Water Quality Guidelines, and an analysis of temporal trends.

1.2 The Whāngārei Harbour

The Whāngārei Harbour is a drowned river valley system located on the east coast of the Northland peninsula (Figure 1). The harbour covers an area of approximately 10,000 ha and

includes 5400 ha of intertidal flats, 1400 ha of mangroves and 200 ha of saltmarsh (Morrison 2003).

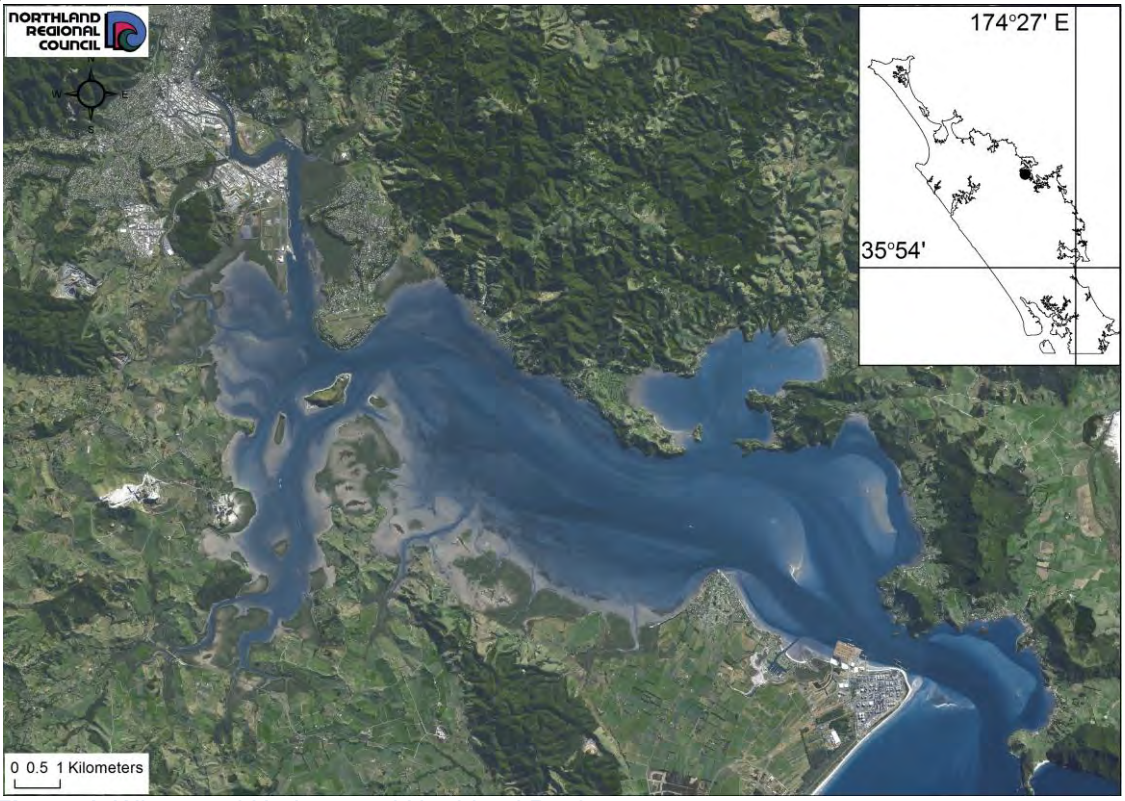

Figure 1. Whāngārei Harbour and Northland Region.

The harbour is connected to Bream Bay, a large coastal embayment, via an inlet approximately 2.4 km wide, between Marsden Point and Home Point. The main channel extends inland approximately 24 km in a north-westerly direction and then divides into two arms, the Hātea River in the north and the Mangapai River in the south.

The harbour drains a catchment of 29,507 ha. The catchment has been heavily modified, with a large amount of native vegetation cleared for urban use in the north-west and agricultural land use in the east and south. GIS catchment analysis using the land use classification from the New Zealand Land Cover Database (LCDB2) indicated that in 2001, 49% (14541 ha) of the catchment was covered by high producing exotic grassland, for cattle and dairy farming, 10% (3006 ha) with plantation forestry, 10% (2933 ha) with urban land uses, and 20% (5903 ha) with indigenous forest (Figure 2 & Appendix 1). The city of Whāngārei, located on the banks of the Hātea River is the regional capital of Northland and had an estimated population of 51,900 in June 2010 (Statistics New Zealand, 2010).

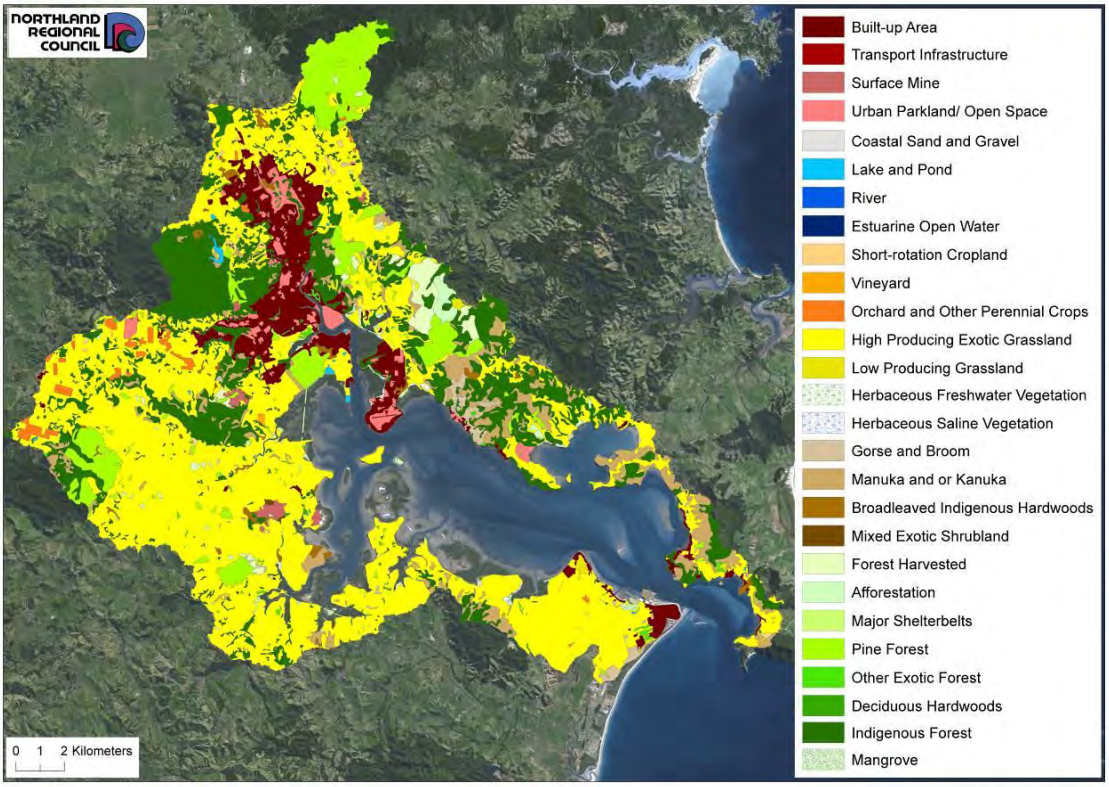

Figure 2. Land-cover in the Whāngārei Harbour Catchment (LCDB2, 2001).

2. Methodology

2.1 Programme design

The Council has conducted routine water quality monitoring in the Whāngārei Harbour since 1986. However, the monitoring programme has been adapted and modified during this period, in response to changes in best practice and changes to the objectives for collecting this data (for more information see Appendix 2 - Programme Changes). The programme has existed in its current form since 2008.

2.2 Sampling interval

Sampling is currently undertaken bi-monthly throughout the year (in January, March, May, July, September and November), with up to three additional sampling events conducted following heavy rainfall (rain-driven sampling). Historically, sampling was conducted on an outgoing tide. However since 2008 sampling has been conducted on a predetermined date with no regard to tidal state, to coincide with the River Water Quality Monitoring Network (RWQMN) sampling also undertaken by the Council. By collecting samples on a pre-determined date without regard to the tidal state, the sampling should provide a more representative picture of water quality in the harbour over time, by incorporating the influence of tidal state into water quality.

2.3 Sample sites

A total of 16 sites are currently monitored in the Whāngārei Harbour (Table 1 & Figure 3). These sites have been selected in order to capture the main freshwater inputs (rivers and streams) and to ensure a good geographical spread throughout the Harbour. In the inner harbour, six sites are located in the channel draining the Hātea River and two sites are located in the channel that drains the Mangapai River. A further eight sites are located along the main channel of the harbour. The sites cover a range of exposures from open water to sheltered tidal creeks. Site co-ordinates have been fixed using a handheld GPS (Appendix 3) so that samples are collected from the same location.

2.4 Sampling parameters

In 2000, only physical parameters (dissolved oxygen, temperature and salinity) and micro-bacteria (enterococci and faecal coliforms) were monitored but additional parameters have subsequently been added to the programme and the Council currently monitors 12 water quality parameters (Table 2).

Table 1. Whāngārei Harbour State of the Environment Water Quality Monitoring sites.

Site Name	Location	Dates
Town Basin	Victoria Bridge, Town Basin	Prior to 2000*
Riverside Drive	South East corner of pile berths – lower Town Basin	2008
Waiharohia Canal	Beginning of Waiharohia Canal	2008
Limeburner's Creek	Entrance to Limeburner's Creek	Prior to 2000*
Kissing Point	On edge of moorings / marina	Prior to 2000*
Lower Port Road	Near Waimahanga Creek	2008
Kaiwaka Point	Kaiwaka Point, Onerahi	Prior to 2000*
Onerahi	South east of Sea Scouts	2008
Portland	Off old Portland Cement wharf	2008
Mangapai River	Off jetty remains, near SH1	2008
Tamaterau	Out from Scott Road (Starboard marker)	Prior to 2000*
One Tree Point	Out from public boat ramp / yacht club	Prior to 2000*
Snake Bank	Mid north-east side	2008
Blacksmiths Creek	Between entrance to Marsden Cove Marina and Refinery	2006
Marsden Point	At the harbour entrance, at end of the oil refinery wharves	Prior to 2000*
Mair Bank	Mair Bank pile	Prior to 2000*

*Note, this report only reports data from 2000 – 2010.

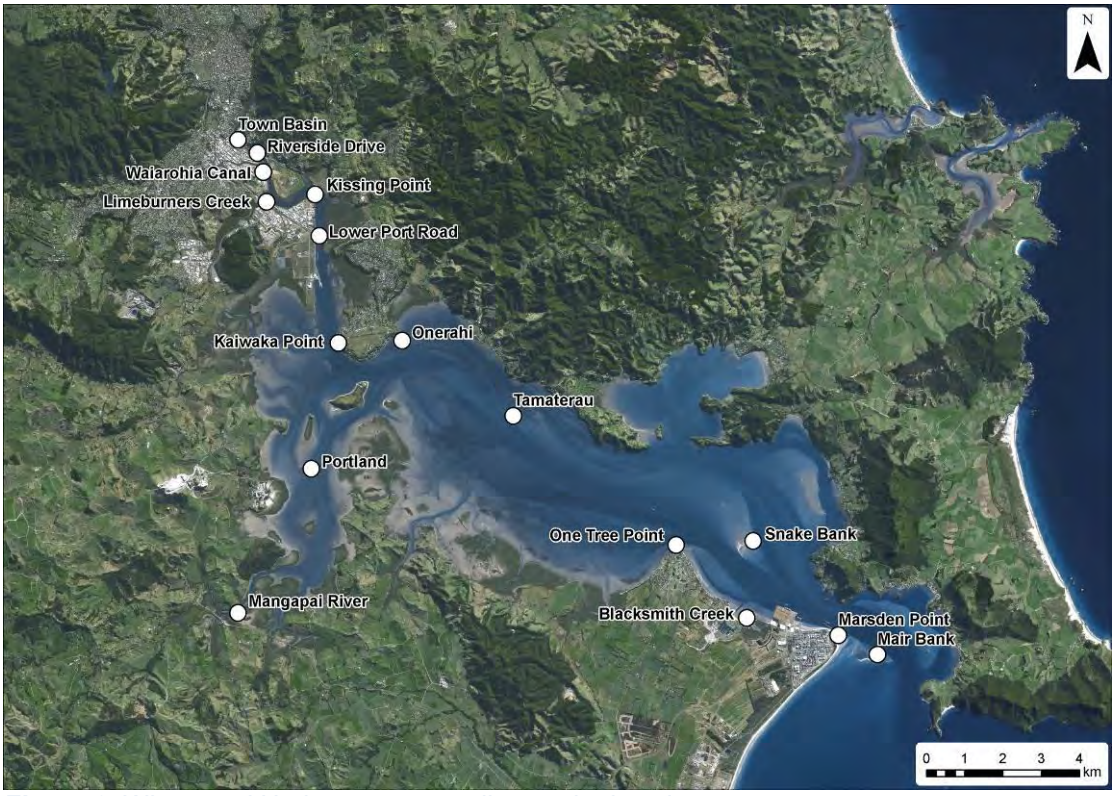

Figure 3. Whāngārei Harbour water quality monitoring sites.

Table 2. Summary of water quality parameters monitored in Whāngārei Harbour.

Water Quality Parameter	Date	ANZECC default trigger values	Coastal water quality standards	Reason for Monitoring
Temperature	2000-present	N/A	N/A	• Indicator of ability to sustain aquatic life and support biological diversity • Indicator of excessive primary productivity • Influences dissolved oxygen
Salinity	2000-present	N/A	N/A	• Indicator of fresh and seawater mixing • Affects biological diversity
Secchi depth (Water Clarity)	September 2004-present	N/A	N/A	• Indicator of the quantity suspended material in water column, e.g. sediment • Indicator of ability to support aquatic life • Affects primary production. • Affects predator-prey relationships
Turbidity (Water clarity)	September 2004-present	<10 NTU	NA	• Indicator of the quantity suspended material in water column. • Indicator of ability to support aquatic life • Affects primary production. • Affects predator-prey relationships
Dissolved oxygen (DO)	July 2002-present	>80%-110%<	CA: >80%	• Indicator of ability to support marine flora and fauna • Indicator of organic material • Indicator of excessive primary productivity
Enterococci Bacteria (ENT)	2000-present	MfE: <140/100mL	N/A	• Indicator of faecal contamination • Indicator of public health risk
Faecal Coliforms (FC)	2000-present		CA: <14/100ml CB: <150/100ml	• Indicator of faecal contamination • Indicator of public health risk
Total Phosphorus (TP)	March 2008-present	<0.03 mg/L	NA	• Indicator of nutrient enrichment • Indicator of point-source and non-point source inputs • Affects primary productivity
Dissolved Reactive Phosphorus (DRP)	March 2008-present	<0.01 mg/L	CA: <0.01 mg/L CB: N/A	• Indicator of nutrient enrichment • Indicator of point and non-point source inputs • Affects primary productivity
Ammonium (NH_4)	March 2008-present	<0.015 mg/L	CA: 0.005 mg/L CB: N/A	• Indicator of nutrient enrichment • Indicator of point source and non-point source inputs • Indicator or waste products
Nitrate-nitrite nitrogen (NNN)	November 2008-present	<0.015 mg/L	CA: (NO_3-N) 0.06 CB: N/A	• Indicator of nutrient enrichment • Indicator of point source and non-point source inputs • Affects primary productivity

2.5 Sampling methodology

Physical water quality parameters (temperature, salinity and dissolved oxygen) are measured in the field with a YSI handheld meter. The YSI meter is lowered over the side of the boat into the water to approximately 0.5m depth (surface water) and the measurement recorded.

Secchi depth is measured by lowering a secchi disk over the side of the boat slowly down into the water. The depth at which the pattern on the disk is no longer visible is recorded as the secchi depth. The secchi reading is taken on the shady side of the boat and is made by the same observer during a sampling run.

Micro-bacteria, turbidity and nutrient samples are collected from the top 0.5m of the water column in the appropriate sample bottle, using a gripper pole. The samples are stored on ice and transported to the laboratory for analysis. Micro-bacteria and turbidity samples were analysed at the Council's laboratory and nutrient samples were sent to external laboratories for analysis.

2.6 Data analysis

All results that were reported as below the laboratory detection limit were replaced by a value of half the detection limit (Chapman 1996). For example a value reported as < 10 enterococci MPN/100ml by the laboratory would be included in the data analysis as 5 enterococci MPN/100ml. All results reported as a greater than value were replaced by the greater than value. For example a value reported as > 30,000 enterococci MPN/100ml by the laboratory would be included in the analysis as 30,000 enterococci MPN/100ml.

The range and median were calculated for each parameter at each site. The median values were then overlain onto maps of the harbour using graduated circles, with the size of the circle representing the median value at each site. If the median value for a given site was within the relevant trigger value the circle is coloured green and if the median value exceeded the trigger value the circle is coloured red.

The results were assessed against appropriate water quality guidelines (Table 2), which include the coastal water quality standards outlined in the Regional Coastal Plan for Northland (Northland Regional Council 2004), ANZECC interim trigger values (Australian New Zealand Environment Conservation Council 2000) and Ministry for Environment (MfE) Microbiological Water Quality Guidelines (Ministry for Environment 2003). Median values that fell outside of the recommended guideline values are highlighted in red and the percentage of samples which were within the recommended guideline values is also reported.

The Regional Coastal Plan for Northland (RCP) classifies Whāngārei harbour for the management of water quality (Northland Regional Council 2004). This classification zones the harbour, for management purposes, in accordance with the desired and actual uses and the required water quality for these uses (Figure 4). These classifications have water quality standards, as set out in the Appendix 4 of the RCP, appropriate for the uses of the area (Table 2 & Appendix 4).

The ANZECC water quality guidelines provide a framework for developing guideline values and present default trigger values for different geographical regions and ecosystem types (Australian New Zealand Environment Conservation Council 2000). The default trigger values used the statistical distribution of referenced data collected from five geographical regions across Australia and New Zealand together with the professional judgement of representatives from these regions to derive trigger values for each ecosystem type in their region. Specific guidelines were not developed for New Zealand estuarine and marine ecosystems and the document states that

consideration should be given to the use of interim trigger values for south-east Australian estuarine and marine ecosystems. In this report we refer to the interim trigger values for south-east Australian estuarine ecosystems.

The guideline document states 'The guideline trigger values are the concentrations of the key performance indicators, below which there is a low risk that adverse biological effects will occur. The physical and chemical trigger values are not designed to be used as 'magic numbers' or threshold values at which an environmental problem is inferred if they are exceeded. Rather they are designed to be used in conjunction with professional judgement, to provide an initial assessment of the state of a water body regarding the issue in question' (New Zealand Environment Conservation Council 2000).

Because the ANZEEC interim trigger values refer to ammonium but not total ammoniacal nitrogen ammonium concentrations were calculated from the values for total ammoniacal nitrogen. The formula and calculations are detailed in Appendix 5. Typically the ammonium values were very similar to the concentrations of total ammoniacal nitrogen.

The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas recreational guidelines (Ministry for the Environment and the Ministry of Health 2003) use bacteriological indicators associated with the gut of warm-blooded animals to assess the risk of faecal contamination and therefore the potential presence of harmful pathogens. In marine environments enterococci is used as the bacteriological indicator. Compliance with the guidelines should ensure that people using water for contact recreation or gathering shellfish are not exposed to significant health risks. The recreational guidelines work with a defined 'tolerable risk' rather than no risk at all. For most healthy people coming into contact with water within the guideline value will pose a minimal level of health risk. However, the same water may still pose a greater health risk to high-risk user groups such as the very young, the elderly, and those with impaired immune systems.

Sites were also ranked using a similar system used by Auckland Council (Scarsbrook 2008). Seven water quality variables (FC, DRP, TP, NNN, NH4, turbidity and secchi depth) were selected to form the basis of this simple water quality ranking index by first ranking the median value for each parameter across the 16 sites, and then calculating the average rank of all parameters for each individual site (see Table 15).

Any changes over time (trends) have been calculated using the excel spreadsheet for automatic processing of water quality data, developed by the National Groundwater Monitoring Programme (NGMP) and the Trend and Equivalence Analysis software developed by the National Institute of Water and Atmospheric Research (NIWA). The Mann-Kendall test was applied to data for each parameter at each site in order to identify any significant trends in this data.

Pearson correlations were also performed, using Minitab 16 (Minitab Inc., Pennsylvania, USA), in order to examine the relationship between the water quality parameters monitored, using raw data from all sites. Correlations between dissolved oxygen, faecal coliforms, enterococci, salinity and temperature were calculated using data from 2000-2010. Correlations between concentrations of nutrients, turbidity and secchi depth were calculated using data from 2008 to 2010 (two complete sampling years) as prior to 2008, these variables were not monitored.

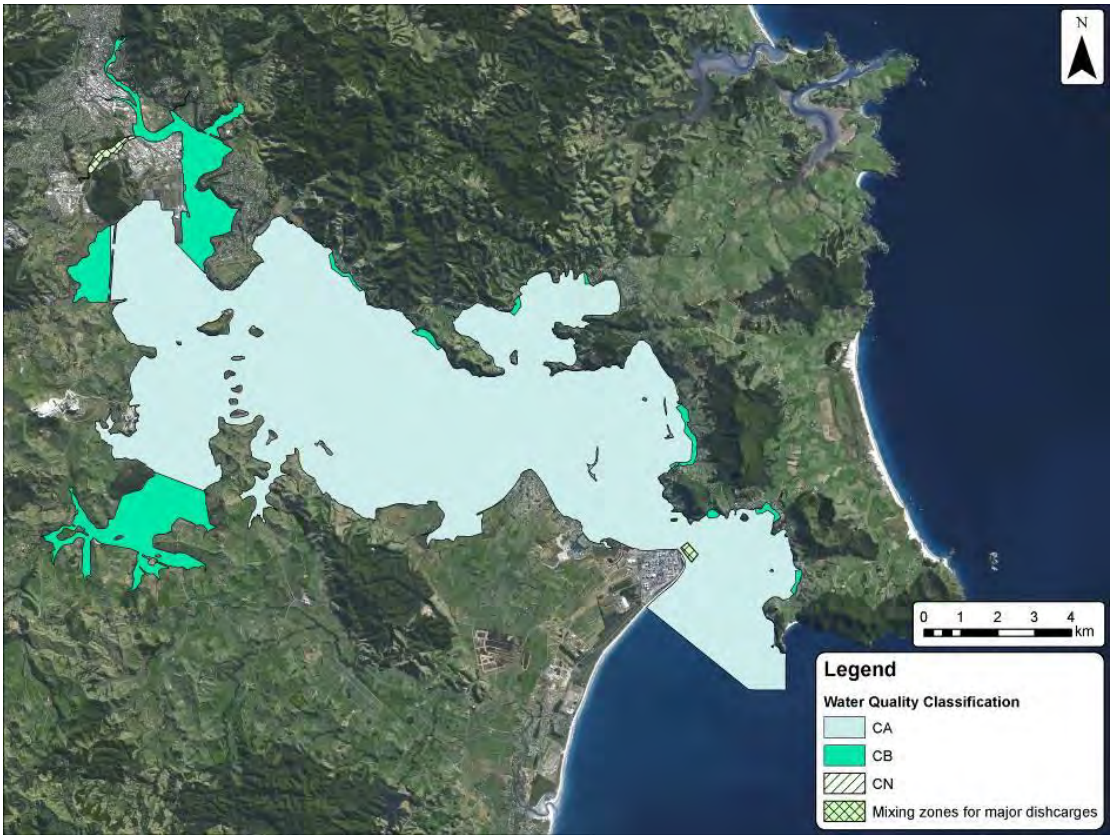

Figure 4. Water quality classification of the Whāngārei Harbour in the Regional Coastal Plan for Northland.

3. Results

3.1 Salinity

There are no ANZECC default trigger values for salinity. In the Whāngārei Harbour, sites with high median salinity were located near the entrance of the harbour and sites with low salinity were located close to freshwater inputs in the Hātea River and the Mangapai River (see Table 3). The sites in the Hātea River had a wider range of salinity than sites located near to the harbour entrance. The lowest salinity range was recorded at Snake Bank.

Table 3. Range and median value for salinity at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of samples	Range	Median	% of samples within guideline value
Mair Bank	59	20.8 – 37.6	35.0	N/A
Marsden Point	62	14.8 – 37.6	34.8	N/A
One Tree Point	50	25.1 – 37.7	34.6	N/A
Blacksmith's Creek	23	30.2 – 36.1	34.5	N/A
Snake Bank	18	30.4 – 36.0	34.5	N/A
Tamaterau	60	11.8 – 36.2	33.5	N/A
Onerahi	18	27.0 – 35.7	32.5	N/A
Portland	18	26.2 – 36.6	32.4	N/A
Kaiwaka Point	99	11.5 – 36.5	31.2	N/A
Mangapai River	18	19.2 – 36.3	30.3	N/A
Lower Port Road	18	16.3 – 35.5	30.3	N/A
Kissing Point	98	3.1 – 35.8	29.1	N/A
Limeburners Creek	101	0.3 – 34.4	27.7	N/A
Town Basin	100	1.1 – 30.1	20.5	N/A
Riverside Drive	18	5.6 – 31.4	19.9	N/A
Waiharohia Canal	18	1.8 – 32.5	14.7	N/A

3.2 Temperature

There are no ANZECC default trigger values for temperature. The two sites with the lowest median temperature were located in the Hātea River at Waiharohia Canal and Blacksmiths Creek, followed by sites close to the harbour entrance, at Mair Bank, Snake Bank and Marsden Point (Table 4). The sites with the highest temperature were also located in the Hātea River at the Town Basin, Kissing Point and Limeburner's Creek.

Table 4. Range and median value for temperature (ºC) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (ºC)	Median (ºC)	% of samples within guideline value
Town Basin	100	9.8 – 25.3	18.5	N/A
Kissing Point	99	11.1 – 25.2	18.3	N/A
Limeburners Creek	101	11.0 – 25.3	18.3	N/A
Tamaterau	62	12.0 – 22.9	18.1	N/A
Kaiwaka Point	99	11.4 – 24.8	18.0	N/A
Mangapai	18	11.1 – 23.8	17.8	N/A
Lower Port Road	18	11.9 – 24.3	17.5	N/A
Onerahi	18	12.0 – 24.1	17.4	N/A
Portland	18	11.6 – 24.2	17.3	N/A
Riverside Drive	18	11.0 – 25.1	17.3	N/A
One Tree Point	52	12.8 – 22.2	17.2	N/A
Snake Bank	18	13.3 – 22.3	17.2	N/A
Mair Bank	60	13.6 – 22.0	17.1	N/A
Marsden Point	64	13.1 – 22.2	17.1	N/A
Waiharohia Canal	18	11.1 – 25.2	17.0	N/A
Blacksmith's Creek	24	13.0 – 22.2	16.9	N/A

3.3 Turbidity

The ANZECC default trigger values for turbidity in estuarine and marine environments is 0.5-10 NTU. None of the sites had median values for turbidity that exceeded 10 NTU. The highest median values for turbidity (lowest water clarity) were found at sites close to freshwater inputs in the Mangapai River and the Hātea River. Sites with the lowest median turbidity (highest water clarity) were located near the harbour entrance at One Tree Point, Blacksmith's Creek, Marsden Point and Mair Bank, where freshwater inflows are likely to have less influence on water quality (Table 5 and Figure 5).

Table 5. Range and median value for turbidity (NTU) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (NTU)	Median (NTU)	% of samples within guideline value (<10 NTU)
One Tree Point	25	0.5 – 5.7	1.0	100
Blacksmith's Creek	18	1.0 – 3.4	1.0	100
Marsden Point	38	0.4 – 6.6	1.0	100
Mair Bank	39	0.2 – 2.4	1.0	100
Snake Bank	18	1.0 – 15.3	2.1	94
Tamaterau	39	1.0 – 37.0	2.9	92
Town Basin	25	3.4 – 63.0	5.0	92
Onerahi	18	2.5 – 12.4	5.1	89
Lower Port Road	18	3.6 – 11.9	5.4	89
Kaiwaka Point	22	3.4 – 11.7	5.4	91
Kissing Point	50	2.8 – 92.0	5.4	94
Riverside Drive	18	3.4 – 11.1	5.7	94
Waiharohia Canal	18	3.4 – 13.2	6.6	83
Portland	18	4.0 – 18.1	7.4	78
Limeburners Creek	25	4.1 – 67.0	7.9	88
Mangapai	18	4.6 – 15.2	9.3	67

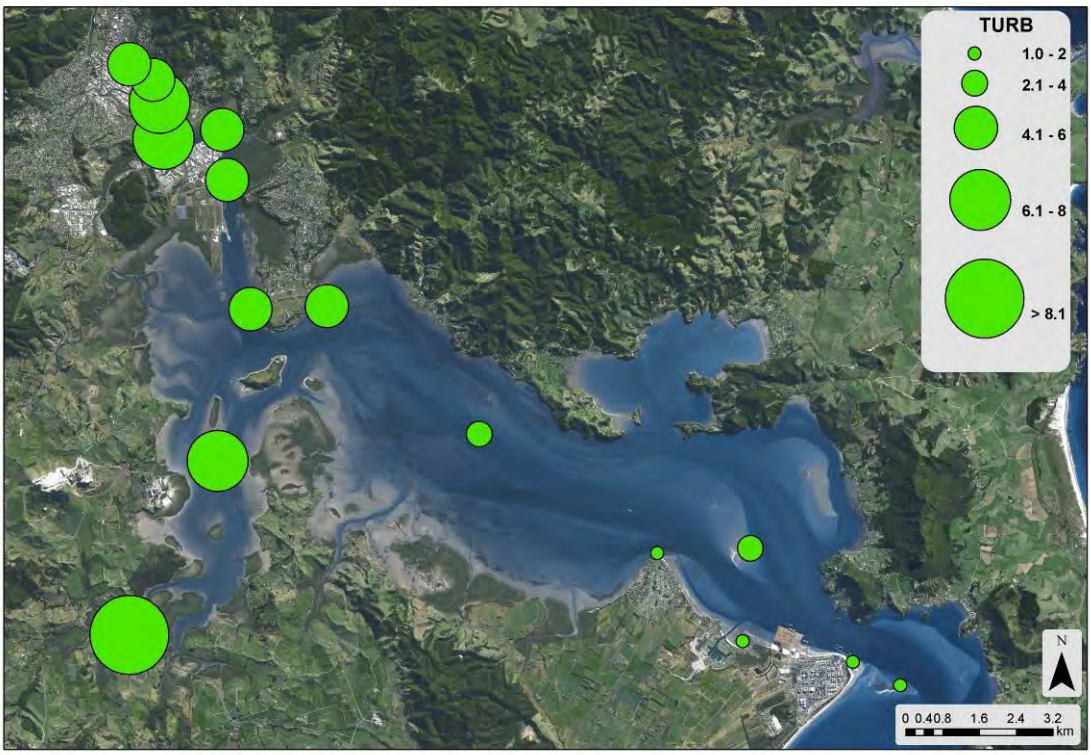

Figure 5. Median value for turbidity at 16 Whāngārei Harbour sites 2000-2010. Green circles indicate that the median value was within the ANZECC trigger value.

3.4 Secchi Depth

There are currently no ANZECC default trigger values for secchi depth. A similar spatial trend to turbidity was observed for secchi depth with the lowest median secchi depths (lowest water clarity) found in the Hātea River and Mangapai River, and the highest median secchi depths (highest water clarity) found near the harbour entrance (Table 6).

Table 6. Range and median value for secchi depth (m) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (m)	Median (m)	% of samples within guideline value
Marsden Point	37	0.9 – 9.0	4.5	N/A
Blacksmith's Creek	15	1.6 – 6.0	4.0	N/A
Mair Bank	34	1.8 – 7.5	3.85	N/A
One Tree Point	24	2.0 – 6.3	3.8	N/A
Snake Bank	14	1.3 – 7.0	3.65	N/A
Tamaterau	33	0.3 – 4.7	2.4	N/A
Onerahi	17	0.9 – 2.2	1.5	N/A
Kaiwaka Point	18	0.47 – 1.8	1.4	N/A
Lower Port Road	17	0.8 – 1.7	1.3	N/A
Portland	17	0.6 – 2.1	1.3	N/A
Town Basin	18	0.5 – 1.9	1.23	N/A
Kissing Point	47	0.15 – 2.1	1.2	N/A
Waiharohia Canal	17	0.7 – 2.0	1.1	N/A
Riverside Drive	17	0.7 – 1.8	1.0	N/A
Limeburners Creek	21	0.3 – 2.2	1.0	N/A
Mangapai	17	0.2 – 1.5	0.9	N/A

3.5 Dissolved Oxygen

The ANZECC default trigger values for dissolved oxygen (% saturation) are 80 – 110 (Australian New Zealand Environment Conservation Council 2000) and the RCP states that dissolved oxygen should not be reduced below 80% in areas classified for 'General Quality Standard CA' (Figure 4) (Northland Regional Council 2004). The median dissolved oxygen (% saturation) was between 80 and 110 at all 16 sites. Sites with the highest dissolved oxygen (% saturation) were located close to the entrance of the harbour (Table 7) at Snake Bank, Mair Bank, Blacksmith's Creek and One Tree Point. Sites with the lowest dissolved oxygen (% saturation) were located in the Hātea River and the Mangapai River, and values at these sites were outside of the trigger values more frequently than sites near the harbour entrance. The range for dissolved oxygen (% saturation) was generally bigger at sites in the Hātea River and Mangapai River. The lowest range was at Snake bank, although only 16 samples were collected at this site.

Table 7. Range and median value for dissolved oxygen (% saturation) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (%)	Median (%)	% of samples within guideline value
Snake Bank	16	91.9 – 107.3	98.8	94
Mair Bank	46	81.2 – 135.5	98.1	83
Blacksmith's Creek	22	82.0 – 112.9	97.7	86
One Tree Point	37	79.2 – 135.3	97.3	86
Marsden Point	50	80.9 – 137.2	96.8	88
Tamaterau	48	73.3 – 139.5	95.6	85
Onerahi	16	89.5 – 109.2	95.2	94
Portland	16	86.2 – 98.5	92.4	94
Kaiwaka Point	76	70.5 – 129.1	90.7	88
Lower Port Road	16	81.1 – 99.1	87.0	94
Kissing Point	78	50.1 – 130.2	86.2	72
Mangapai	16	69.4 – 100.4	84.2	56
Waiharohia Canal	17	63.0 – 104.8	84.0	71
Town Basin	79	52.4 – 136.8	83.9	51
Limeburners Creek	80	36.4 – 129.1	82.8	55
Riverside Drive	17	62.0 – 142.2	82.5	47

A similar spatial trend was observed for median dissolved oxygen concentrations (mg/L) with the lowest median concentrations recorded at sites in the Hātea River and Mangapai River (Table 8) and the highest medians at sites near the harbour entrance. The range for dissolved oxygen concentrations was again bigger at sites in the Hātea River and Mangapai River than at sites near the harbour entrance. The lowest range was again measured at Snake bank, although only 17 samples were collected at this site.

Table 8. Range and median value for dissolved oxygen (mg/L) at all Whāngārei Harbour sites 2000-2010.

Site Name	No. of Samples	Range (mg/l)	Median (mg/l)	% of samples within guideline value
Snake Bank	17	6.6 – 8.9	7.9	N/A
Blacksmith's Creek	23	5.9 – 9.2	7.8	N/A
Waiharohia Canal	18	4.5 – 9.5	7.7	N/A
Mair Bank	59	5.8 – 10.6	7.6	N/A
Marsden Point	63	5.9 – 11	7.6	N/A
One Tree Point	51	5.7 – 10.3	7.5	N/A
Onerahi	17	6.3 – 9.1	7.4	N/A
Tamaterau	61	5.6 – 10.7	7.4	N/A
Portland	17	5.9 – 8.9	7.2	N/A
Kaiwaka Point	97	5.0 – 11.3	7.2	N/A
Kissing Point	99	4.5 – 10.9	7.0	N/A
Lower Port Road	17	5.6 – 9.0	7.0	N/A
Town Basin	100	3.2 – 11.4	7.0	N/A
Limeburners Creek	101	2.6 – 10.6	6.7	N/A
Riverside Drive	18	4.5 – 13.6	6.7	N/A
Mangapai	17	4.8 – 9.3	6.5	N/A

3.6 Enterococci

The RCP does not set a limit for concentrations of enterococci but the MfE sets the 'safe' limit for marine recreational swimming water quality at less than 140 enterococci /100 ml per single sample from a site (Ministry for the Environment 2003). The median number of enterococci was below 140 per 100 ml at all 16 sites and at seven sites all of the samples collected were below the MfE guideline value of 140/100ml.

The highest median values were found in the upper Hātea River, at the Waiharohia Canal, Town Basin, Riverside Drive and Limeburners Creek (Table 9). These sites also exceeded the MfE guideline value of 140/100ml most frequently. The lowest median values were generally found at sites near the harbour entrance and in the Mangapai River.

Table 9. Range and median value for enterococci (MPN/100ml) at all Whāngārei Harbour sites 2000-2010.

Site Name	No. of Samples	Range (MPN/100ml)	Median (MPN/100ml)	% of samples within guideline value
Mangapai	18	5 – 20	5	100
Snake Bank	18	5 – 10	5	100
Onerahi	18	5 – 10	5	100
Portland	18	5 – 20	5	100
One Tree Point	46	1 – 10	5	100
Blacksmith's Creek	18	5 – 10	5	100
Marsden Point	63	1 – 31	5	100
Kaiwaka Point	98	1 – 624	5	98
Tamaterau	62	1 – 4611	5	98
Mair Bank	60	1 - 42	5	100
Lower Port Road	18	5 – 697	10	94
Kissing Point	98	1 – 6131	11	89
Limeburners Creek	100	2 – 4884	30	74
Riverside Drive	18	5 – 2005	42	72
Town Basin	97	5 – 2489	53	73
Waiharohia Canal	18	5 – 2005	59	78

3.7 Faecal Coliforms

The MfE has not set a 'safe' limit for faecal coliforms in marine recreational swimming water. The RCP sets a median limit for faecal coliforms in areas with a water classification of 'General quality standard CA' as less than 14/100ml, and a median limit of less than 150/100mL in waters classified as 'Contact Recreation CB' (Northland Regional Council 2004). The Hātea and Mangapai River arms of the harbour are classified as CB and the main body of the harbour is classified as CA (Figure 4). None of the sites located in areas classified as CA had median values that exceeded 14/100 ml (Table 10) but four sites in areas classified as CB had median values that exceeded 150/100 ml.

A very similar spatial trend to enterococci was observed for faecal coliforms with the highest levels recorded in the Hātea River at the Waiharohia Canal, Town Basin, Riverside Drive and Limeburners Creek (Table 10). Sites with the lowest levels of faecal coliforms were again located close to the harbour entrance at Snake bank, One Tree Point, Marsden Point, Mair Bank and Blacksmith's Creek.

Table 10. Range and median value for faecal coliforms (CFU/100ml) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (CFU/100ml)	Median (CFU/100ml)	% of samples within guideline value (<14/100ml CA <150/100ml CB)
Snake Bank (CA)	18	1 – 2	1	100
One Tree Point (CA)	52	1 – 4	1	100
Marsden Point (CA)	62	1 – 20	1	98
Mair Bank (CA)	59	1 – 68	1	97
Blacksmith's Creek (CA)	24	1 – 112	1	93
Portland (CA)	18	1 – 24	2	97
Tamaterau (CA)	62	1 – 6200	2	81
Onerahi (CA)	18	1 – 22	3	93
Mangapai (CB)	18	1 – 160	10	94
Kaiwaka Point (CB)	98	1 – 1860	10	87
Lower Port Road (CB)	18	1 – 850	20	79
Kissing Point (CB)	98	1 - 80000	40	64
Limeburner's Creek (CB)	100	5 – 86000	162	45
Riverside Drive (CB)	18	10 – 3000	200	42
Town Basin (CB)	100	5 – 37000	265	27
Waiharohia Canal (CB)	18	50 – 3000	325	32

3.8 Dissolved Reactive Phosphorus (DRP)

The ANZECC default trigger value is 0.005 mg/l for dissolved reactive phosphorus (DRP) (Australian New Zealand Environment Conservation Council 2000) and the median values for DRP exceeded the trigger value at all 16 sites. The Regional Coastal Plan for Northland sets a standard of 0.01 mg/L for coastal waters classified as 'General quality standard CA' and no standard for waters classified as 'Contact Recreation CB'. The Hātea and Mangapai River arms of the harbour are classified as CB and the main body of the Harbour is classified as CA (Figure 4). There are eight sites located in the area of the harbour classified as CA and three of these sites had median values that exceeded 0.01 mg/L.

Sites with the lowest median concentration of DRP were located near the harbour entrance at Mair Bank, Marsden Point and Snake Bank (Table 11 and Figure 6). The highest median levels

were recorded in the upper Hātea River at Waiharohia Canal, Riverside Drive, Limeburners Creek and the Town Basin. These sites also most frequently exceeded the ANZECC trigger value.

Table 11. Range and median value for dissolved reactive phosphorus (mg/L) at 16 sites in Whāngārei Harbour 2000-2010.

Site Name	No. of Samples	Range (mg/l)	Median (mg/l)	% of samples within standard (<0.01 mg/l CA no standard CB)
Mair Bank (CA)	15	0.005 – 0.028	0.007	73
Marsden Point (CA)	17	0.005 – 0.015	0.008	65
Snake Bank (CA)	17	0.004 – 0.015	0.009	59
One Tree Point (CA)	17	0.005 – 0.025	0.010	59
Blacksmith's Creek (CA)	17	0.005 – 0.018	0.010	53
Tamaterau (CA)	17	0.005 – 0.032	0.015	24
Onerahi (CA)	17	0.010 – 0.032	0.020	12
Portland (CA)	17	0.010 – 0.034	0.023	6
Mangapai (CB)	17	0.010 – 0.032	0.025	NA
Kaiwaka Point (CB)	17	0.013 – 0.048	0.028	NA
Lower Port Road (CB)	16	0.020 – 0.182	0.040	NA
Kissing Point (CB)	17	0.030 – 0.327	0.055	NA
Town Basin (CB)	17	0.017 – 0.200	0.080	NA
Riverside Drive (CB)	17	0.026 – 0.200	0.094	NA
Limeburners Creek (CB)	17	0.028 – 0.910	0.110	NA
Waiharohia Canal (CB)	17	0.030 – 0.210	0.120	NA

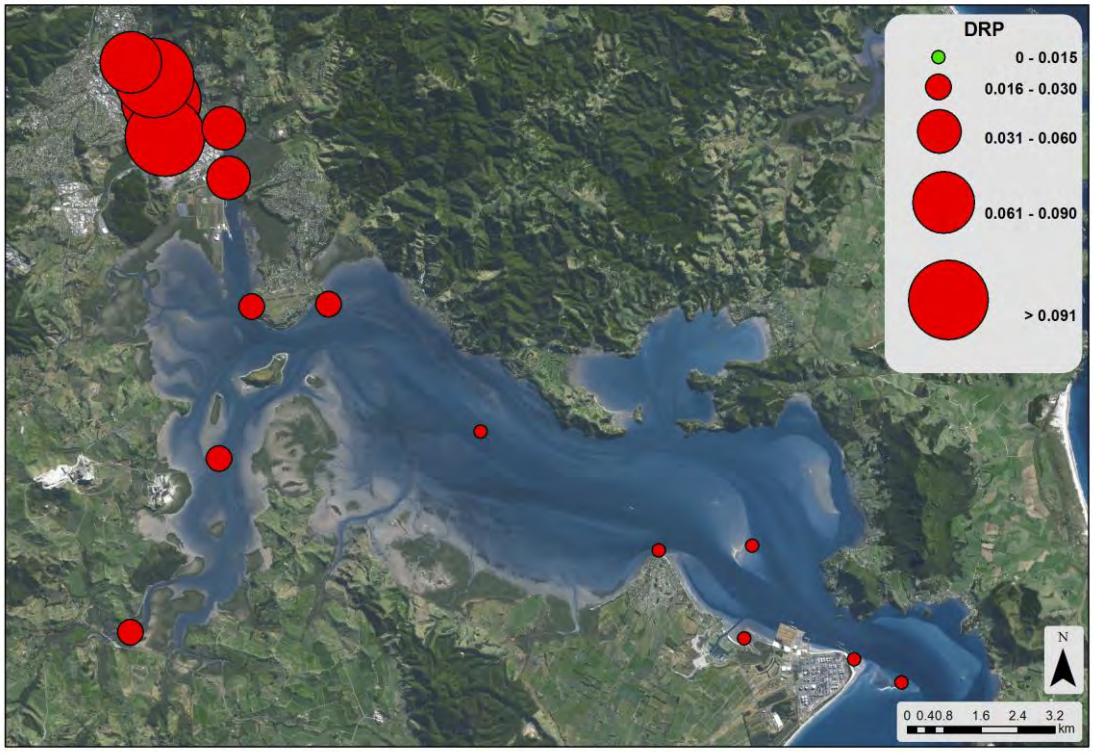

Figure 6. Median values for dissolved reactive phosphorus (mg/L) at 16 sites in the Whāngārei Harbour 2000-2010. Green circles indicate that the median value was within the ANZECC trigger value and red circles indicate that the median value exceeded the ANZECC trigger value.

3.9 Total Phosphorus (TP)

The RCP does not set a limit for total phosphorus but the ANZECC default trigger value is 0.03 mg/l for total phosphorus (Australian New Zealand Environment Conservation Council 2000). The median values at all sites located in the Hātea River and the Mangapai River exceeded the ANZECC default trigger values. In addition none of the samples collected at Waiharohia Canal, Riverside Drive and Kissing Point were within the ANZECC default trigger values (Table 12). The highest median concentrations of total phosphorus were recorded in the upper Hātea River at Waiharohia Canal, Limeburners Creek, Riverside Drive and the Town Basin. Sites with the lowest median concentration of total phosphorus were located near the harbour entrance at Mair Bank, One Tree Point, Marsden Point and Snake Bank (Table 12 and Figure 7).

Table 12. Range and median value for total phosphorus (mg/L) at 16 sites in Whāngārei Harbour, 2000-2010.

Site Name	No. of Samples	Range (mg/l)	Median (mg/l)	% of samples within trigger value (<0.03 mg/l)
Mair Bank	16	0.005 – 0.032	0.014	87
One Tree Point	18	0.005 – 0.031	0.014	94
Marsden Point	18	0.005 – 0.03	0.015	100
Snake Bank	18	0.005 – 0.418	0.016	89
Blacksmith's Creek	18	0.005 – 0.043	0.016	89
Tamaterau	18	0.012 – 0.06	0.024	72
Onerahi	18	0.017 – 0.052	0.033	33
Portland	18	0.021 – 0.066	0.037	33
Mangapai	18	0.024 – 0.063	0.042	11
Kaiwaka Point	18	0.027 – 0.070	0.042	11
Lower Port Road	18	0.029 – 0.197	0.067	6
Kissing Point	22	0.038 – 0.350	0.072	0
Town Basin	22	0.021 – 0.509	0.112	5
Riverside Drive	18	0.054 – 0.220	0.117	0
Limeburners Creek	22	0.013 – 0.970	0.132	5
Waiharohia Canal	18	0.066 – 0.300	0.161	0

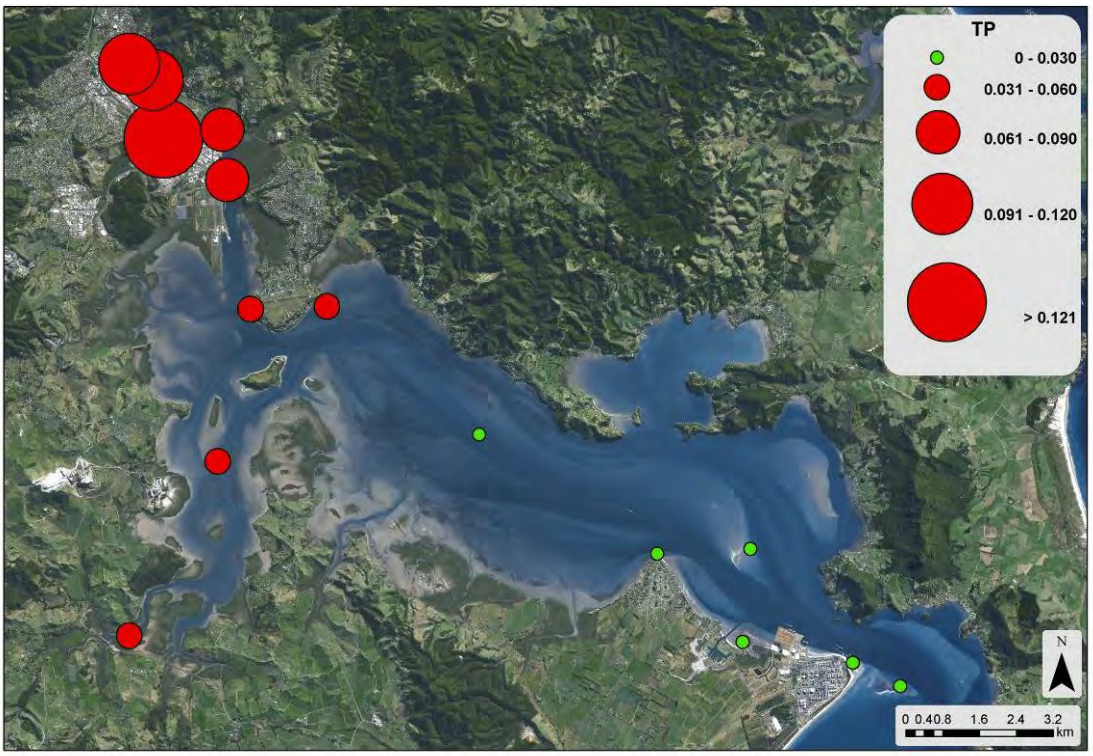

Figure 7. Median values for total phosphorus (mg/L) at 16 sites in the Whāngārei Harbour 2000-2010. Red circles indicate that the median value exceeded the ANZECC trigger value.

3.10 Nitrate-nitrite Nitrogen (NNN)

The ANZECC default trigger value for oxides of nitrogen (NO_X) is 0.015 mg/l. Only three sites had a median value within this trigger value and none of the 16 sites had 100% of samples within the trigger value (Table 13). Sites with the highest median concentrations of NNN were located in the upper Hātea River and sites with the lowest medians were near the harbour entrance and in the Mangapai River (Table 13 and Figure 8).

Table 13. Range and median value for Nitrate-nitrite nitrogen (mg/L) at 16 sites in Whāngārei Harbour 2000-2010.

Site Name	No. of Samples	Range (mg/l)	Median (mg/l)	% of samples within trigger value (<0.015 mg/l)
One Tree Point	20	0.001 – 0.073	0.014	55
Mangapai	14	0.001 – 0.051	0.015	50
Marsden Point	14	0.001 – 0.057	0.015	50
Snake Bank	14	0.001 – 0.049	0.016	50
Onerahi	14	0.001 – 0.083	0.016	50
Mair Bank	13	0.001 – 0.050	0.017	46
Blacksmith's Creek	20	0.001 – 0.067	0.017	50
Portland	14	0.001 – 0.084	0.018	50
Tamaterau	14	0.001 – 0.068	0.022	43
Kaiwaka Point	14	0.011 – 0.130	0.067	21
Lower Port Road	13	0.036 – 0.560	0.122	0
Kissing Point	19	0.035 – 1.000	0.220	0
Limeburners Creek	19	0.067 – 1.500	0.231	0
Town Basin	19	0.172 – 0.980	0.486	0
Riverside Drive	14	0.194 – 0.880	0.525	0
Waiharohia Canal	14	0.185 – 1.600	0.590	0

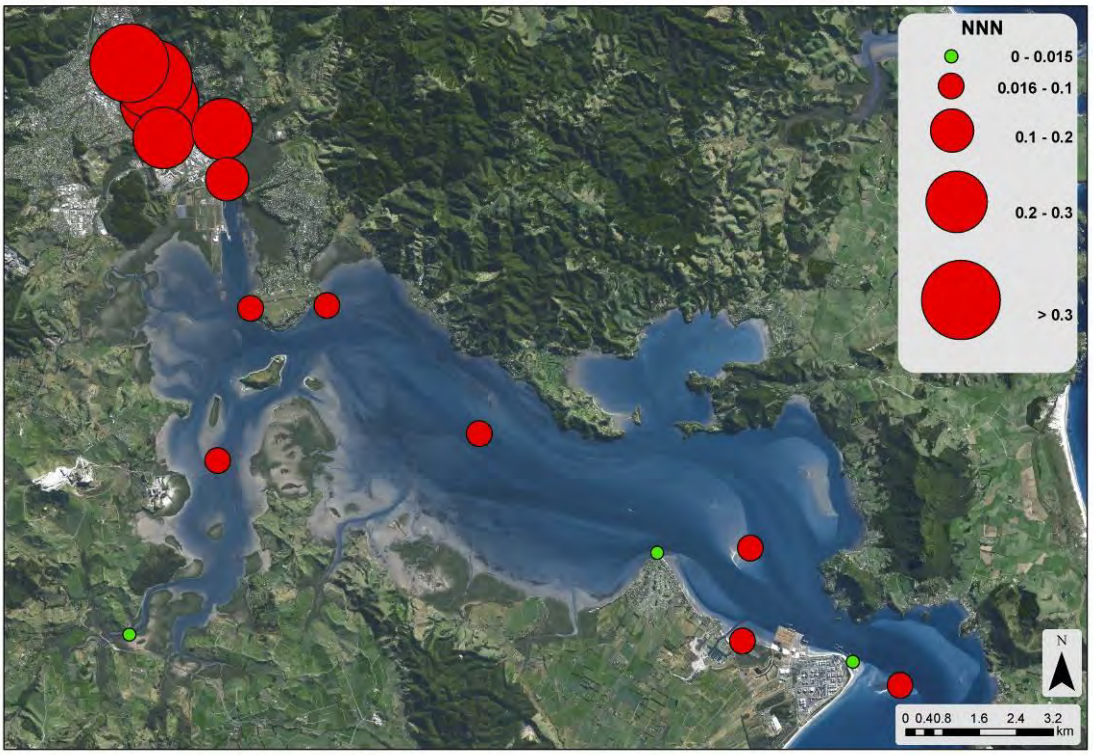

Figure 8. Median values for Nitrate-nitrite nitrogen (mg/L) at 16 sites in the Whāngārei Harbour 2000-2010. Green circles indicate that the median value was within the ANZECC trigger value and red circles indicate that the median value exceeded the ANZECC trigger value.

3.11 Ammonium (NH_4)

The ANZECC default trigger values for ammonium (NH_4) is 0.015 mg/l in estuaries (Australian New Zealand Environment Conservation Council 2000). Seven sites had a median value within this trigger value but none of the 16 sites sampled recorded 100% of samples within the trigger value (Table 14). Sites with the highest levels of NH_4 were located in the Hātea River while the lowest concentrations of NH_4 were found near the harbour entrance and (Table 14 and Figure 9).

The RCP sets a standard of 0.005 mg/L for coastal waters classified as 'General quality standard CA' and no standard for waters classified as 'Contact Recreation CB' (Northland Regional Council 2004). The Hātea and Mangapai River arms of the harbour are classified as CB and the main body of the harbour is classified as CA (Figure 4). There are eight sites located in the area of the harbour classified as CA and three of these sites had median values that exceeded 0.005 mg/L.

Table 14. Range and median value for ammonium (mg/L) at 16 sites in Whāngārei Harbour 2000-2010.

Site Name	No. of Samples	Range (mg/l)	Median (mg/l)	% of samples within trigger value (< 0.015 mg/l)
Snake Bank (CA)	18	0.005 – 0.37	0.005	72
Blacksmith's Creek (CA)	24	0.005 – 0.36	0.005	71
One Tree Point (CA)	24	0.005 – 0.35	0.005	79
Mair Bank (CA)	16	0.005 – 0.37	0.005	87
Marsden Point (CA)	18	0.005 – 0.36	0.005	89
Tamaterau (CA)	18	0.005 – 0.340	0.010	61
Onerahi (CA)	18	0.005 – 0.35	0.011	67
Mangapai (CB)	18	0.005 – 0.35	0.018	39
Portland (CA)	18	0.005 – 0.34	0.019	44
Kaiwaka Point (CB)	18	0.005 – 0.242	0.020	22
Lower Port Road (CB)	18	0.005 – 0.39	0.047	11
Kissing Point (CB)	18	0.005 – 0.504	0.057	11
Town Basin (CB)	18	0.005 – 0.16	0.079	6
Limeburners Creek (CB)	18	0.005 – 2.06	0.087	6
Riverside Drive (CB)	18	0.005 – 0.26	0.096	6
Waiharohia Canal (CB)	18	0.005 – 0.39	0.115	6

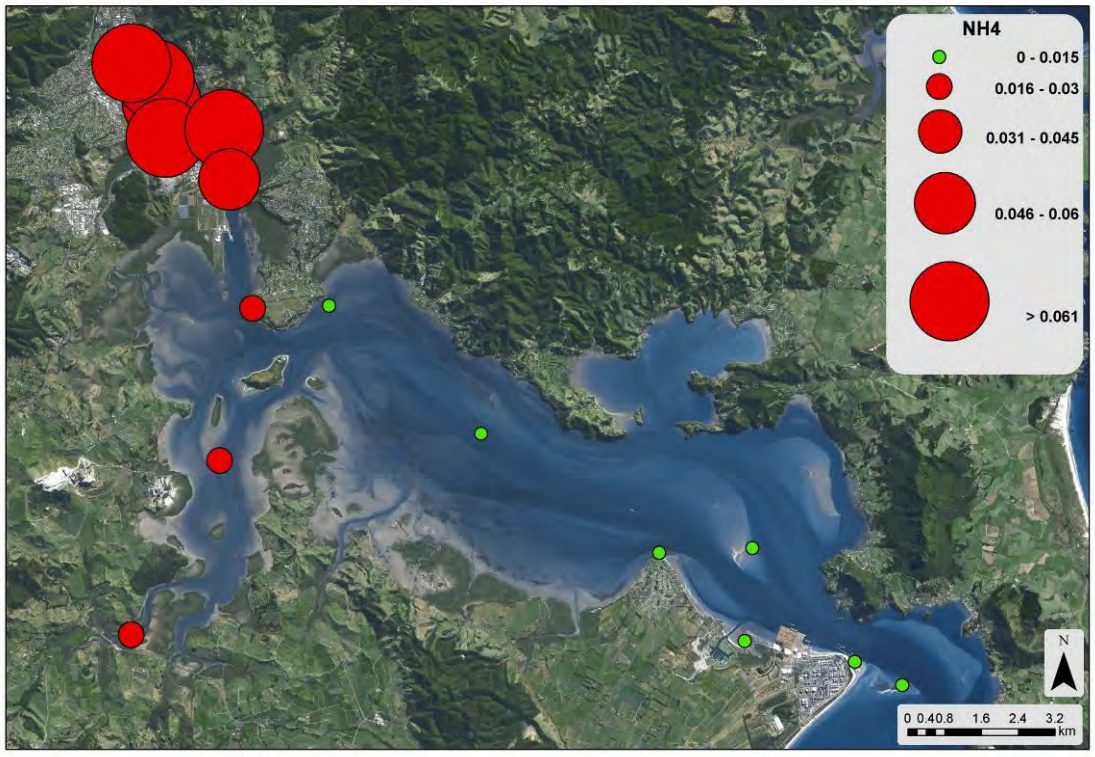

Figure 9. Median values for ammonium (mg/L) at 16 sites in the Whāngārei Harbour 2000-2010. Green circles indicate that the median value was within the ANZECC trigger value and red circles indicate that the median value exceeded the ANZECC trigger value.

3.12 Site rankings

Sites close to the harbour entrance had the lowest average rank, indicating these sites had relatively good water quality (Table 15). In contrast sites in the Hātea River, which are more influenced by freshwater inputs, had high average ranks indicating that these sites had poorer water quality (Table 15). The positive relationship between median salinity rank and average rank (Figure 10) provides further evidence of the influence of freshwater inputs on water quality. As the median salinity increases average water quality rank also increases (Figure 10).

Table 15. Water Quality Index for 16 sites in the Whāngārei Harbour 2000-2010. Sites are ordered by average rank across seven parameters with low rank indicating relatively good water quality and high ranks reflecting poorer water quality.

Site name	Median ranking by parameter							Average ranking
	FC	DRP	TP	NNN	NH_4	Turbidity	Secchi	
Marsden Point	1	2	3	3	1	1	1	1.7
One Tree Point	1	4	2	1	1	1	4	2
Mair Bank	1	1	1	6	1	1	3	2
Blacksmiths	1	4	5	6	1	1	2	2.9
Snake Bank	1	3	6	5	1	2	5	3.3
Tamaterau	2	5	7	8	2	3	6	4.7
Onerahi	3	6	8	4	3	5	7	5.1
Portland	2	6	9	7	5	10	9	6.9
Kaiwaka Point	4	8	10	9	6	6	8	7.3
Mangapai	4	7	10	2	4	12	14	7.7
Lower Port Road	5	9	11	10	7	6	9	8.1
Kissing Point.	6	10	12	11	8	7	11	9.3
Town Basin	9	11	13	13	9	4	10	9.9
Riverside Drive	8	12	14	14	10	8	9	10.7
Limeburners Creek	7	13	15	12	10	11	13	11.6
Waiharohia Canal	10	14	16	15	11	9	12	12.4

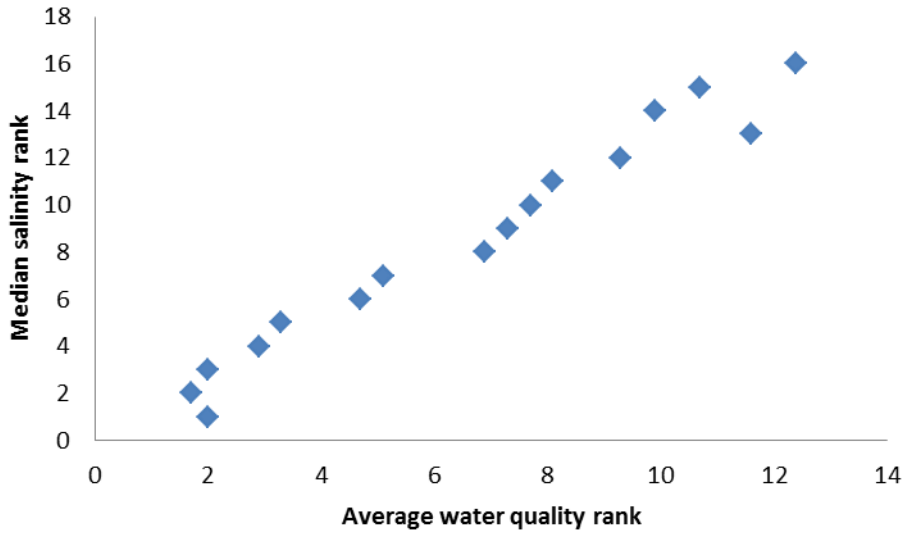

Figure 10. Relationship between median salinity rank and average water quality rank at 16 sites in Whāngārei Harbour 2000-2010.

3.13 Trend analysis

Trend analysis was undertaken on data collected through the State of the Environment monitoring programme over the last ten years for each site. Eight sites have more than ten years of data (not all parameters), one site has five years of available data (not all parameters) and seven sites have three years of available data (see Table 1).

For sites with ten years data, six parameters have been measured consistently throughout this period (dissolved oxygen (% saturation and mg/L), enterococci, faecal coliforms, salinity and temperature) (Table 2). A further five parameters have been measured for three years (turbidity, secchi depth, total phosphorus, dissolved reactive phosphorus and ammonium) and one parameter (nitrate-nitrite nitrogen) has been measured for two years.

The amount of data available for each site and each parameter greatly influences the ability of the software to detect any significant trends over time. The National Groundwater Monitoring Programme (NGMP) software did not detect any significant trends in the data for the seven sites that have only three years data or for the one site that has five years data.

The analysis found a decreasing trend for salinity at six sites (Mair Bank, Marsden Point, One Tree Point, Kaiwaka Point, Kissing Point and Limeburners Creek). This 'trend' is likely to be a consequence of a change in the monitoring practice from always collecting samples at high tide (when salinity will tend to be high) to monitoring at predetermined dates regardless of the stage of the tide.

The analysis also found that enterococci had decreased at two sites (Marsden Point and One tree Point). However, analysis of the data indicated that this apparent 'trend' can be attributed to a change in the laboratory detection limit in 2001 from <1 to < 10. When the data was reanalysed using only data collected after the change in the laboratory detection limits (2001-2010), no trend was detected.

Tamaterau

Both the NGMP and NIWA software indicate a decreasing trend in enterococci (Figure 11) at Tamaterau (P-value < 0.01). A decrease in enterococci is a positive improvement and indicates that there was a decrease in faecal contamination at this site.

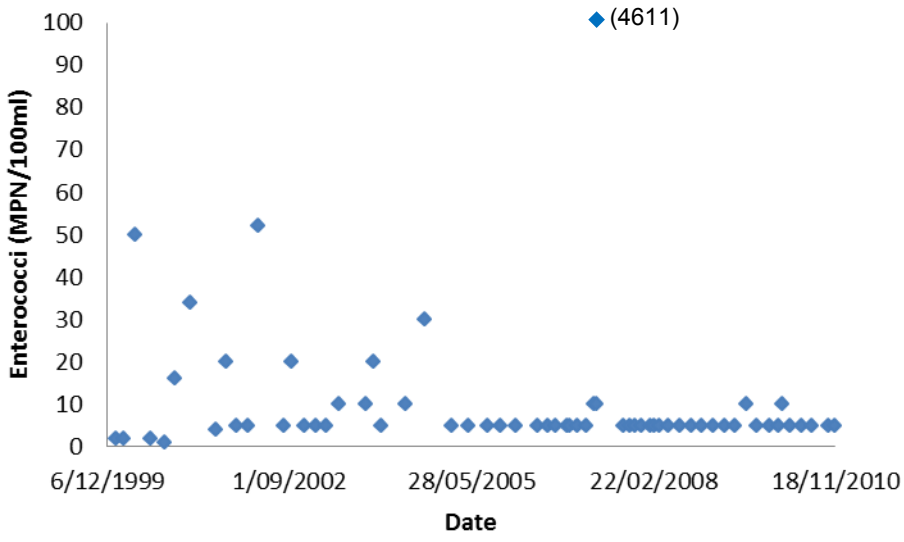

Figure 11. Number of enterococci (MPN/100ml) at Tamaterau, 2000-2010.

Mair Bank

Trend analysis using the NGMP software found an increasing trend in secchi depth (water clarity) at Mair Bank (Figure 12) (P-value = 0.01). The NIWA software also found an increasing trend in secchi depth (P-value = 0.02). An increase in secchi depth is a positive trend and indicates that there has been an increase in water clarity.

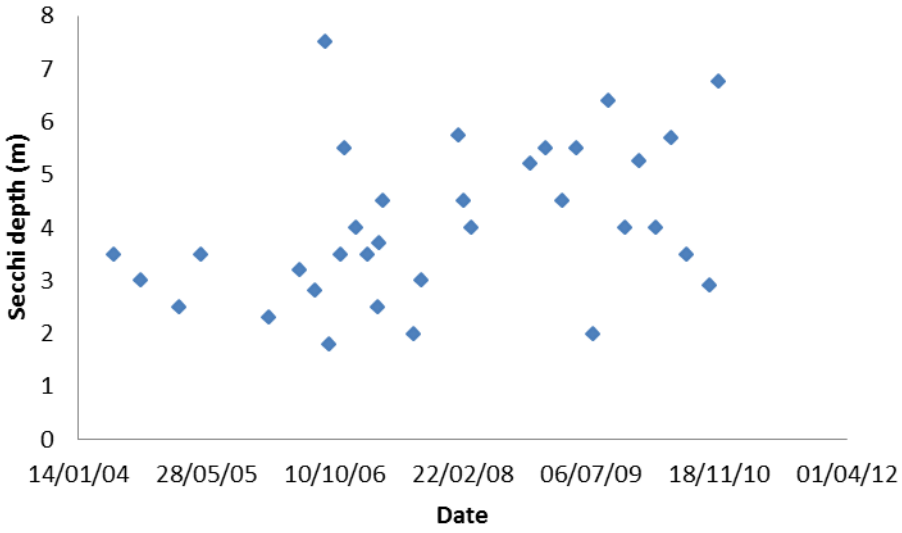

Figure 12. Secchi depth (m) at Mair Bank 2004-2010.

Mangapai River

The NIWA software found a decreasing trend in ammonium (Figure 13) at Mangapai River (P-value = 0.01). A reduction in ammonium is a positive trend. No significant trends were detected for this site using the NGMP software. Results for this site are based on only three years data so more data is required to validate this result.

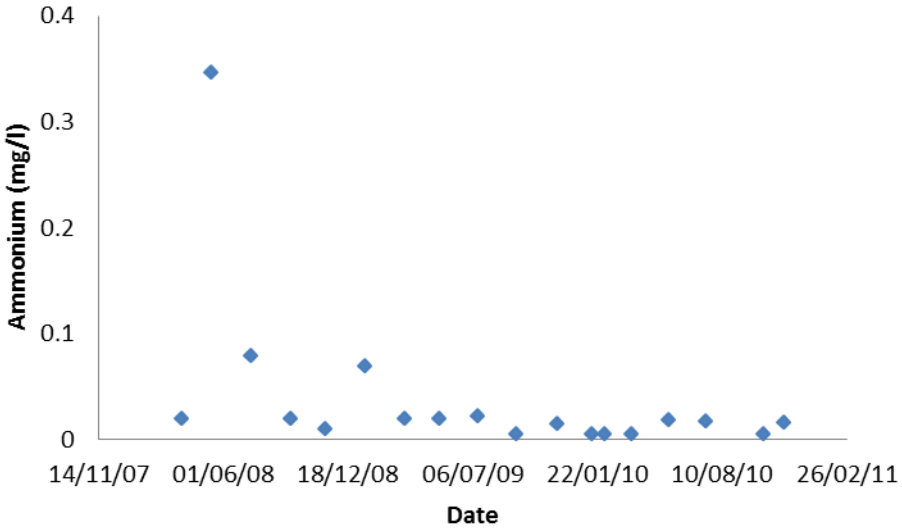

Figure 13. Ammonium (mg/l) at Mangapai 2008-2010.

Marsden Point

The NGMP software found an increasing trend in secchi depth (P-value = 0.03) at Marsden Point (Figure 14). An increase in secchi depth is a positive improvement and indicates that there has been an increase in water clarity.

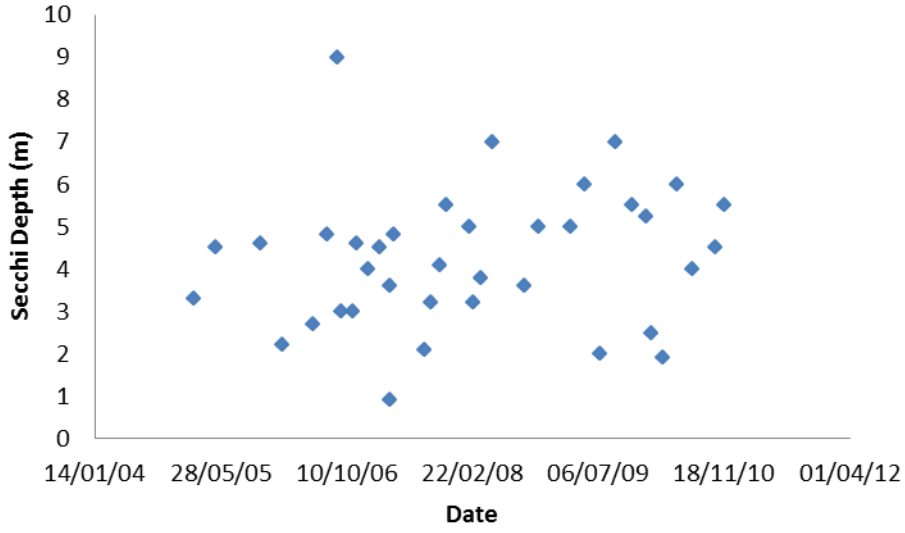

Figure 14. Secchi depth (m) at Marsden Point, 2005-2010.

One Tree Point

The NIWA software found a decreasing trend in ammonium (P-value = 0.02) (Figure 15) and a decreasing trend in total phosphorus (P-value = 0.04) at One Tree Point (Figure 16). Decreases in ammonium and total phosphorous are positive trends.

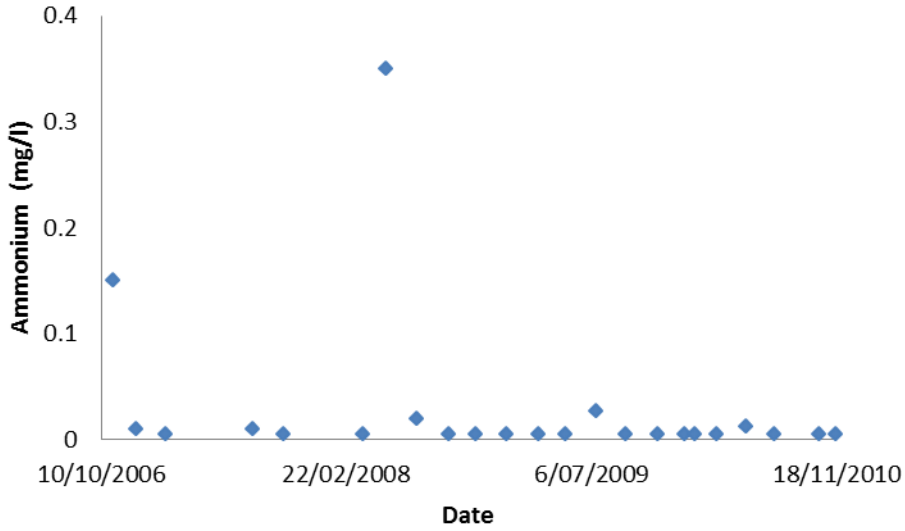

Figure 15. Concentration of ammonium (mg/l) at One Tree Point, 2006-2010.

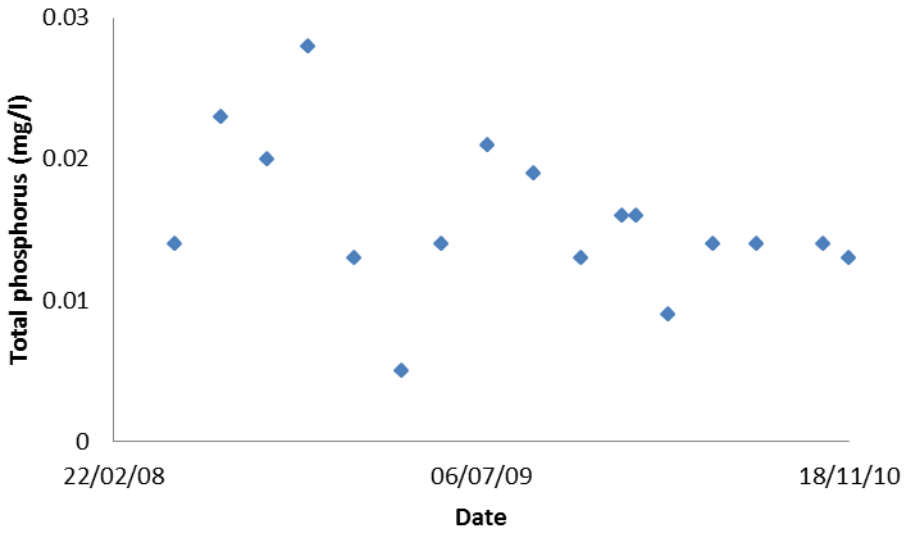

Figure 16. Concentration of total phosphorus at (mg/L) at One Tree Point, 2006-2010.

Onerahi

The NIWA software found an increasing trend in turbidity (P-value = 0.04) at Onerahi (Figure 17). An increase in turbidity is a negative trend and indicates that there was a reduction in water clarity at this site. No significant trends were detected for this site using the NGMP software. Results for this site are based on only three years data so more data is required to validate this result.

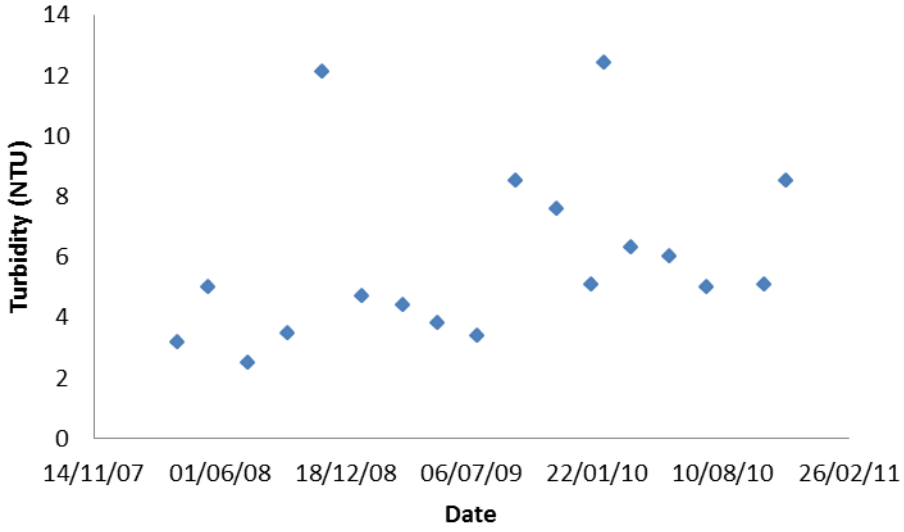

Figure 17. Turbidity (NTU) at Onerahi, 2006-2010.

Kissing Point

Both the NGMP and NIWA software found an increasing trend in secchi depth (water clarity) (P-value = 0.01) at Kissing Point (Figure 18). The NGMP software also found an increasing trend in dissolved oxygen (mg/l) (P-value = 0.01) (Figure 19). No trend was detected for dissolved oxygen (% saturation). An increase in both secchi depth and dissolved oxygen are positive trends.

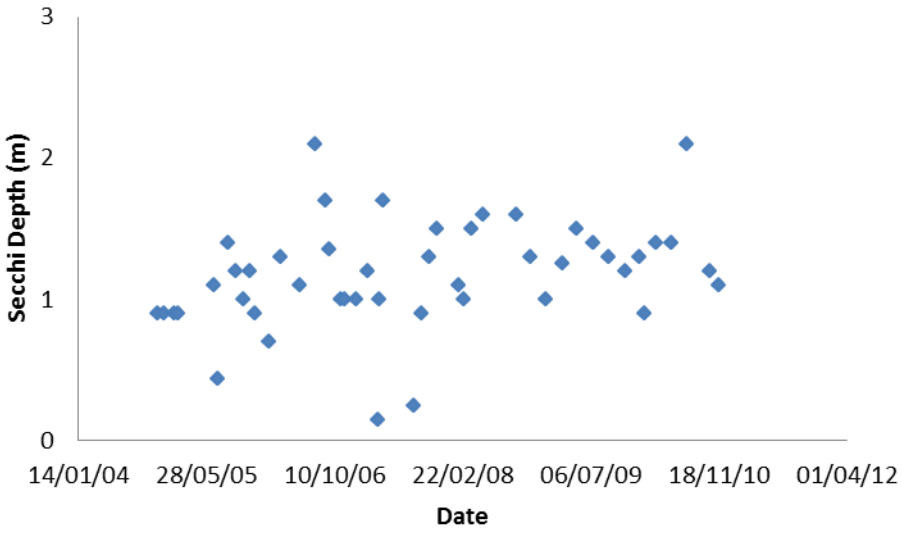

Figure 18. Secchi depth (m) at Kissing Point, 2005-2010.

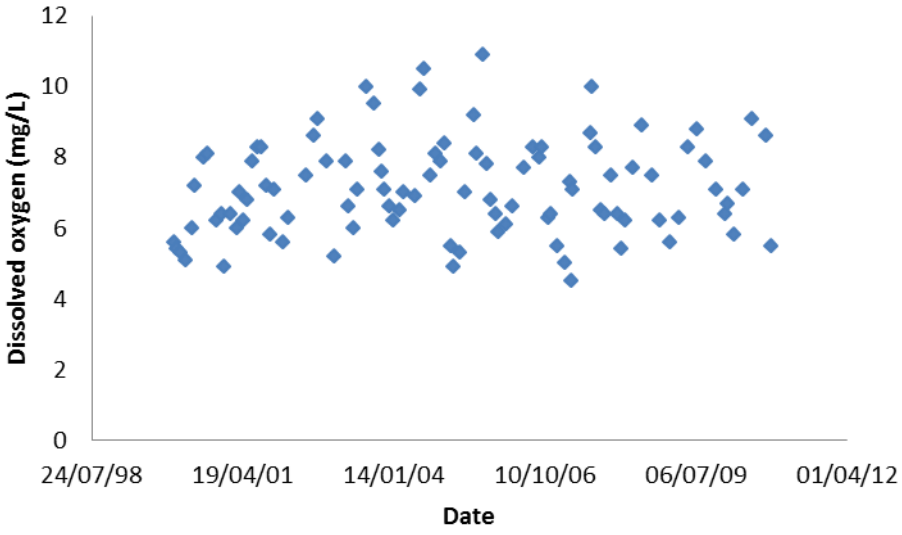

Figure 19. Dissolved oxygen concentration (mg/l) at Kissing Point, 2000-2010.

Limeburners Point

The NGMP software found an increasing trend in dissolved oxygen (P-value = 0.02) at Limeburner's Creek (Figure 20). No trend was detected for dissolved oxygen (% saturation). In this instance an increase in dissolved oxygen is a positive trend.

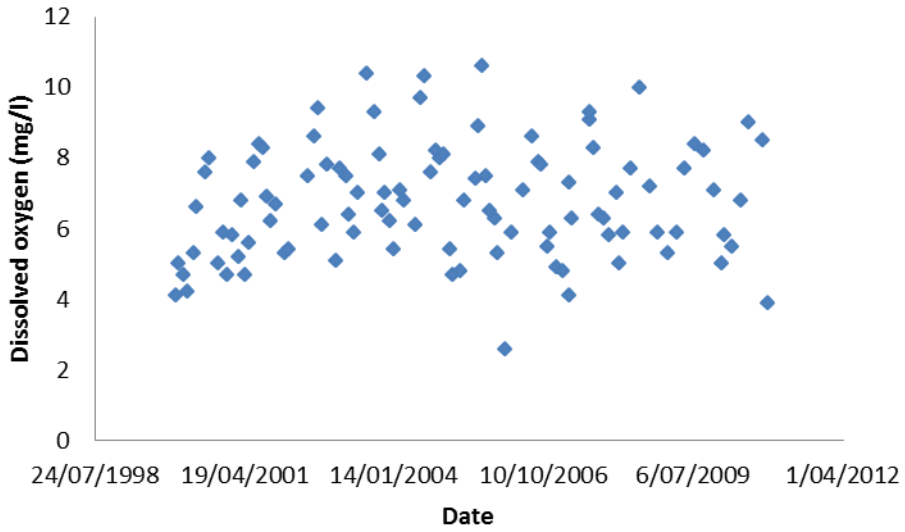

Figure 20. Dissolved oxygen concentration (mg/l) at Limeburner's Creek, 2000-2010.

Kaiwaka Point

The NGMP software found a decreasing trend in faecal coliforms (P-value = 0.02) at Kaiwaka Point (Figure 21). A decrease in faecal coliforms is a positive improvement and indicates that there was a decrease in faecal contamination at this site.

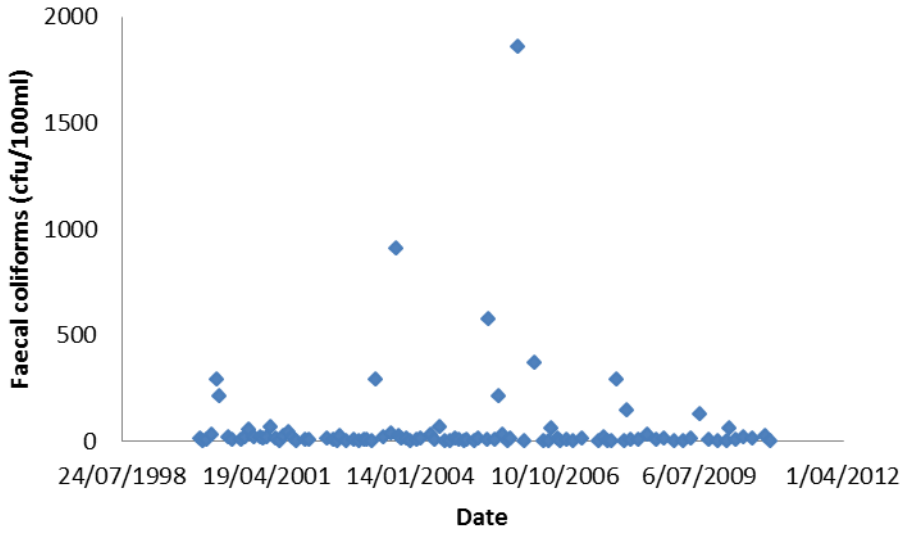

Figure 21. The number of faecal coliforms (cfu/100ml) at Kaiwaka Point, 2000-2010.

Town Basin

The NIWA software found an increasing (improving) trend in dissolved oxygen (P-value = 0.01) at the Town Basin (Figure 22). No trend was detected for dissolved oxygen (% saturation).

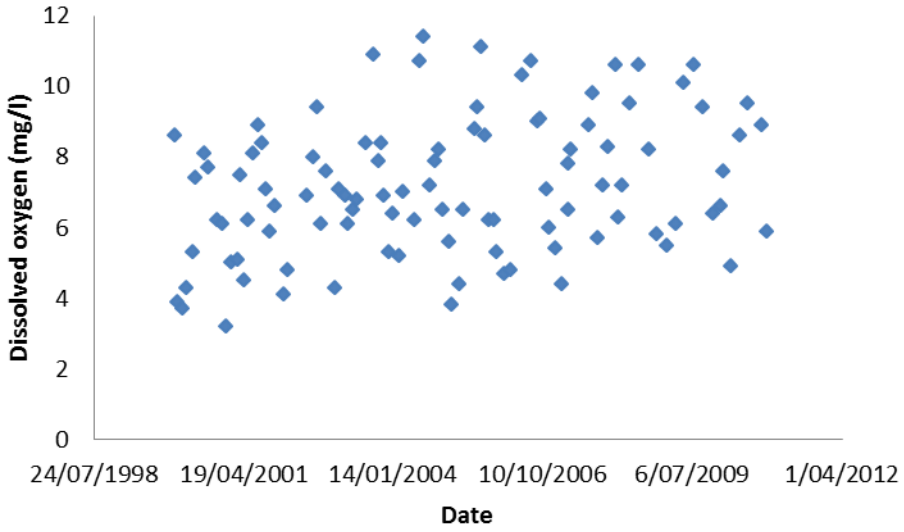

Figure 22. The concentration of dissolved oxygen (mg/l) at Town Basin, 2000-2010.

Riverside Drive

The NIWA software found an increasing trend in turbidity (P-value = 0.03) at Riverside Drive (Figure 23). An increase in turbidity is a negative trend as it indicates that there has been a decrease in water clarity. Results for this site are based on only three years data and should therefore be used with caution. No significant trends were detected for this site using the NGMP software.

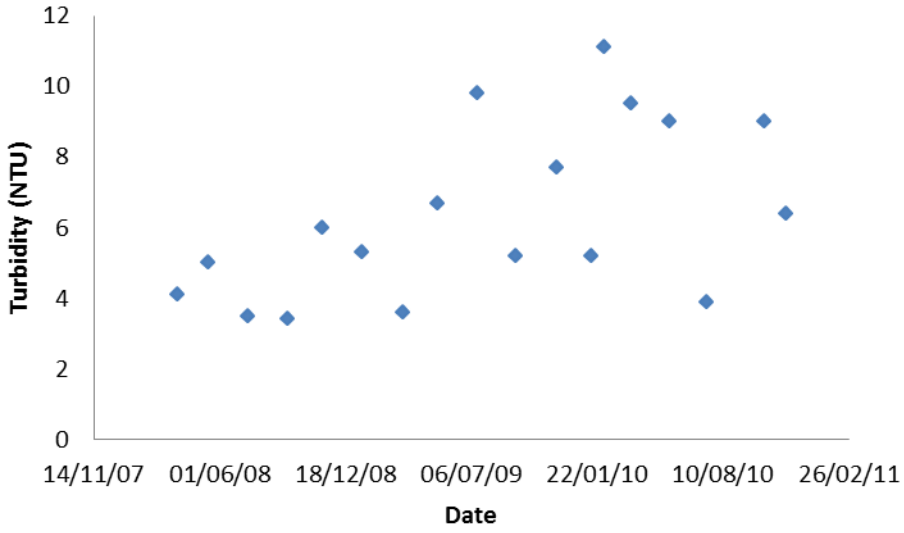

Figure 23. Turbidity at Riverside Drive, 2006-2010.

Other Sites

No significant trends were detected at the following sites using either the NIWA or NGMP software:

- Blacksmiths Creek
- Snake Bank
- Portland
- Lower Port Road
- Waiharohia Canal

3.14 Relationship between water quality variables

In general weak relationships were observed between the different water quality variables (Table 16). The concentration of dissolved oxygen (mg/l) and dissolved oxygen % saturation had a strong positive correlation with each other (Figure 24 and Table 16). Dissolved reactive phosphorus also had strong positive correlations with total phosphorus and ammonium (Figure 25, Figure 26 and Table 16).

Negative correlations were found between salinity and dissolved oxygen (mg/l), turbidity, micro bacteria and nutrient concentrations (Table 16). Although these correlations were generally quite weak this indicates that turbidity, levels of micro bacteria and concentrations of nutrients tend to decrease with distance from freshwater sources.

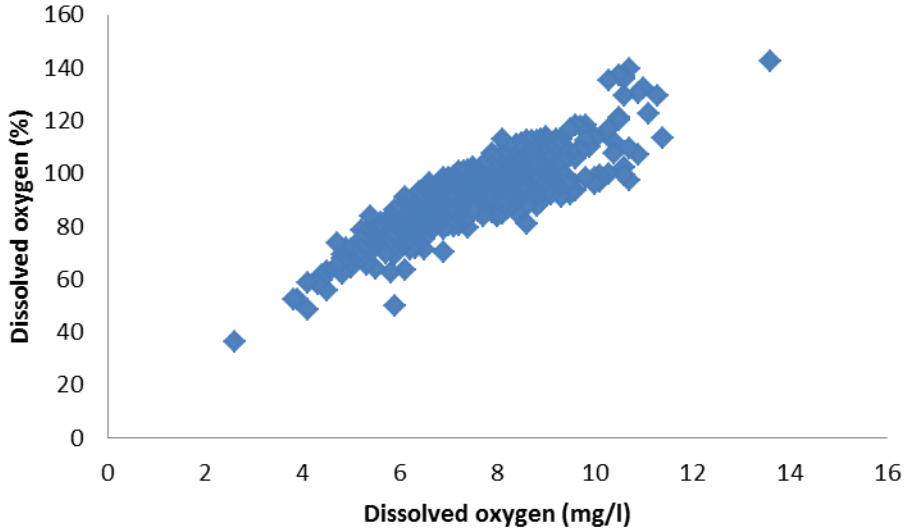

Figure 24. Relationship between dissolved oxygen (mg/l) and dissolved oxygen (% saturation) in Whāngārei Harbour.

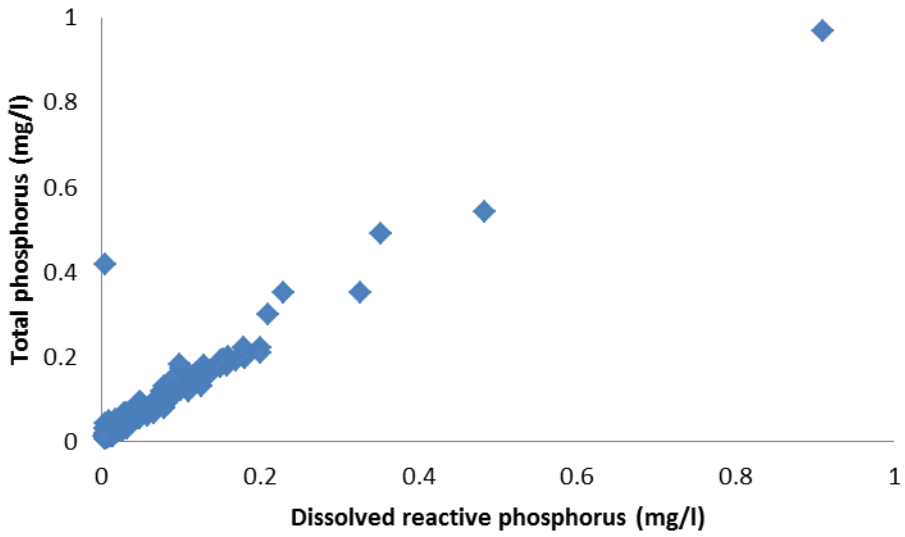

Figure 25. Relationship between dissolved reactive phosphorus and total phosphorus in Whāngārei.

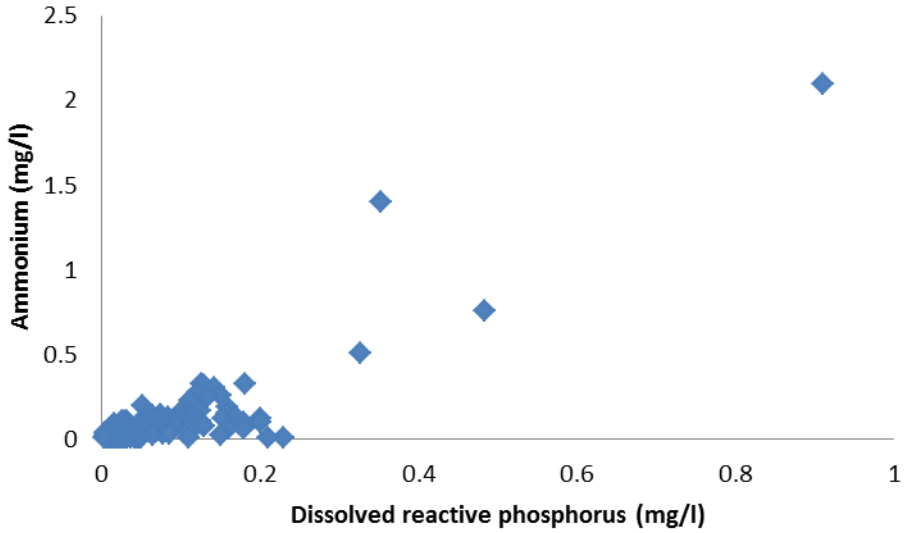

Figure 26. Relationship between ammonium and dissolved reactive phosphorus in Whāngārei Harbour.

Table 16. Pearson correlations and number of samples (N) of water quality parameters measured at 16 sites in the Whāngārei Harbour 2000-2010. Bold indicates correlation coefficients > 0.8.

	DO (mg/l)	DO (%)	DRP	Enterococci	Faecal coliforms	Ammonia	Nitrate nitrite nitrogen	Salinity	Secchi	Temp	Total phosphorus
Dissolved oxygen (%)	**0.855** N = 618										
Dissolved reactive phosphorus	-0.216 N = 258	-0.506 N = 252									
Enterococci	-0.022 N = 726	-0.139 N = 596	0.091 N = 278								
Faecal coliforms	-0.058 N =727	-0.126 N = 585	0.171 N = 270	0.442 N = 735							
Ammonia	-0.122 N = 300	-0.344 N = 281	**0.860** N = 278	0.091 N = 311	0.137 N = 303						
Nitrate-nitrite nitrogen	0.044 N = 234	-0.289 N = 215	0.621 N = 230	0.199 N = 245	0.394 N = 237	0.349 N = 245					
Salinity	-0.252 N = 748	0.113 N = 597	- 0.385 N = 277	-0.283 N = 742	-0.370 N = 743	-0.298 N = 310	-0.676 N = 244				
Secchi	0.177 N = 347	0.428 N = 332	-0.357 N = 255	- 0.283 N = 359	-0.128 N = 345	-0.152 N =273	-0.394 N = 226	0.462 N = 359			
Temperature	-0.716 N = 752	-0.410 N = 601	0.110 N = 278	-0.026 N = 747	0.039 N = 747	0.005 N = 311	-0.114 N = 245	0.288 N = 768	-0.095 N = 359		
Total phosphorus	-0.265 N = 289	- 0.517 N = 272	**0.951** N = 270	0.239 N = 300	0.241 N = 300	0.743 N = 300	0.639 N = 234	-0.368 N = 299	- 0.387 N = 265	0.140 N = 300	
Turbidity	-0.008 N = 420	-0.217 N = 385	0.214 N = 278	0.478 N = 419	0.757 N = 421	0.121 N = 293	0.235 N = 229	-0.443 N = 438	-0.495 N = 351	-0.026 N = 439	0.248 N = 285

4. Discussion

4.1 Turbidity and secchi depth

Both secchi depth and turbidity are a measure of water clarity. Water clarity can be reduced by the growth of phytoplankton and human activities that increase levels of suspended solids entering the coastal environment. High levels of material in the water column can restrict light transmission which affects the amount of photosynthesis (primary production) of aquatic plants and consequently other species that are dependent on them such as fish and shellfish. Seaweeds and seagrass typically require more light for photosynthesis than phytoplankton and are particularly susceptible to reduced light levels of suspended sediments by nature of being attached to the seabed (Thrush *et al*. 2004). Suspended sediments can also clog fish gills and reduce the ability of fish to see prey and detect predators (ANZECC 2000). High levels of suspended solids may also protect bacteria from ultraviolet light, (Oliver and Cosgrove 1975).

There is currently no ANZECC default trigger value for secchi depth but the relevant ANZECC trigger value for turbidity for estuarine and marine is 0.5-10 NTU (Australian New Zealand Environment Conservation Council 2000). All 16 sites had median values within the ANZECC default trigger value.

A similar spatial trend was observed for both turbidity and secchi depth. Sites with the highest secchi depth and lowest turbidity (highest water clarity) were located near the harbour entrance and sites with the highest turbidity and the lowest secchi depth (lowest water clarity) were located in the Hātea River and Mangapai River. The site in the Mangapai River had the highest median turbidity and the lowest median water clarity. Generally areas that receive freshwater input will have higher turbidity as this freshwater input carries material entrained in run-off from the land or from river and stream bank erosion. These areas are also depositional zones of sediment, due to flocculation of sediments within the fresh/saline water mixing interface. Therefore these areas are susceptible to re-suspension of 'historically' deposited material also contributing to higher turbidity. The direct discharge of material from consented and non-consented activities may also affect the level of turbidity at some sites.

4.2 Dissolved oxygen

Dissolved oxygen is the measure of the amount of oxygen that is dissolved in water. The oxygen dissolved in the water is essential for all plants and animals living in it and if dissolved oxygen levels drop below normal levels plants and animals may become stressed, die or migrate to other areas. Dissolved oxygen concentrations that exceed 110% can also be harmful and fish in water containing excessive dissolved oxygen may suffer from 'gas bubble disease' although this is very rare.

Oxygen enters estuaries and marine waters from stream and rivers, groundwater, diffusion from the atmosphere and as a waste product from photosynthesis. Plants and animals use oxygen during respiration and bacteria can consume oxygen during the decay of organic matter. If nutrient enrichment causes excess plant growth, dissolved oxygen levels may fall as oxygen is consumed by bacteria that break down the organic matter.

Healthy freshwater aquatic ecosystems generally have dissolved oxygen above 6mg/L, however there is currently no relevant ANZECC default trigger value for the concentration of dissolved oxygen. The relevant ANZECC default trigger value for dissolved oxygen (% saturation) is between 80 and 110% saturation (Australian New Zealand Environment Conservation Council 2000).

A similar spatial pattern was observed for both the concentration of dissolved oxygen and dissolved oxygen saturation. Sites near the entrance to the harbour generally had higher dissolved oxygen than sites in the Hātea River and Mangapai River. Sites located in the Hātea River and Mangapai River also generally had higher temperatures, higher concentrations of nutrient enriched and low water clarity. This suggests that there was more phytoplankton and organic material at these sites which might have reduced the dissolved oxygen levels.

4.3 Micro-bacteria

Enterococci and faecal coliforms are micro bacteria that indicate faecal contamination. The RCP does not set a limit for enterococci bacteria but MfE sets the 'safe' limit for marine recreational swimming water quality at less than 140 enterococci/100mL per single sample from a site (Ministry for the Environment and the Ministry of Health 2003). The median number of enterococci was below 140 per 100mL at all 16 sites and at seven sites all of the samples collected were below 140/100ml.

The MfE has not set a 'safe' limit for faecal coliforms in marine recreational swimming water but the RCP sets the median limit for faecal coliforms in areas which have been classification for CA as less than 14/100ml and in areas classified for CB as less than 150/100mL (Northland Regional Council 2004). None of the sites located in areas classified as CA had median values that exceeded 14/100ml (Table 10) but four sites in areas classified as CB had median values that exceeded 150/100ml.

Similar spatial patterns were observed for both enterococci and faecal coliforms, with the highest numbers of both micro-bacteria recorded at sites in the Hātea River. The lowest numbers of both micro bacteria were generally recorded at sites near to the entrance of the harbour. Sites in the Hātea River receive freshwater input from the surrounding catchment (which may carry bacteria entrained in run-off from the land), and are located close to treated and untreated discharges of waste water. Enterococci can also occur naturally in mangroves so sites with a lot of mangroves nearby may naturally have elevated levels of Enterococci. In contrast the sites near the harbour entrance are located furthest from freshwater inputs and are more influenced by coastal water.

4.4 Nutrients

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertilizer, storm water runoff and treated wastewater discharges may exceed the needs of an ecosystem. Too much nutrients can cause excessive plant growth leading to algal blooms and lowered levels of dissolved oxygen. This can reduce the life-supporting capacity of the ecosystem, as well as posing a human health risk both through contact with toxic algal blooms and the health effects of eating contaminated shellfish.

The current scientific consensus is that nitrogen is the main limiting nutrient in coastal waters, particularly in the summer and where bacterial denitrification rates are high, but that phosphorus limitation may be important in spring (Rees 2009). Consequently it is important to monitor and manage the levels of both nitrogen and phosphorus.

Nitrogen

Nitrate-nitrite nitrogen is a common contaminant in rural and urban areas and originates from waste water discharges, septic systems, fertilisers and animal effluent. Nitrate may also occur naturally due to the dissolution of nitrate bearing rock within the aquifer.

The main sources of ammonium to coastal water include livestock effluent entrained in rainfall run-off, wastewater (including sewage and household wastewater containing ammonia based cleaning products), industrial discharges and atmospheric deposition of ammonia from combustion.

The relevant ANZECC default trigger value for ammonium and nitrate-nitrite-nitrogen are both 0.15mg/L (Australian New Zealand Environment Conservation Council 2000) and the RCP sets a limit of 0.06 for nitrate-nitrite-nitrogen and 0.005 form ammonium for areas classified for General Water Standard CA (Northland Regional Council 2004). The median concentration of nitrate-nitrite-nitrogen exceeded the ANZECC trigger value at 13 sites and the median value of ammonium exceeded the ANZECC trigger value at seven sites.

Similar spatial patterns were observed for both ammonium and nitrate-nitrite nitrogen with the lowest concentrations generally recorded near the harbour entrance and the highest concentrations recorded at sites in the Hātea River. Sites in the Hātea River are influenced by freshwater input from the Hātea River which drains a relatively large proportion of the entire harbour catchment. The majority of the urban area of the city of Whāngārei is located in the catchment that drains into the Hātea River. The Whāngārei waste water treatment plant also discharges into the Limeburner's Creek and there are a number of consented industrial discharges in the Hātea River. Interestingly, the median concentration of nitrate-nitrite nitrogen recorded at Mangapai was very low compared to other sites and the median concentration of ammonium was lower than all the sites located in the Hātea River. This suggests that the main sources of both ammonium and nitrate-nitrite nitrogen to the Harbour was the Hātea River catchment rather than the Mangapai River catchment.

Phosphorus

Phosphorus occurs naturally in water as a result of the weathering of rocks and soils, and the decomposition of organic material. Human sources of phosphorus include human sewage, cleaning products and detergents, fertilizers and animal effluent. Human activities such as urban development and forestry that can cause soil erosion will also release phosphorus which may reach waterways. The drainage of wetlands for development may also expose phosphorus that was buried. Industrial discharges may also contain phosphorus as polyphosphates are sometimes added to water to prevent iron oxides or calcium carbonates.

The measurement of total phosphorus includes the total of all filterable and particulate forms of phosphorus. Dissolved reactive phosphorus (DRP) is the fraction that consists largely of inorganic orthophosphate (PO_4) form of phosphorus. The inorganic orthophosphate fraction is the form of phosphorus form that is directly taken up by algae. The amount of dissolved reactive phosphorus therefore indicates the amount of phosphorus that is immediately available for algal growth.

The median concentrations of total phosphorus at all sites located in the Hātea and Mangapai River arms of the Harbour exceeded the relevant ANZECC default trigger value and the median concentrations of DRP exceeded the relevant ANZECC trigger value at all 16 sites.

The high concentrations of phosphorus in the Whāngārei Harbour were likely due to sediment erosion and anthropogenic activity within the catchment. Agricultural activity, including the application of phosphorus fertiliser and livestock effluent will have contributed to the amount of phosphorus entering the harbour through run-off and effluent discharges. Discharges from the water treatment plan and other industrial discharges are also likely to have contributed.

Similar spatial patterns were observed for both total phosphorus and DRP with the lowest concentrations generally recorded near the harbour entrance and the highest concentrations recorded at sites in the Hātea River. Sites in the Hātea River are influenced by freshwater input

from the Hātea River catchment which drains a relatively large proportion of the entire harbour catchment and the majority of the area that comprises the city of Whāngārei. The Whāngārei waste water treatment plant also discharges into the Limeburner's Creek and there are a number of consented industrial discharges into the Hātea River.

4.5 Relationship between parameters

In general weak relationships were observed between most water quality variables. The concentration of dissolved oxygen and dissolved oxygen saturation had a strong positive correlation with each other as would be expected. Dissolved reactive phosphorus also had strong positive correlations total phosphorus and ammonia. Weak negative correlations were found between salinity and dissolved oxygen (mg/l), turbidity, micro bacteria and concentrations of nutrients, which indicates that these parameters tend to decrease with distance from freshwater sources.

4.6 Trend analysis

Trend analysis found an increase in secchi depth at three sites, which is a positive trend, indicating that water clarity had improved. Two of these sites are located in the outer harbour and one in the mid-harbour area. However, the analysis also found that turbidity had increased at two sites (Onerahi and Riverside Drive), indicating that water clarity had decreased at these sites, which is a negative trend.

Dissolved oxygen concentrations (mg/L) had increased at three sites in the Hātea River (Kissing Point, Limeburner's Creek and the Town Basin), which is a positive trend. The number of faecal coliforms at Tamaterau had decreased which is a positive trend. Total phosphorus increased and ammonia decreased at One Tree Point and ammonia also decreased at the Mangapai River, which are positive trends.

4.7 Conclusion

Analysis of data collected over the last ten years for 16 sites in the Whāngārei Harbour has shown that sites with the best water quality were located near the harbour entrance and sites with the lowest water quality are located in the Hātea River.

Looking at the long term median values for each site and ranking them based on their average median ranking, the site at Marsden Point appears to have the best water quality and the site at the Waiharohia Canal appears to have the worst water quality.

Of the parameters where default trigger values have been developed by ANZECC, the median value was within the recommended guideline for turbidity, dissolved oxygen (%) and enterococci at all sites.

Four out of 16 sites had a median value that fell outside of the guideline value for faecal coliforms; 16 out of 16 sites had a median value that fell outside of the guideline value for dissolved reactive phosphorus; 10 out of 16 sites had a median that fell outside of the guideline value for total phosphorus; 13 out of 16 sites had a median value that fell outside of the guideline value for nitrate-nitrite nitrogen and nine out of 16 sites had a median value that fell outside of the guideline value for ammonium.

No site recorded 100% of samples within the guideline value for DRP, NNN and NH_4 and only one site recorded 100% of samples within the guideline for TP.

Trend analysis found positive trends for a number of parameters at specific sites but no consistent pattern in water quality trends was apparent throughout the harbour. For example trend analysis found that the secchi depth had increased at three sites, which indicates that water clarity had improved at these sites but turbidity had decreased at two sites, which indicates that water clarity had deteriorated at these sites.

4.8 Recommendations

- Continue bi-monthly sampling of coastal water quality at the same 16 sites in the Whāngārei Harbour to monitor the state and trends over time and identify any emerging environmental issues.

- Review available data again in five years time, when sufficient data has been collected for nutrient parameters to identify trends.

- Where negative trends are detected, or environmental issues identified, undertake further investigations to determine the cause. Identify the process and pathways of contaminants entering the harbour and implement management initiatives to mitigate these sources and improve water quality.

- Review the management aims and objectives of the different zones and existing water quality standards in the RCP.

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6. Appendices

Appendix 1: Land use cover in the Whāngārei Harbour catchment

Land Classes in Whāngārei Harbour catchment from New Zealand Land Cover Database (2001).

1st Order Class	2nd Order Class	Area (Ha)	Percentage
Artificial Surfaces **(10%)**	Built-up Area	2357	8
	Urban Parkland/ Open Space	576	2
	Surface Mine	148	1
	Transport Infrastructure	6	>1
Bare/lightly vegetated surfaces **(>1%)**	Coastal Sand and Gravel	12	>1
	River and Lakeshore Gravel and Rock	2	>1
Water Bodies **(>1%)**	Lake and Pond	57	>1
	River	8	>1
	Estuarine Open Water	0	>1
Cropland **(>1%)**	Short-rotation Cropland	69	>1
	Vineyard	12	>1
	Orchard and Other Perennial Crops	270	1
Grassland (**50%)**	High Producing Exotic Grassland	14541	49
	Low Producing Grassland	134	>1
	Herbaceous Freshwater Vegetation	9	>1
Sedgeland Saltmarsh **(>1%)**	Herbaceous Saline Vegetation	43	>1
Scrub and Shrubland **(7%)**	Gorse and Broom	267	1
	Manuka and or Kanuka	1592	5
	Broadleaved Indigenous Hardwoods	265	1
	Mixed Exotic Shrubland	15	>1
Forest **(31%)**	Major Shelterbelts	13	>1
	Afforestation	199	1
	Forest Harvested	413	1
	Pine Forest - Closed Canopy	1130	4
	Pine Forest - Open Canopy	1170	4
	Other Exotic Forest	94	>1
	Deciduous Hardwoods	47	>1
	Indigenous Forest	5903	20
	Mangrove	157	1
Total		**29507**	**100**

Appendix 2: Programme changes

- **Site locations**:
  Water Quality in the Whāngārei Harbour has been regularly monitored since 1986. Originally, the programme monitored 15 “upper harbour” sites between Onerahi and the Town Basin, and 33 sites in the “mid to lower harbour”, between Onerahi and the Whāngārei Heads. .

  In 2006, the “upper harbour” and “mid to lower harbour” runs were combined. By 2007, only 20 sites were being monitored through the programme.

  In 2007, a review of marine water quality was undertaken by the Council and the National Institute of Water and Atmospheric Research (NIWA). As a result of this review, the number of sites was reduced to 16. This change was implemented in 2008.

- **Frequency**:
  From 1986 – 1998, the “upper harbour” run was undertaken at two-weekly intervals. From 1998, it was carried out monthly.

  From 1989, the “mid to lower harbour” run was undertaken bi-monthly.

  In 2008, sampling was changed to bi-monthly for all sites monitored.

- **Tide:**
  Prior to 2007, sampling was always undertaken at high tide.

  Following a review of the programme in 2007, sampling is now timed to coincide with the River Water Quality Monitoring Network sampling and as such, is undertaken regardless of tide.

- **Sampling parameters**:
  From 1986, salinity, temperature and dissolved oxygen were recorded at each site and a water sample taken for faecal coliforms. From 1999, this sample was also analysed for enterococci bacteria.

  From July 2002, the dissolved oxygen percentage (DO%) was also measured and from September 2004, turbidity was also included.

  From February 2005, secchi measurements (a measure of water clarity) were taken. From March 2008, dissolved reactive phosphorus (DRP), total phosphorus (TP) and ammonia (NH4) were also measured. Nitrite/Nitrate/Nitrogen (NNN) has been measured since November 2008.

Appendix 3: Whāngārei Harbour sampling site co-ordinates

Site name	X	Y
Town Basin	1719871	6045912
Riverside Drive	1720380	6045570
Waiharohia Canal	1720529	6045073
Limeburners Creek	1720611	6044292
Kissing Point	1721885	6044481
Lower Port Road	1721994	6043396
Kaiwaka Point	1722500	6040598
Onerahi	1721786	6037296
Portland	1724164	6040654
Mangapai River	1719865	6033523
Tamaterau	1726701	6039908
One Tree Point	1731336	6035303
Snake Bank	1733359	6035404
Blacksmiths Creek	1733188	6033389
Marsden Point	1735580	6032934
Mair Bank	1736610	6032428

All co-ordinates in GD2000, NZTM.

Appendix 4: Regional Coastal Plan for Northland Coastal Water Quality Standards

The following standards apply to coastal waters classified under this Plan, and differ from those specified in the Third Schedule of the RMA

	Standards for Coastal Waters		
Standard	**Natural Quality Standard CN**	**General Quality Standard CA**	**Contact Recreation Standard CB**
Purpose	Protection of natural state	Provides for virtually all uses and protection of marine ecosystems	Provides for contact recreation in coastal waters
Natural temperature	Shall not be altered	Not changed by more than $3^{o}C$	n/a
Natural pH	"	Not changed by more than 0.2 units	n/a
Concentration of dissolved oxygen	"	Not reduced below 80% saturation	n/a
Natural visual clarity	"	Not reduced more than 20%	
Natural hue	"	Not changed more than 10 Maunsell units	
Natural euphotic depth	"	Water deeper than $0.5.z_{eu}$ not changed more than 10% Water shallower than $0.5.z_{eu}$ maximum reduction in light at sediment bed not more than 20%	n/a
Oil/grease film, scum, foam, odour	"	No conspicuous oil or grease film, scums or foams, floatable or suspended materials, or emissions of objectionable odour	
Toxic Metals	"		
Total Arsenic	"	50 mg/m^3	n/a
Total Cadmium	"	2 mg/m^3	n/a
Total Chromium	"	50 mg/m^3	n/a
Hexavalent Chromium	"	-	n/a
Total Copper	"	5 mg/m^3	n/a
Total Lead	"	5 mg/m^3	n/a
Total Zinc	"	50 mg/m^3	n/a
Faecal Coliforms	"	Based on not fewer than 10 samples within any 30 day period median < 14/100 ml 90%ile < 43/100 ml	Based on not fewer than 5 samples within any 30 day period median < 150/100 ml 80%ile < 600/100 ml
Nutrients (Default standards in the absence of specific site investigations)	"	DRP 1-10 mg/m^3 NO_3-N 10-60 mg/m^3 NH_4-N <5 mg/m^3	Nutrient levels are not relevant to waters managed for contact recreation.
Other toxicants and parameters	"	As per Table 2.1 of ANZECC Water Quality Guidelines 1992 as appropriate	As per Drinking Water Standards for New Zealand 1989

The following additional standard shall also apply to specific coastal waters classified for Cultural Purposes (as shown in Regional Coastal Plan Maps).

Appendix 5: Ammonium calculations

Unionized ammonia (NH3) was calculated using the following formula. The actual temperature and salinity measured in the field were used for the calculations but because pH is not usually measured, site means were calculated and used for the calculation.

Unionized Ammonia (NH3) = (17*NH3-N)
/(14*(1+10^((0.09018+(2729.92/(Temperature+273.15))+((0.1552-(0.0003142*Temperature))*((19.9273*salinity)/(1000-(1.2005109*salinity)))))-pH)))

Ammonium was then calculated by subtracting the unionized ammonium value from the total ammoniacal nitrogen value, as below

Ammonium (NH4+) = Total ammoniacal nitrogen (NH3-N), - Unionized Ammonia (NH3)

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DARGAVILLE: 61B Victoria Street, Dargaville; Phone 09 439 3300, Fax 09 439 3301.
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