Coastal Water Quality Monitoring:

2010-2014 Results

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1. Introduction

The Northland Regional Council (the council) carries out routine state of the environment monitoring of the region's coastal water quality to assess its state, identify environmental issues and to track changes in water quality over time.

The council carries out long-term state of the environment water quality monitoring at 42 sites in the Kaipara Harbour, Whangārei Harbour and Bay of Islands. This report presents the results from monitoring undertaken by the council between January 2010 and December 2014 (five full years of data). The report includes a comparison of the results with the relevant Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC) (Australian New Zealand Environment Conservation Council, 2000) and the Ministry for Environment (MfE) Microbiological Water Quality Guidelines (Ministry for Environment, 2003). The report also includes a water quality index used by the Canadian Council of Ministers for the Environment (Canadian Council of Ministers of the Environment, 2001) and an analysis of temporal trends.

The results from council's water quality programme provide resource planners, politicians and the public with information regarding the quality of Northland's coastal waters, and help to enable informed decision-making relating to activities which may impact water quality. Importantly, the programme will help council assess the effectiveness of the Regional Coastal Plan for Northland and the Regional Water and Soil Plan for Northland. The programme addresses the council's responsibilities under the Resource Management Act (1991) in relation to sustainable management principles set out in Part II (Section 5) and directives to monitor the state of the environment as set out in Part IV (Section 35; 1 and 2a).

2 Methodology

2.1 Programme design

The council has conducted routine water quality monitoring in the Whangārei 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. The programme has existed in its current form since 2008. In May 2008, council began a routine water quality monitoring programme in the Bay of Islands. In June 2009, council initiated a routine water quality monitoring programme in the Kaipara Harbour in conjunction with Auckland Council. Initially nine sites were sampled in the northern Kaipara but one site was dropped from the programme in June 2014.

2.2 Sampling frequency

In Whangārei Harbour and the Bay of Islands sampling is currently undertaken bi-monthly throughout the year (in January, March, May, July, September and November). In the Kaipara Harbour, sampling is conducted ever month. Historically, sampling in Whangārei Harbour was always conducted on an outgoing tide. However, since 2008 sampling in the Whangārei Harbour and Bay of Islands has been conducted on a predetermined date with no regard to tidal state, to coincide with council's River Water Quality Monitoring Network. 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 over time, as the influence of tidal state is incorporated into the water quality results. In the Kaipara Harbour sampling starts at high tide, to coincide with Auckland Council's sampling. Typically all samples are collected within three hours of high tide.

2.3 Sampling sites

Initially 16 sites were monitored in the Whangārei Harbour. 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 seven sites are located along the main channel of the harbour. The sites cover a range of exposures from open water to sheltered tidal creeks. One site, Mair Bank, is located outside the entrance of the harbour and is considered to be an open coast site. An extra site was added in January 2013, at Otaika Creek, in order to monitor the water quality from this sub-catchment. There are now 17 sites sampled in the Whangārei Harbour (Figure 1).

Sixteen sites are monitored in the Bay of Islands (Figure 2), with these sites selected to capture the main freshwater inputs to the system. Five sites are located in and around the Kawakawa River and the Waikare Inlet and five sites are located in the Kerikeri Inlet, which receives freshwater inputs from the Kerikeri River and Waipapa River. Sample sites are also located in the Waitangi Estuary, Te Haumi Estuary and Te Puna Inlet. The remaining sites are located in more exposed outer estuarine locations around Paihia and Russel.

Initially nine sites were monitored in the Kaipara Harbour (Figure 3) although one of these sites (Otamatea Channel) was dropped from the programme in June 2014. The nine sites are located in the different arms of the harbour (the Main Wairoa arm, the Arapaoa River, the Otamatea River and the Oruawharo River) in order to capture the main freshwater inputs to this system.

All site co-ordinates have been fixed using a handheld GPS (Appendix 1) so that samples are collected from the same location.

2.4 Sampling parameters

When the Whangārei Harbour programme first started in 1986, 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. Dissolved reactive phosphorus (DRP), ammonium (NH_4), and total phosphorus (TP) were added to the programme in March 2008 and nitrate-nitrite nitrogen (NNN) was added in November 2008. Chlorophyll *a* was then added to the programme in January 2013.

When the Bay of Islands programme was initiated in 2008 dissolved oxygen, temperature, turbidity, micro bacteria, TP and NH4 were sampled. Other nutrients (DRP and NNN) were added to the programme in November 2009 with chlorophyll *a* added in January 2013.

Total suspended solids was also added to the Whangārei Harbour and Bay of Islands programmes in November 2014 but the results are not included in this report as there is only one data point for each site during the reporting period.

In the Kaipara Harbour, the full suite of 14 parameters (Table 1) have been sampled since the beginning of the programme. Samples from three sites (Otamatea Channel, Hargreaves Basin and Oruawharo River) were initially collected by Auckland Council using a helicopter so secchi depth was not recorded at these sites between June 2009 and June 2014. Secchi depths were recorded at these sites from July 2014 onwards but there are only six data points for these sites in the reporting period. The Otamatea Channel site was dropped from the programme in June 2014 so there are no secchi depth measurements for this site.

The water quality parameters sampled by council are presented in Table 1.

2.5 Reporting period

Although the Whangārei and Bay of Islands programmes have been running in their current form since 2008, the Kaipara programme has only been running since June 2009 so in order to have comparable data sets and to reduce any bias from seasonality the reporting period of January 2010 to December 2014 was selected. There is therefore five full years of data for each programme.

2.6 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 and the measurement recorded. The surface water is measured (top 0.5m depth).

Secchi depth is measured by lowering a secchi disk (with a 20cm diameter) 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 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.

Table 1: Summary of water quality parameters monitored by council.

Water quality parameter	Programme	Guideline values	Reason for monitoring
Temperature	Kaipara Bay of Islands Whangārei	Not applicable	• Indicator of ability to sustain aquatic life and support biological diversity. • Indicator of excessive primary productivity. • Influences dissolved oxygen.
Salinity	Kaipara Bay of Islands Whangārei	Not applicable	• Indicator of fresh and seawater mixing. • Affects biological diversity.
Secchi depth (water clarity)	Kaipara Bay of Islands Whangārei	None	• Indicator of the quantity suspended material in water column, for example, sediment and algae. • Indicator of ability to support aquatic life. • Affects primary production. • Affects predator-prey relationships.
Turbidity (water clarity)	Kaipara Bay of Islands Whangārei	ANZECC <10 NTU	• Indicator of the quantity suspended material in water column. • Indicator of ability to support aquatic life. • Affects primary production. • Affects predator-prey relationships.
Total suspended solids	Kaipara	None	• Indicator of the quantity suspended material in water column. • Indicator of ability to support aquatic life. • Affects primary production. • Affects predator-prey relationships.
Enterococci bacteria (ENT)	Kaipara Bay of Islands Whangārei	MfE: <140/100mL	• Indicator of faecal contamination. • Indicator of public health risk.
Faecal coliforms (FC)	Bay of Islands Whangārei	ANZECC <150 faecal coliforms/100ml	• Indicator of faecal contamination. • Indicator of public health risk.
Dissolved oxygen (DO)	Kaipara Bay of Islands Whangārei	ANZECC 80%-110%	• Indicator of ability to support marine flora and fauna. • Indicator of organic material. • Indicator of excessive primary productivity.
Chlorophyll *a*	Kaipara Bay of Islands Whangārei	ANZECC 0.004mg/L	• Indicator of phytoplankton abundance and biomass. • Indicator of organic enrichment.
Total Phosphorus (TP)	Kaipara Bay of Islands Whangārei	ANZECC 0.03mg/L	• Indicator of nutrient enrichment. • Indicator of point-source and non-point source inputs. • Affects primary productivity.
Dissolved Reactive Phosphorus (DRP)	Kaipara Bay of Islands Whangārei	ANZECC 0.01mg/L	• Indicator of nutrient enrichment. • Indicator of point and non-point source inputs. • Affects primary productivity.
Total Nitrogen (TN)	Kaipara	ANZECC 0.3mg/L	• Indicator of nutrient enrichment. • Indicator of point and non-point source inputs. • Affects primary productivity.
Ammonium (NH_4)	Kaipara Bay of Islands Whangārei	ANZECC 0.015mg/L	• Indicator of nutrient enrichment. • Indicator of point source and non-point source inputs. • Indicator or waste products.
Nitrate-nitrite nitrogen (NNN)	Kaipara Bay of Islands Whangārei	ANZECC <0.015mg/L	• Indicator of nutrient enrichment. • Indicator of point source and non-point source inputs. • Affects primary productivity.

2.7 Data analysis

The mean, standard error and the median were calculated for each parameter at each site and are presented in summary tables together with the range (maximum and minimum values). The data is also presented in box plots. The box displays the interquartile range (middle 50% of the data) with the middle line indicating the median. The upper whisker extends to the maximum data point within 1.5 box heights from the top of the box and the lower whisker extends to the minimum data point within 1.5 box heights from the bottom of the box. Outliers are depicted by an asterisk (*).

Prior to this analysis 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 less than 10 enterococci MPN/100ml by the laboratory would be replaced in the data set as five enterococci MPN/100ml. Results reported by the laboratory as a greater than value were replaced with the greater than value. For example a value reported as greater than 30,000 enterococci MPN/100ml by the laboratory would be included in the data set as 30,000 enterococci MPN/100ml. This rule was not applied to greater than values for secchi depth measurements. This occurs when the secchi disk is still visible when it is on the seabed. In this situation, replacing the greater than value with that value might significantly underestimate secchi depth, particularly at shallow sites. In these circumstances the data points were removed from the data set.

2.7.1 Guideline values

The results were assessed against the appropriate water quality guidelines (Table 1), which include the ANZECC default interim trigger values (Australian New Zealand Environment Conservation Council, 2000) and the Ministry for Environment (MfE) Microbiological Water Quality Guidelines (Ministry for Environment 2003). Median values for each parameter at each site were assessed against these guideline values.

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 ANZECC 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' (Australian and New Zealand Environment Conservation Council, 2000).

The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas recreational (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 preferred indicator of faecal contamination. 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.

2.7.2 Water quality index

A water quality score was also calculated for each site using a water quality index used by the Canadian Council of Ministers for the Environment (CCME) (Canadian Council of Ministers of the Environment 2001). This index is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment. The index incorporates three elements; scope – the number of parameters not meeting water quality standards; frequency – the number of times that these water quality standards were not met; and amplitude – the amount by which the water quality standards were not met. The index produces a score between 0 (worst water quality) and 100 (best water quality). Seven parameters were used to calculate the water quality index score, with the ANZECC default trigger values used for turbidity and nutrient concentrations and MfE's Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas recreational was used for enterococci concentrations (Table 2).

Table 2: Water quality parameters and the standards used to calculate water quality indices.

Water Quality Parameter	Water quality standards
Dissolved oxygen (% saturation)	>80 <110mg/l (ANZECC)
Turbidity	10 NTU (ANZECC)
Enterococci	140 enterococci/100ml (MfE 2003)
Ammonium	0.015 mg/L (ANZECC)
NNN	0.015 mg/L (ANZECC)
DRP	0.005 mg/L (ANZECC)
TP	0.003 mg/L (ANZECC)

2.7.3 Trend analysis

Any changes over time (trends) have been calculated using the Trend and Equivalence Analysis software developed by the National Institute of Water and Atmospheric Research (NIWA). The seasonal Mann-Kendall test was applied to data for each parameter at each site in order to identify any significant trends in the data (Scarsbrook, 2008). Data from Otaika Creek was not included in the trend analysis as there was only two years of data for this site.

2.7.4 Relationships between variables

Pearson correlations were also performed, using Minitab 16 (Minitab Inc., Pennsylvania, USA), in order to examine the relationship between the water quality parameters monitored. Data from all 42 sites was used in this analysis.

Figure 1: Location of sampling sites in Whangārei Harbour.

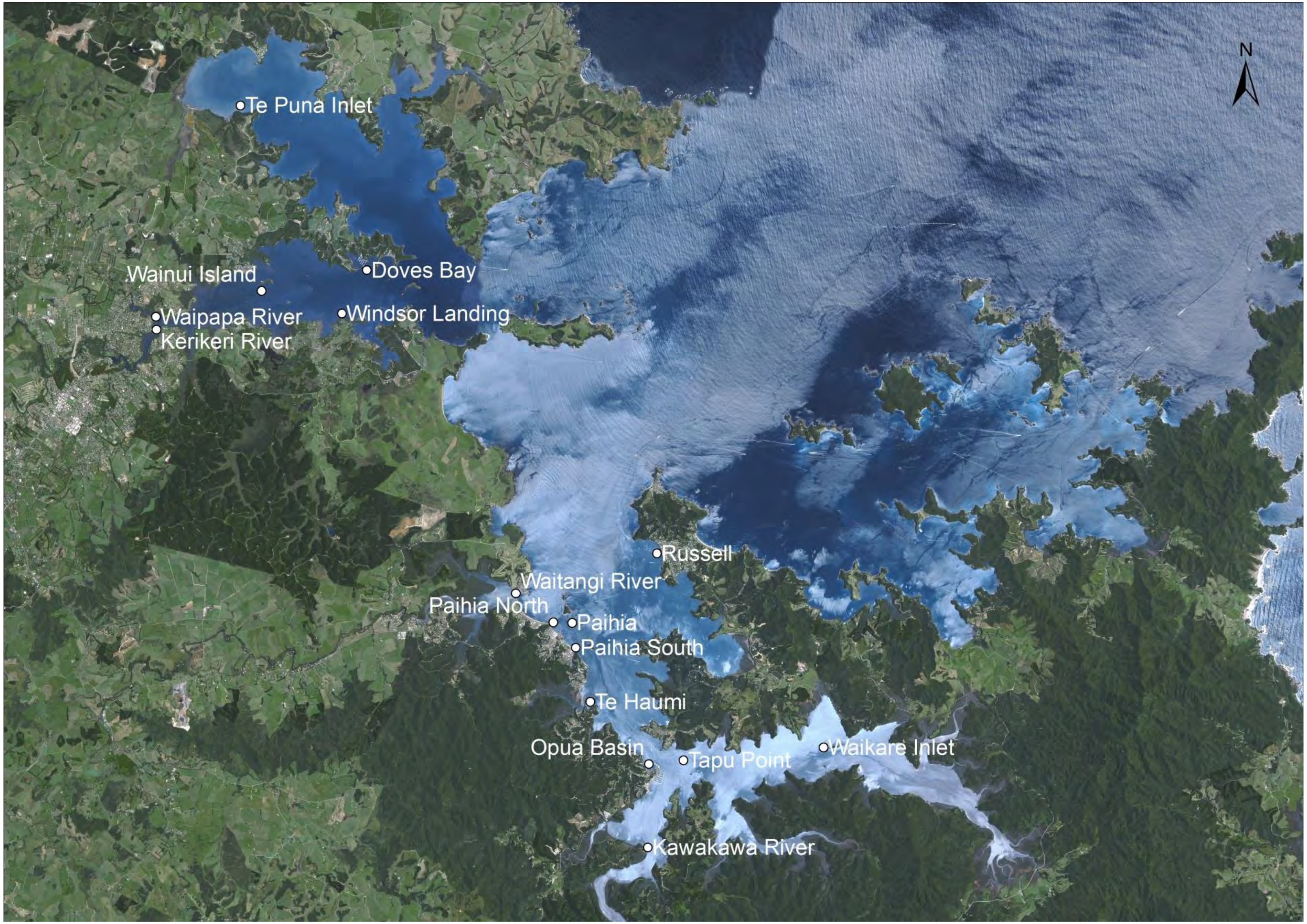


Figure 2: Location of sampling sites in Bay of Islands.

Figure 3: Location of sampling sites in Kaipara Harbour.

3 Results

3.1 Physical properties

3.1.1 Salinity

The highest median salinity was recorded at sites near the entrance of Whangārei Harbour, at Te Puna and Russel in the Bay of Islands and at the Otamatea Channel in the Kaipara Harbour (Table 3 and Figure 4). The lowest median salinity was recorded at Otaika Creek, the Town Basin and Waiarohia Canal in the Whangārei Harbour and at Waipapa River and Kerikeri River in the Bay of Islands. The lowest median salinity in the Kaipara Harbour was recorded at Wahiwaka Creek. These sites are all close to freshwater inputs. The biggest salinity ranges were measured at the Kawakawa River, Te Hoanga Point, Waiarohia Canal, Town Basin, Waipapa River, Five Fathom Channel and the Upper Hātea River. The sites with the largest salinity ranges are generally close to fresh water inputs. The lowest ranges were recorded close to the entrance of Whangārei Harbour (Snake Bank, One Tree Point, Mair Bank and Marsden Point) and at the Otamatea River in the outer Kaipara Harbour.

3.1.2 Temperature

The highest median temperatures were recorded at Hargreaves Basin (18.0^{o} C), Onerahi (18.0^{o} C), Snake Bank (17.7^{o} C) and Wahiwaka Creek (17.7^{o} C) (Table 4 and Figure 5). The lowest median temperatures were recorded at Otaika Creek (15.1^{o} C), the Town Basin (15.9^{o} C) and the Upper Hātea River (15.1^{o} C).

Table 3: Salinity data collected from January 2010 to December 2014. Ranked highest to lowest median.

Site	Count	Minimum	Maximum	Mean	S.E	Median
Marsden Point	30	28.9	36.7	34.4	0.3	34.7
Mair Bank	29	29.4	36.7	34.4	0.3	34.7
Snake Bank	29	31.1	36.7	34.5	0.3	34.5
Blacksmith Creek	29	23.2	36.7	33.9	0.5	34.5
One Tree Point	30	30.3	36.7	34.3	0.3	34.4
Te Puna	29	23.8	37.7	33.2	0.5	34.0
Russell	29	23.1	37.2	33.3	0.5	33.6
Tamaterau	30	27.4	36.6	33.3	0.4	33.6
Otamatea Channel	53	28.5	36.0	33.4	0.2	33.5
Windsor Landing	29	21.4	36.4	32.1	0.6	33.2
Onerahi	30	22.6	36.2	32.6	0.6	33.1
Doves Bay	29	21.5	36.6	31.8	0.7	32.8
Paihia	29	18.7	37.1	31.2	0.7	32.5
Paihia South	29	16.4	37.0	31.6	0.7	32.3
Portland	30	21.8	36.6	32.0	0.7	32.3
Paihia North	29	18.9	36.1	30.3	0.8	31.8
Ōpua Basin	28	18.3	36.9	30.9	0.7	31.7
Tapu Point	28	11.8	36.5	29.5	1.2	31.6
Waitangi	29	14.7	36.2	28.9	1.1	31.6
Wainui Island	29	10.7	35.7	28.9	1.1	31.4
Te Haumi	29	18.8	36.7	31.0	0.7	31.3
Oruawharo River	58	20.2	35.7	30.3	0.5	30.8
Five Fathom Channel	60	9.1	36.6	29.6	0.6	30.8
Mangapai River	30	19.1	36.3	30.2	1.0	30.7
Waikare Inlet	28	14.0	36.4	29.3	1.0	30.7
Kaiwaka Point	30	20.0	35.9	30.2	0.8	30.6
Hargreaves Basin	58	18.3	35.7	29.8	0.5	30.5
Te Kopua Point	60	15.7	37.3	28.8	0.6	30.1
Kapua Point	60	15.4	37.2	28.6	0.6	29.8
Lower Hātea River	30	17.5	35.5	29.2	0.9	29.7
Te Hoanga Point	60	5.4	37.2	28.2	0.7	29.4
Kissing Point	30	17.4	35.1	27.1	1.0	27.9
Wahiwaka Creek	59	12.9	37.4	26.7	0.8	27.4
Limeburners Creek	30	8.2	34.4	25.2	1.3	27.0
Burgess Island	60	11.3	34.0	24.2	0.8	25.1
Kawakawa River	29	5.8	35.5	23.0	1.5	24.2
Upper Hātea River	30	4.0	31.4	19.9	1.5	20.9
Waiarohia Canal	30	1.4	32.5	19.1	1.7	18.7
Kerikeri River	28	3.7	29.8	15.5	1.5	13.7
Town Basin	30	0.5	31.4	15.7	1.7	13.5
Waipapa River	28	3.5	32.6	14.7	1.7	12.6
Otaika Creek	11	0.1	26.5	10.3	2.9	10.0

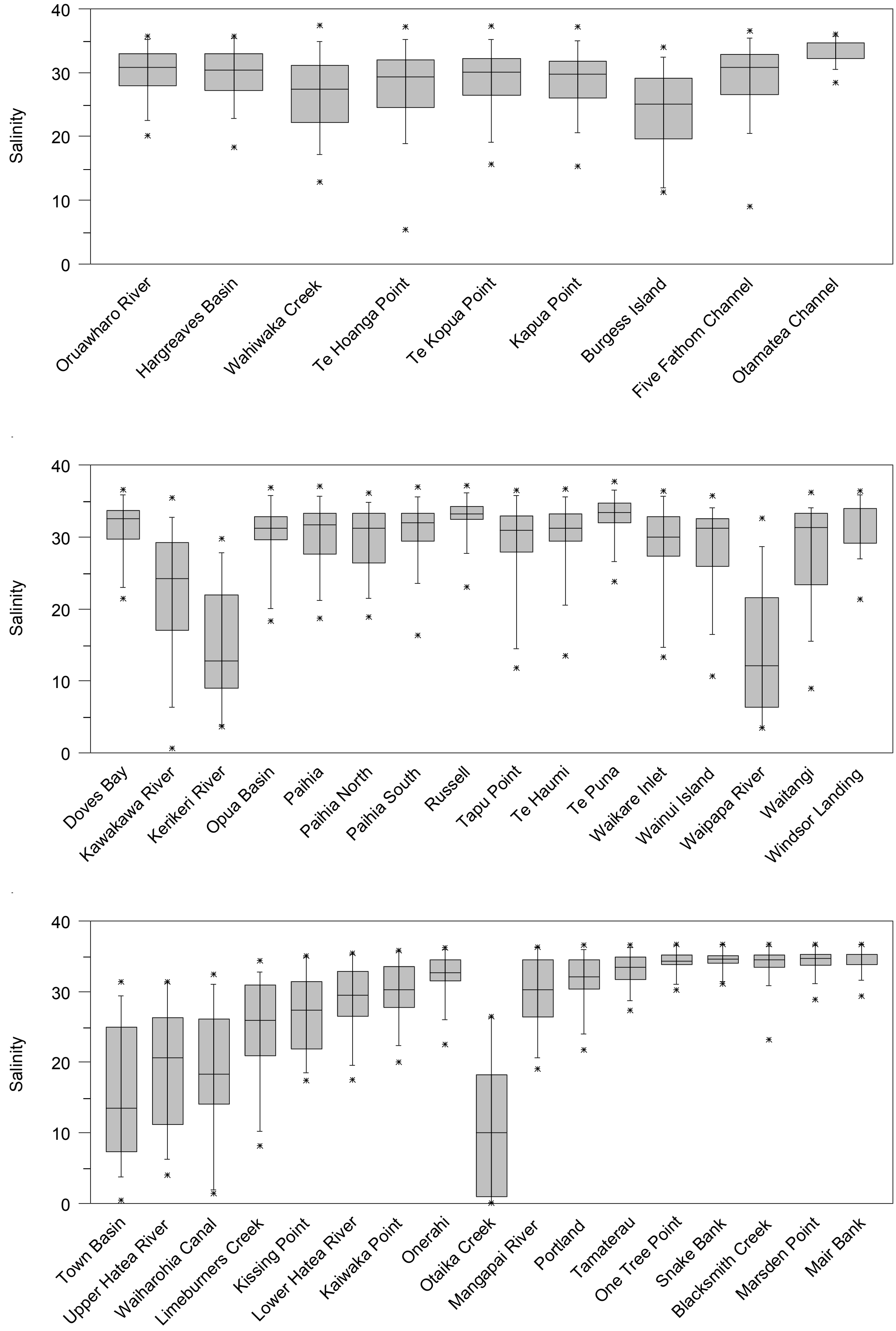


Figure 4: Salinity data collected from January 2010 to December 2014.

Table 4: Temperature data (^{O}C) collected from January 2010 to December 2014. Ranked highest to lowest median.

Site	Count	Minimum	Maximum	Mean	S.E	Median
Hargreaves Basin	57	11.6	24.1	17.7	0.5	18.0
Onerahi	30	11.3	24.0	18.0	0.7	18.0
Snake Bank	30	12.6	22.4	17.5	0.5	17.7
Wahiwaka Creek	58	11.5	24.2	17.8	0.5	17.7
Waikare Inlet	30	11.7	23.1	17.6	0.6	17.6
One Tree Point	30	12.0	22.5	17.6	0.6	17.6
Mair Bank	30	13.4	22.3	17.5	0.5	17.6
Oruawharo River	57	12.0	23.6	17.6	0.4	17.6
Waipapa River	30	11.4	24.4	17.7	0.7	17.6
Windsor Landing	30	13.2	23.1	17.8	0.5	17.6
Blacksmith Creek	30	12.2	22.6	17.5	0.6	17.6
Marsden Point	30	12.7	22.7	17.5	0.5	17.6
Kapua Point	58	11.7	24.0	17.7	0.5	17.6
Russell	30	14.2	22.2	17.7	0.5	17.5
Limeburners Creek	30	11.3	24.9	17.7	0.7	17.5
Kerikeri River	30	11.4	23.9	17.7	0.7	17.4
Kissing Point	30	11.3	24.4	17.8	0.7	17.4
Lower Hātea River	30	11.3	24.3	17.8	0.7	17.4
Te Puna	30	12.3	23.7	17.9	0.6	17.4
Kawakawa River	30	11.8	22.4	17.2	0.6	17.3
Paihia South	30	13.7	22.9	17.5	0.5	17.3
Otamatea Channel	53	13.1	22.4	17.2	0.4	17.3
Tapu Point	30	12.3	22.8	17.6	0.6	17.3
Te Haumi	30	13.1	23.6	17.5	0.5	17.3
Kaiwaka Point	30	11.0	24.3	17.7	0.7	17.3
Portland	30	10.9	24.4	17.7	0.7	17.3
Te Hoanga Point	58	11.8	23.8	17.7	0.5	17.3
Te Kopua Point	58	11.9	23.5	17.7	0.5	17.3
Burgess Island	58	11.6	25.1	17.8	0.5	17.3
Ōpua Basin	30	13.3	23.7	17.7	0.5	17.2
Paihia North	30	13.3	22.7	17.5	0.5	17.2
Wainui Island	30	13.2	23.1	18.0	0.5	17.2
Tamaterau	30	11.4	23.7	17.7	0.6	17.2
Five Fathom Channel	58	12.2	24.1	17.5	0.4	17.2
Paihia	30	13.7	22.7	17.5	0.5	17.1
Doves Bay	30	12.5	23.0	17.6	0.5	17.1
Mangapai River	30	10.1	24.2	17.4	0.8	17.1
Waitangi	30	13.0	22.6	17.6	0.5	17.0
Waiarohia Canal	30	11.1	24.6	17.6	0.8	17.0
Upper Hātea River	30	10.8	24.3	17.5	0.8	16.4
Town Basin	30	10.8	24.1	17.1	0.8	15.9
Otaika Creek	11	10.0	23.5	17.1	1.5	15.1

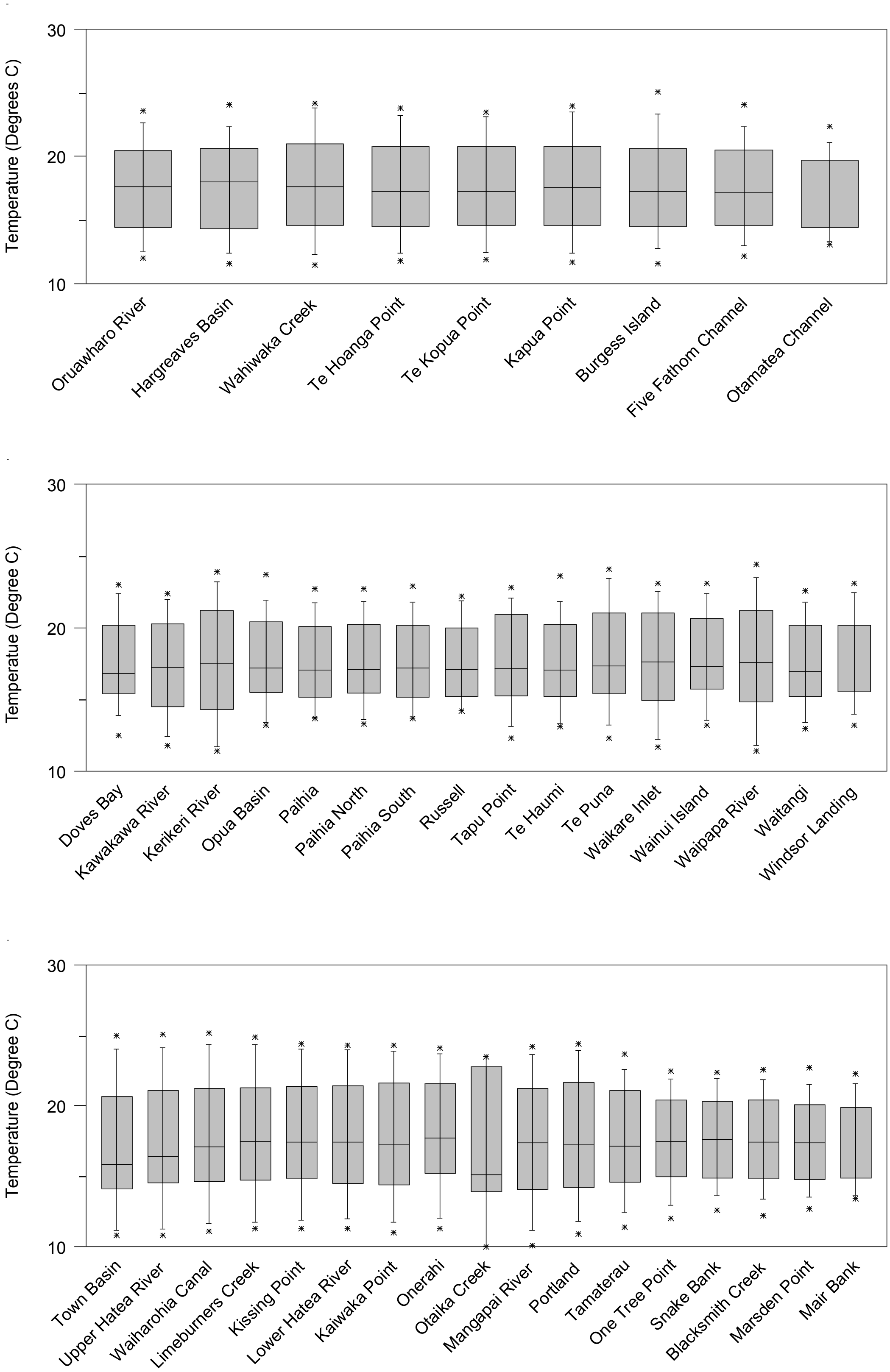


Figure 5: Temperature data collected from January 2010 to December 2014.

3.2 Water clarity

Water clarity is important for the healthy functioning of marine ecosystems. Increased suspended solid loads that reduce water clarity can affect the amount of photosynthesis (primary production) of aquatic plants. Reduced water clarity can also affects the feeding efficiency of visual predators like fish and sea birds and sediment particles can clog the feeding structures and gills of fish and suspension feeding animals like cockles and pipi. Water clarity is also an important attribute for recreation and aesthetics values as poor water clarity makes the water less desirable for swimming and recreational activities.

3.2.1 Secchi depth

The secchi depth is a measure of the transparency of the water body. High secchi depth readings indicate high levels of transparency or good water clarity, while low secchi depth readings indicate low transparency or poor water clarity. It is not an exact measure as there may be errors caused by the sun's glare, shading, the roughness of the surface of the water and the eyesight of the sampler. Another error with this measurement is that when water clarity is high, the secchi disk may exceed the water depth. In this situation secchi depth will be under-estimated.

The highest median secchi depths were recorded at sites close to the entrance of the Whangārei Harbour (Marsden Point, Blacksmith Creek, Mair Bank, One Tree Point and Snake Bank). All these sites had a median secchi depth of at least 3.5m and the secchi depth at these sites consistently exceeded 2.0m, which suggests that water clarity at these sites is very good (Table 5 and Figure 6). In the Bay of Islands the highest median secchi depth was at Russel (2.0m) and Doves Bay (1.90m) and these two sites appeared to have noticeably higher secchi depth than the other sites in the Bay of Islands (Figure 6). Doves Bay is located towards the entrance of the Kerikeri Inlet and Russel is an exposed outer estuarine site. In the Kaipara Harbour the highest secchi depth was recorded at Five Fathom Channel (2.00m), which is located close to the entrance of the harbour. Secchi depth was not measured at Otamatea Channel, because this site was sampled with a helicopter by Auckland Council. As the Otamatea Channel is located close to the entrance of the Kaipara Harbour the secchi depth at this site is likely to be similar or slightly better than at Five Fathom Channel.

The lowest median secchi depth was recorded at Hargreaves Basin (0.75m) in the Kaipara Harbour, although there are only five data points for this site. Low median secchi depths were also recorded at Mangapai River (0.80m) and Limeburners Creek (0.90m) in the Whangārei Harbour, at Waikare Inlet (0.90m) and Kawakawa River (0.90m) in Bay of Islands and at Wahiwaka Creek (0.90m) in the Kaipara Harbour. These sites are all located in tidal creek locations or in the upper reaches of estuarine systems. They are therefore likely to be influenced by sediment inputs from freshwater streams and rivers. These sites are also likely to be affected to some extent by the resuspension of sediment from the seabed as they are all relatively shallow. The ANZECC 2000 guidelines do not include a default trigger value for secchi depth so there is no guideline value for comparison.

Table 5: Secchi depth data collected from January 2010 to December 2014. Ranked highest to lowest median.

Site	Count	Minimum	Maximum	Mean	S.E	Median
Marsden Point	25	2.00	8.50	4.58	0.4	4.50
Blacksmith Creek	24	1.90	6.00	3.67	0.2	3.80
Mair Bank	17	2.25	6.75	4.05	0.3	3.60
One Tree Point	29	1.70	6.00	3.75	0.2	3.50
Snake Bank	20	2.00	6.10	3.48	0.3	3.50
Tamaterau	30	0.75	3.80	2.26	0.1	2.15
Russell	29	1.30	4.00	2.10	0.1	2.00
Five Fathom Channel	59	0.90	3.95	2.09	0.1	2.00
Doves Bay	30	1.00	5.40	1.95	0.2	1.90
Paihia North	30	0.40	3.00	1.61	0.1	1.60
Paihia	30	0.50	2.70	1.55	0.1	1.53
Paihia South	30	0.75	2.50	1.52	0.1	1.50
Windsor Landing	30	1.00	3.00	1.59	0.1	1.50
Te Kopua Point	58	0.60	2.90	1.42	0.1	1.40
Wainui Island	30	0.80	2.10	1.27	0.1	1.30
Waitangi	30	0.25	2.05	1.33	0.1	1.28
Onerahi	24	0.55	2.00	1.28	0.1	1.28
Te Puna	30	0.70	2.00	1.27	0.1	1.25
Town Basin	30	0.30	2.25	1.24	0.1	1.25
Te Hoanga Point	58	0.45	2.00	1.21	0.0	1.25
Lower Hātea River	30	0.75	3.50	1.32	0.1	1.23
Kaiwaka Point	30	0.60	2.90	1.30	0.1	1.23
Kerikeri River	29	0.60	1.65	1.19	0.1	1.20
Te Haumi	25	0.45	2.30	1.09	0.1	1.10
Waipapa River	30	0.55	1.60	1.15	0.0	1.10
Upper Hātea River	30	0.25	1.80	1.10	0.1	1.10
Kissing Point	30	0.50	2.10	1.17	0.1	1.10
Oruawharo River	5	0.95	1.25	1.11	0.1	1.10
Portland	30	0.50	2.25	1.15	0.1	1.08
Ōpua Basin	30	0.65	2.30	1.10	0.1	1.00
Waiarohia Canal	28	0.20	2.20	1.07	0.1	1.00
Tapu Point	30	0.55	2.30	1.02	0.1	0.98
Kapua Point	58	0.45	2.05	1.02	0.0	0.98
Kawakawa River	29	0.25	1.20	0.85	0.0	0.90
Waikare Inlet	30	0.40	1.80	0.90	0.1	0.90
Limeburners Creek	25	0.25	2.20	0.99	0.1	0.90
Wahiwaka Creek	58	0.25	1.75	0.90	0.0	0.90
Burgess Island	59	0.50	2.80	1.07	0.1	0.90
Mangapai River	30	0.20	1.80	0.84	0.1	0.80
Hargreaves Basin	5	0.65	1.00	0.79	0.1	0.75

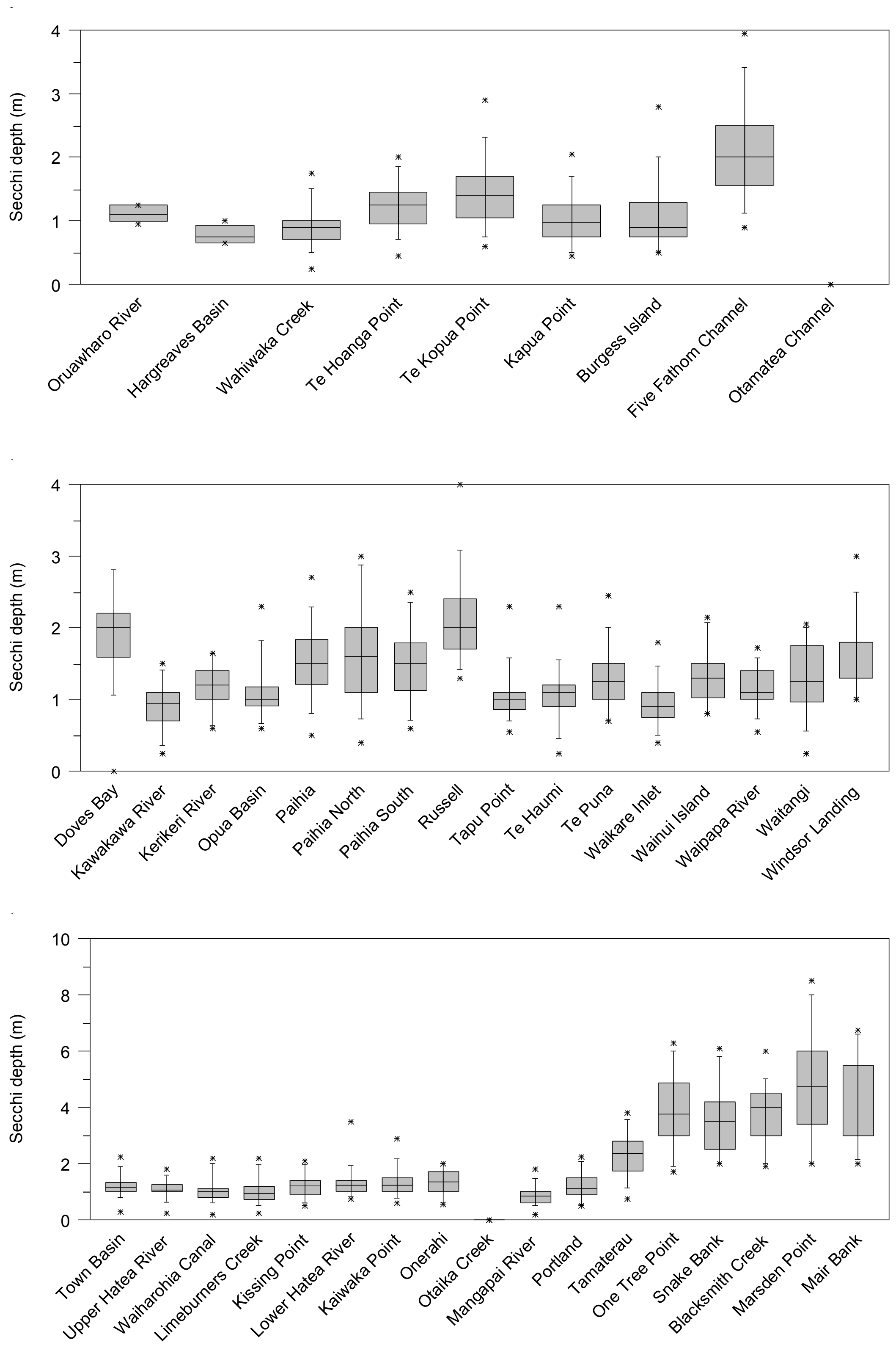


Figure 6: Secchi depth data collected from January 2010 to December 2014. Note: graphs have different scales.

3.2.2 Turbidity

Turbidity is a measure of the degree to which light is scattered in water by particles, such as sediment and algae. The higher the concentration of these substances in water, the more turbid the water is. Turbidity is measured in the laboratory using a nephelometer, which uses a light beam and a light detector (at 90^{o} to the source) to measure the light scatter from particles in the water sample. Turbidity measured using a nephelometer can therefore be influenced by the properties of the material in the sample, specifically its light scattering properties such as their shape, colour and reflectivity (Morrisey and Barter, 2015).

The lowest median turbidity was recorded at sites close to the entrance of the Whangārei Harbour (Mair Bank, Marsden Point, Blacksmith Creek, One Tree Point and Snake Bank) (Table 6 and figure 7). All these sites had a median turbidity of less than 1.0 NTU and turbidity was consistently very low at these sites (Figure 7). These five sites are located a long way from freshwater inputs of sediment and are in deep water so they are unlikely to be affected by resuspension of seabed sediment. In the Kaipara Harbour the lowest median turbidity was recorded at Otamatea Channel (1.8 NTU) and at Five Fathom Channel (2.1 NTU) and these two sites appeared to have noticeably lower turbidity than the other seven sites in the Kaipara Harbour (Figure 7). In the Bay of Islands, the lowest median turbidity was recorded at Russell (2.7 NTU), which also had the highest median secchi depth. Low turbidity was also recorded at Doves Bay and Windsor Landing (Figure 7).

None of the 42 sites had a median turbidity which exceeded the ANZECC guideline value of 10 NTU for estuarine and marine waters. The highest median was recorded at Otaika Creek (9.1 NTU), with high turbidity also recorded at Mangapai River (8.5 NTU) in Whangārei Harbour, at Wahiwaka Creek (8.3 NTU) in the Kaipara Harbour and at Waikare Inlet (8.1 NTU) in the Bay of Islands.

Table 6: Turbidity (NTU) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site	Count	Minimum	Maximum	Mean	S.E	Median
Mair Bank	28	0.4	2.7	0.8	0.1	0.6
Marsden Point	28	0.4	3.5	1.0	0.2	0.7
Blacksmith Creek	28	0.4	3.6	1.1	0.2	0.7
One Tree Point	28	0.4	2.7	1.3	0.2	0.9
Snake Bank	28	0.4	3.4	1.3	0.2	0.9
Otamatea Channel	53	0.7	15.9	2.9	0.4	1.8
Five Fathom Channel	57	0.5	7.7	2.5	0.2	2.1
Tamaterau	27	0.4	9.7	2.7	0.3	2.7
Russell	28	1.0	6.3	2.7	0.2	2.7
Doves Bay	28	1.0	6.5	3.0	0.2	2.9
Paihia North	27	1.0	18.0	4.3	0.6	3.5
Windsor Landing	28	1.3	7.6	3.6	0.3	3.6
Paihia	27	1.0	11.1	4.3	0.4	3.7
Te Kopua Point	57	1.5	11.7	4.4	0.3	3.8
Oruawharo River	57	2.2	30.0	5.3	0.5	4.0
Paihia South	28	1.3	10.5	5.0	0.5	4.2
Waiarohia Canal	28	2.1	50.0	7.1	1.7	4.3
Town Basin	28	2.6	32.0	5.3	1.0	4.3
Kerikeri River	28	2.1	10.4	4.7	0.4	4.3
Upper Hātea River	28	2.4	35.0	6.0	1.1	4.5
Te Hoanga Point	57	2.1	24.5	5.5	0.5	4.7
Te Puna	27	2.0	13.7	5.2	0.5	4.7
Wainui Island	28	1.0	14.2	5.3	0.5	4.7
Kaiwaka Point	28	1.5	12.4	5.7	0.5	5.0
Onerahi	27	1.7	8.5	5.1	0.4	5.0
Waipapa River	28	2.5	20.9	5.7	0.6	5.2
Waitangi	28	2.0	16.0	5.5	0.6	5.2
Lower Hātea River	28	1.5	9.2	4.8	0.4	5.2
Te Haumi	28	1.7	16.7	6.7	0.6	5.5
Kissing Point	28	1.0	11.0	5.7	0.5	5.7
Ōpua Basin	28	1.9	9.4	6.0	0.4	6.0
Limeburners Creek	28	1.6	78.2	10.4	3.0	6.2
Portland	28	2.1	16.5	6.9	0.6	6.2
Burgess Island	57	1.7	17.3	6.9	0.5	6.6
Kapua Point	57	2.2	28.8	8.2	0.7	6.6
Hargreaves Basin	58	2.6	19.0	7.1	0.4	6.9
Tapu Point	28	1.9	12.2	6.8	0.4	7.2
Kawakawa River	28	2.3	20.9	8.9	0.9	7.3
Waikare Inlet	28	1.9	21.0	8.6	0.8	8.1
Wahiwaka Creek	57	2.8	22.6	8.8	0.6	8.3
Mangapai River	28	1.7	16.1	8.7	0.8	8.5
Otaika Creek	12	3.1	112.8	18.6	8.7	9.1

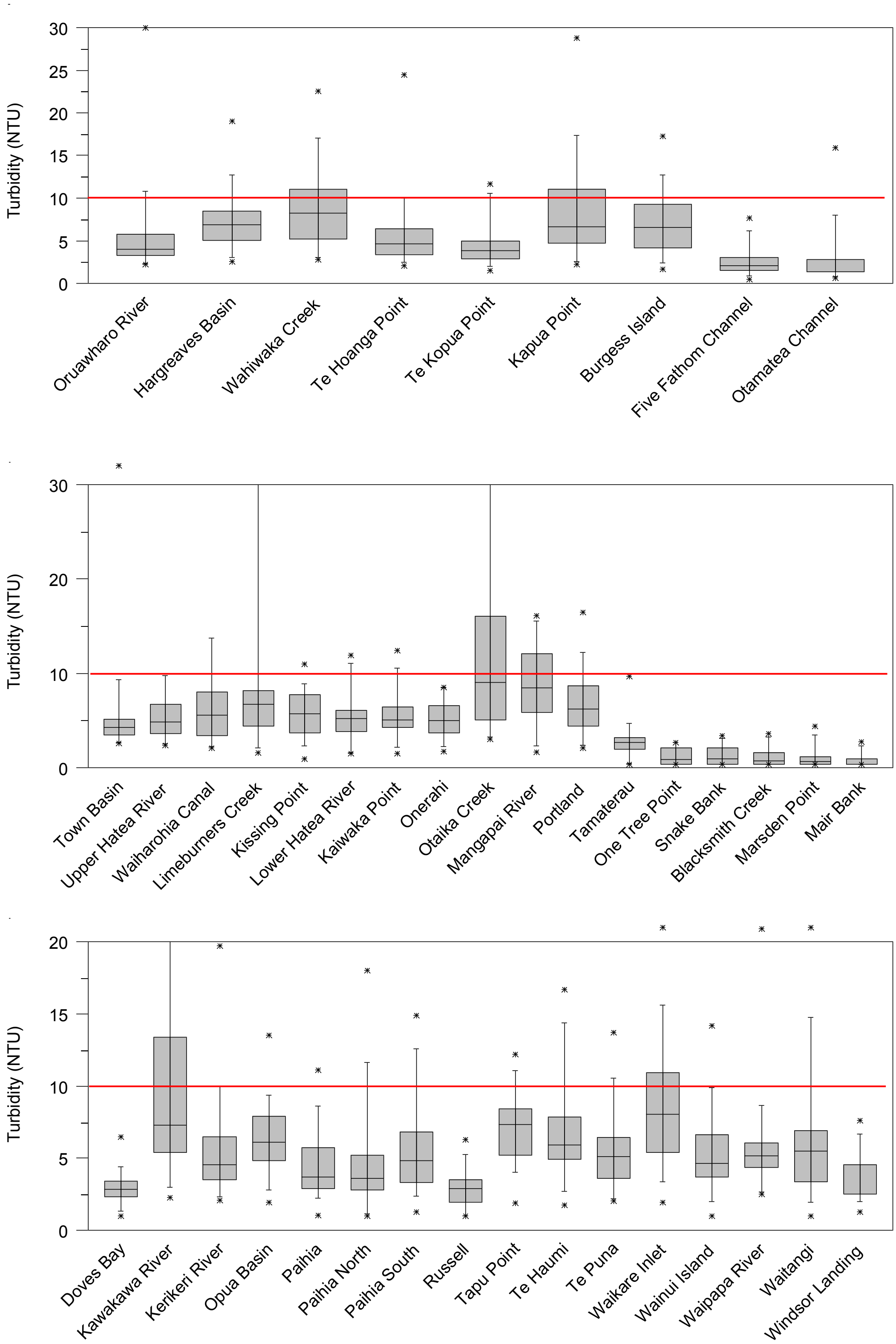


Figure 7: Turbidity data collected from January 2010 to December 2014. Red line = ANZECC guideline (10 NTU). Note: graphs have different scales.

3.2.3 Total suspended solids

Total suspended solids (TSS) is a measure of the amount of suspended material in the water column. TSS is determined by pouring a measured volume of water through a pre-weighed filter of a specified pore size, then weighing the filter again after drying to remove all water. The gain in the weight of the filter paper is the dry weight of the particles present in the water sample. TTS is therefore a direct measure of suspended solid as opposed to turbidity, which is an indirect measure of the particulate matter. Suspended solids were only added to the Whangārei Harbour and Bay of Islands programmes in November 2014 so the results have not been analysed in this report.

The highest median suspended solid concentrations were recorded at Hargreaves Basin (16 g/m^3), Kapua Point (17 g/m^3) and at Wahiwaka Creek (18 g/m^3) (Table 7 and Figure 8). These sites are located in the upper reaches of different arms of the Kaipara Harbour close to fresh water inputs. Resuspension of seabed sediment by wave action and tidal flow is unlikely to be responsible for the higher suspended solid concentrations at these sites as they are all located in relatively deep water. The lowest median suspended solid concentrations were recorded at Five Fathom Channel (7.5g/m^3) and the Otamatea Channel (8.2g/m^3), which are both located close to the entrance of the Kaipara Harbour.

The ANZECC 2000 guidelines do not include a trigger value for suspended solids so there is no guideline value for comparison.

Table 7: Suspended solid (g/m^3) Data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site	n	Min	Max	Mean	S.E.	Median
Five Fathom Channel	60	1.6	32	8.5	0.66	7.5
Otamatea Channel	53	2.3	35	9.6	0.86	8.2
Te Kopua Point	60	4	37	12.5	0.94	10.0
Oruawharo River	57	6.8	58	15.4	1.18	13.0
Burgess Island	60	3.2	32	14.2	0.76	13.0
Te Hoanga Point	60	5	40	15.1	1.05	13.0
Hargreaves Basin	58	7.5	47	17.5	0.95	16.0
Kapua Point	60	6.2	58	19.5	1.37	17.0
Wahiwaka Creek	60	5.8	53	21.6	1.55	18.0

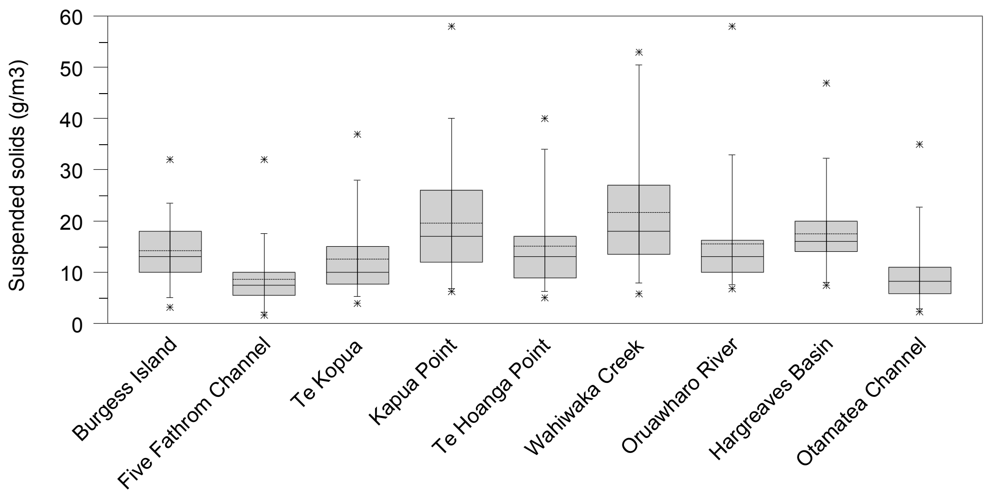


Figure 8: Suspended solid (g/m^3) data collected from January 2010 to December 2014.

3.3 Faecal indicator bacteria

Microbial indicator organisms are used to measure the faecal contamination of the water and therefore its suitability for recreational activities.

3.3.1 Enterococci

The Microbiological Guidelines for Marine and Freshwater Recreational Areas (Ministry for Environment, 2003) set concentrations for different levels of action. This three-tier system is analogous to traffic lights with a green (surveillance) mode, amber (alert) mode and a red (action) mode. For the surveillance/green mode (highly likely to be uncontaminated – 'suitable' for bathing) no single sample should exceed 140 enterococci/100ml. The MfE guidelines also detail concentrations of enterococci for different microbiological assessment categories, which are used to grade beaches according to their suitability for recreation. For grade A (the highest grade) waters the 95% percentile should be ≤ 40 enterococci/100ml.

The highest median enterococci concentrations were recorded at sites in the Hātea River and Otaika Creek in Whangārei Harbour (Table 8 and Figure 9). Interestingly, higher median enterococci concentrations were recorded at the Town Basin, Waiarohia Canal, Otaika Creek and the Upper Hātea River sites than at the Limeburners Creek site, which is the immediate receiving environment for discharges from the Whangārei waste water treatment plant. In the Bay of Islands the highest median enterococci concentrations were found at the Kerikeri River and the Waipapa River (both 10 enterococci/100ml) and in the Kaipara at Wahiwaka Creek (12 enterococci/100ml). The Hātea River, Otaika Creek, Wahiwaka Creek, Kaipara River and Waipapa River are all tidal creek environments, which are the receiving environments for freshwater inputs from the surrounding catchments.

Apart from these tidal creek sites, the enterococci concentrations were generally very low and the median concentration of enterococci at 32 of the 42 sites (or 76% of all sites) was the same as the laboratory detection limit. At 17 of the 42 sites, 100% of samples were within the MfE 'green/surveillance' mode of <140 enterococci/100ml and 21 of the 42 sites had a 95th percentile that was ≤ 40, which equates to a Grade A.

In the Kaipara, eight of the nine sites never had a sample that exceeded 140 enterococci/100ml and had a 95th percentile ≤ 40/100ml. The only site that had a 95th percentile >40/100ml was Wahiwaka Creek. In the Bay of Islands, four sites (Russell, Te Puna, Paihia, Paihia North, Doves Bay and Windsor Landing) had 95th percentiles ≤ 40/100ml. Interestingly, although the highest median concentrations of enterococci were found at Kerikeri River and Waipapa River all of the samples collected at these two sites were within the MfE 'green/surveillance' mode of <140 enterococci/100ml. In Whangārei, seven sites (Onerahi, Tamaterau, Portland, Blacksmith Creek, One Tree point, Marsden Point and Mair Bank) had a 95th percentile ≤ 40 enterococci/100ml and at five sites all of the samples collected were below 140/100ml.

Table 8: Enterococci (enterococci/100ml) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site	Count	Min	Max	Mean	Median	S.E	% of samples < 140	95th percentile
Oruawharo River	58	1	7	2	1	0.1	100%	3
Hargreaves Basin	58	1	35	3	1	0.6	100%	7
Te Hoanga Point	59	1	102	6	1	2.4	100%	25
Te Kopua Point	59	1	7	1	1	0.1	100%	3
Kapua Point	59	1	52	3	1	1.1	100%	8
Burgess Island	59	1	82	7	1	2.0	100%	34
Five Fathom Channel	59	1	18	1	1	0.3	100%	2
Otamatea Channel	53	1	18	2	1	0.3	100%	2
Doves Bay	30	5	228	14	5	7.4	97%	21
Ōpua Basin	30	5	291	23	5	10.1	100%	90
Paihia	29	5	613	28	5	21.0	97%	35
Paihia North	28	5	411	20	5	14.5	96%	10
Paihia South	30	5	738	46	5	26.7	93%	215
Russell	30	5	61	7	5	1.9	100%	8
Tapu Point	30	5	365	32	5	15.1	93%	211
Te Haumi	30	5	238	17	5	8.0	97%	49
Te Puna	29	5	91	8	5	3.0	100%	8
Waikare Inlet	30	5	345	21	5	11.6	97%	75
Wainui Island	30	5	866	37	5	28.7	97%	45
Waitangi	30	5	613	37	5	21.4	93%	149
Windsor Landing	30	5	186	12	5	6.0	97%	10
Lower Hātea River	30	5	598	59	5	24.8	90%	361
Kaiwaka Point	30	5	831	56	5	32.8	93%	337
Onerahi	30	5	5475	204	5	182.3	97%	36
Mangapai River	30	5	517	26	5	17.2	97%	59
Portland	30	5	240	15	5	7.8	97%	16
Tamaterau	30	5	210	13	5	6.8	97%	16
One Tree Point	30	5	82	8	5	2.6	100%	6
Snake Bank	30	5	146	12	5	5.2	97%	46
Blacksmith Creek	30	5	77	8	5	2.4	100%	10
Marsden Point	30	5	66	7	5	2.0	100%	8
Mair Bank	30	5	42	8	5	1.8	100%	36
Kawakawa River	30	5	1785	81	8	59.1	93%	121
Kerikeri River	30	5	137	23	10	4.9	100%	59
Waipapa River	30	5	84	17	10	3.3	100%	47
Kissing Point	30	5	2755	129	10	92.3	90%	401
Wahiwaka Creek	59	1	4300	160	12	78.7	88%	563
Limeburners Creek	30	5	15531	593	15	516.2	83%	724
Otaika Creek	12	5	110	41	31	10.5	100%	109
Upper Hātea River	30	5	12997	507	36	431.1	80%	369
Waiarohia Canal	30	10	11199	444	36	371.3	83%	362
Town Basin	30	5	9804	413	42	324.5	80%	393

Note: the lower median concentrations found at most sites in the Kaipara Harbour is a feature of the lower detection limit of <2 enterococci/100ml for samples sent to Watercare compared to <10 enterococci/100ml for samples sent to Whangārei District Council for analysis.

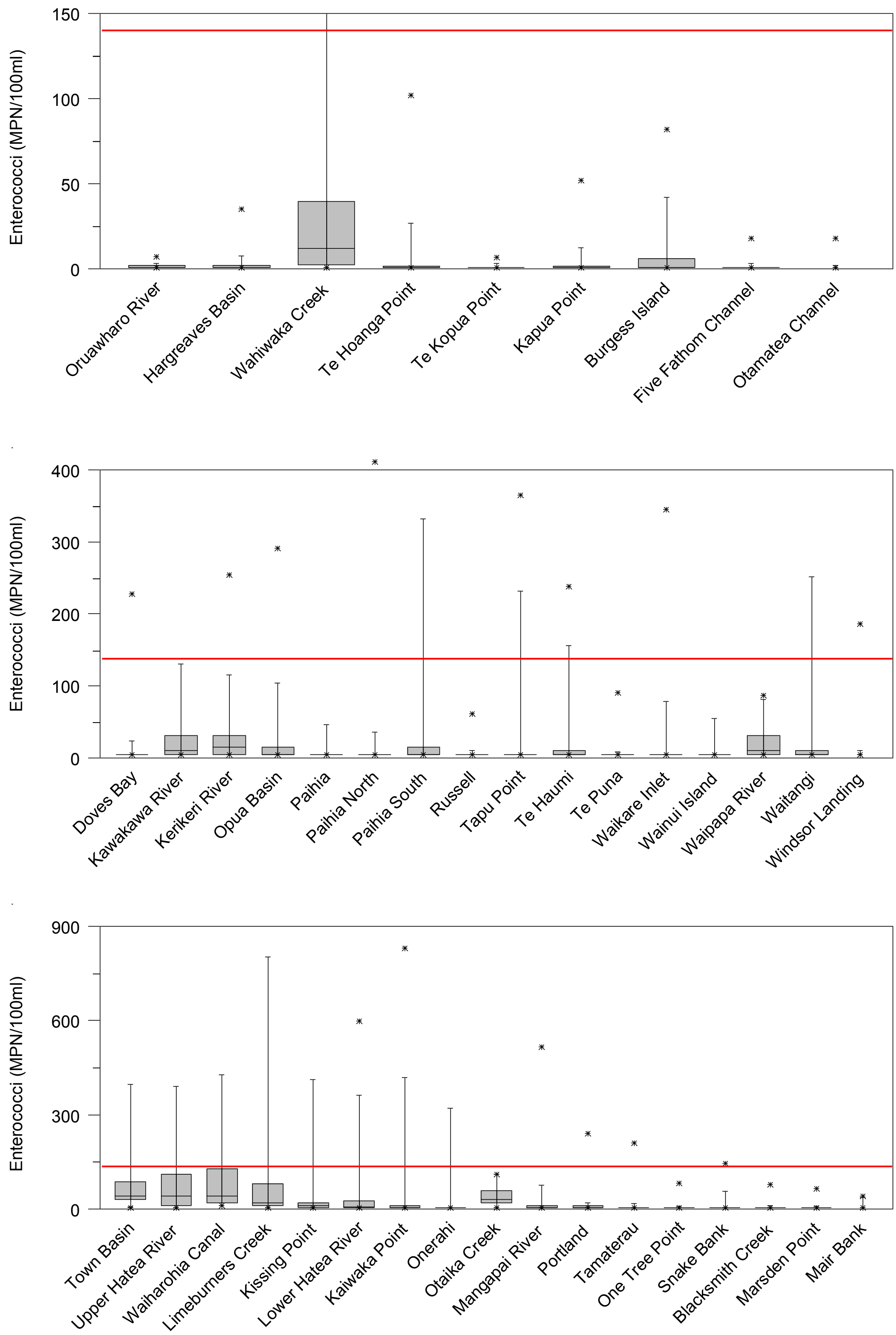


Figure 9: Enterococci data collected from January 2010 to December 2014. Red line = MfE guideline (140 enterococci/100ml). Note: graphs have different scales.

3.3.2 Faecal coliforms

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 and lower concentrations found at outer estuarine locations.

As for enterococci, the highest median faecal coliform concentrations were recorded at the same four sites in the Hātea River and at the Otaika River in Whangārei Harbour (Table 9 and Figure 10). The highest median faecal coliform concentration was found at the site in the Town Basin in Whangārei, which also had the highest median enterococci concentration. In the Bay of Islands, the highest median were recorded at the Kerikeri River (42/100ml) and Waipapa River (25/100ml), which also had the highest median enterococci concentrations in the Bay of Islands.

The lowest median faecal coliform concentrations were recorded at outer estuarine locations in the Whangārei Harbour and the Bay of Islands. A total of 14 sites had a median value of 1 (which is the laboratory detection limit) and 10 of these sites had a 95th percentile of ≤ 10 (Table 9). A further eight sites had a median faecal coliform concentration of less than 10 so in total 67% of sites had median faecal coliform concentrations of less than 10.

The Microbiological Guidelines for Marine and Freshwater Recreational Areas (Ministry for Environment, 2003) recommend that enterococci be used to assess the suitability of marine water for recreation and do not provide a guideline value for faecal coliforms. However, the ANZECC 2000 guideline document recommends that for primary contact recreation the median faecal coliform concentration should not exceed 150 faecal coliforms/100ml. None of the sites had a median that exceeded 150 faecal coliforms/100ml although the median at the Town Basin in Whangārei Harbour was 149 faecal coliforms/100ml.

Table 9: Faecal coliform data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site	Count	Minimum	Maximum	Mean	Median	S.E	95th %ile
Snake Bank	30	1	12	1	1	0.4	1
Russell	30	1	9	1	1	0.3	2
Te Puna	29	1	4	1	1	0.1	2
Tamaterau	30	1	6	1	1	0.2	2
Marsden Point	30	1	8	1	1	0.3	4
Mair Bank	30	1	6	1	1	0.2	4
One Tree Point	30	1	60	3	1	2	6
Portland	30	1	20	3	1	0.7	9
Blacksmith Creek	30	1	14	2	1	0.6	9
Onerahi	30	1	6200	209	1	207	10
Waikare Inlet	30	1	108	7	1	3.7	29
Windsor Landing	30	1	56	5	1	2.2	29
Kaiwaka Point	30	1	520	24	1	17.2	34
Doves Bay	30	1	76	6	1	3.2	39
Ōpua Basin	30	1	44	8	2	2.0	29
Paihia	29	1	92	10	2	3.4	35
Paihia North	29	1	100	12	2	3.9	39
Tapu Point	30	1	114	12	2	4.2	48
Wainui Island	30	1	180	16	2	7.9	108
Paihia South	30	1	68	10	3	2.8	36
Te Haumi	30	1	64	10	4	2.8	38
Mangapai River	30	1	164	18	6	6.4	77
Waitangi	30	1	340	29	11	11.7	94
Kawakawa River	30	1	300	36	12	12.0	173
Lower Hātea River	30	1	580	55	16	22.7	303
Waipapa River	30	4	260	52	25	11.1	171
Kissing Point	30	1	1400	124	27	59.8	791
Kerikeri River	30	6	410	76	42	16.3	220
Waiarohia Canal	30	8	1990	241	76	83.4	1183
Upper Hātea River	30	1	2800	303	79	109.5	1382
Limeburners Creek	30	1	2600	223	100	87.1	582
Otaika Creek	12	1	410	150	111	37.5	361
Town Basin	30	18	3200	310	149	106.8	720

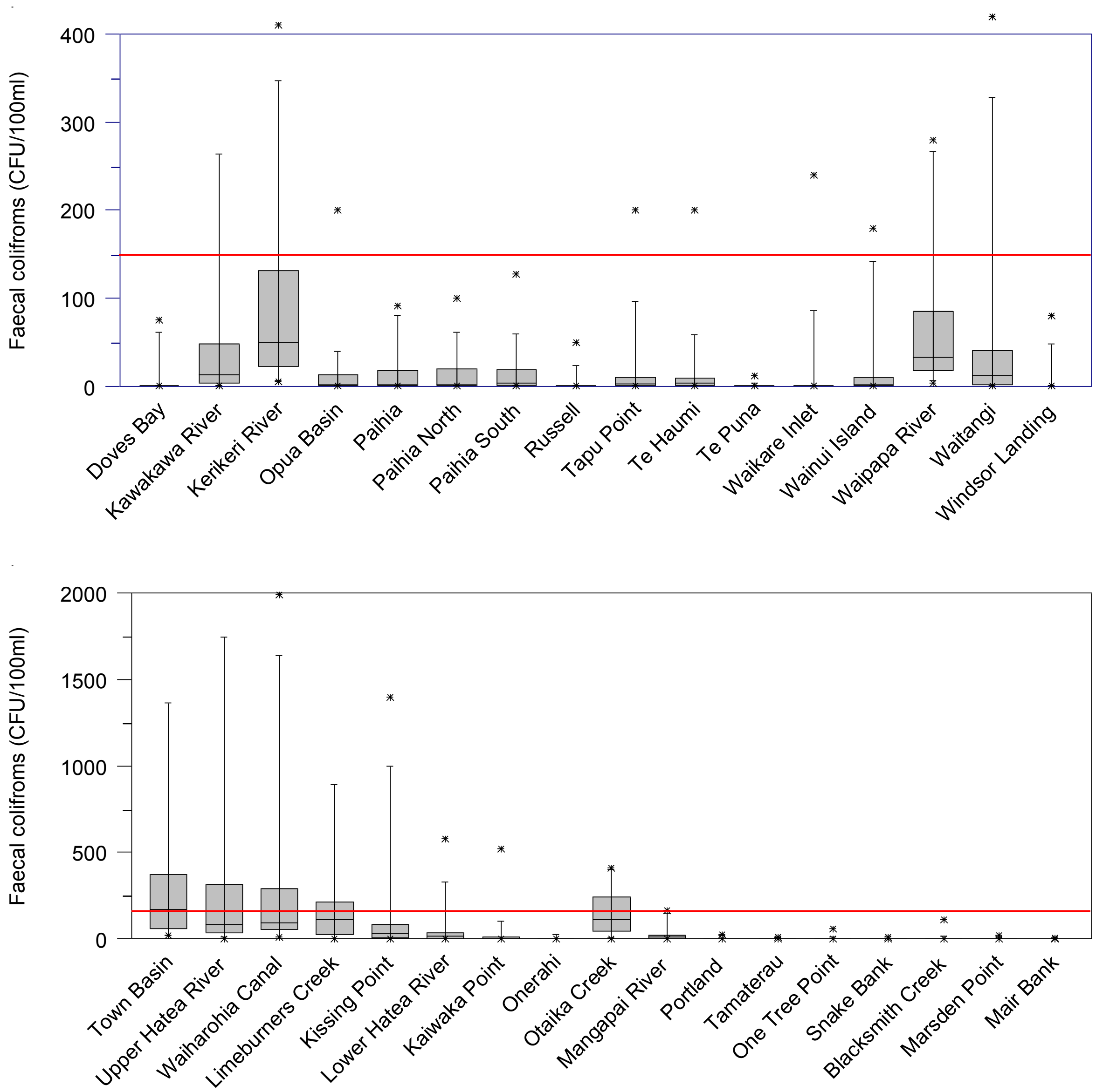


Figure 10: Faecal coliform data collected from January 2010 to December 2014. Red line = ANZECC guideline (150 faecal coliforms/100ml). Note: graphs have different scales.

3.4 Nutrients and trophic state

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertiliser, stormwater, treated wastewater, sewage overflows and failing septic systems, may exceed the needs of an ecosystem. Elevated nutrients in the water can cause excessive plant growth leading to algal blooms, which in turn can cause lowered levels of dissolved oxygen and water clarity. This can reduce the life-supporting capacity of the water, and pose a significant human health risk through contact with toxic algal blooms and eating contaminated shellfish. Excessive plant growth can also look unattractive and can cause an unpleasant odour when it dies and decays.

Concentrations of TN, NNN, NH4, TP and DRP are direct measures of nutrient concentrations which may be responsible for over-enrichment, while chlorophyll *a* and dissolved oxygen are response indicators of nutrient enrichment. Water clarity can also be a response indicator of nutrient enrichment but has been reported separately in section 3.2.

3.4.1 Dissolved oxygen (mg/l)

Dissolved oxygen is a measure of the quantity of oxygen in the water column. Oxygen is required by marine organisms (for example, fish, invertebrates and microorganisms) for efficient functioning (ANZECC, 2002) and reduced oxygen levels have been shown to cause lethal and sub-lethal effects (physiological and behavioural) in a variety of organisms, especially in fish (Canadian Council of Ministers of the Environment, 1999). Significant decreases in dissolved oxygen levels can occur when there is an excess of organic material in the system, for example, sewage effluent or dead plant material.

Dissolved oxygen levels fluctuate diurnally and seasonally. Diurnal changes are caused by the respiration of plants and animals and the photosynthetic activity of aquatic plants during the day. Plants and animals consume oxygen for respiration throughout the day and night but during the daytime oxygen is released by aquatic plants as a bi-product of photosynthesis so typically oxygen levels are higher during the day and decrease at night when photosynthesis ceases. Seasonal variations are related to changes in water temperature, as cold water holds more oxygen than warm water and to seasonal changes in the abundance of plants and animals.

The highest median dissolved oxygen concentration was recorded at the Otamatea Channel (8.0 mg/l) in the Kaipara Harbour (Table 10 and Figure 11). High median dissolved oxygen concentrations were also found at Otaika Creek (7.9mg/l) and Burgess Island (7.0mg/l). The lowest median dissolved oxygen concentrations were recorded at the Mangapai River (6.4 mg/l) and Limeburners Creek (6.8 mg/l) in Whangārei Harbour and at Wahiwaka Creek (6.7 mg/l) in the Kaipara Harbour. These three sites are sheltered tidal creek environments located a long distance from the respective harbour entrances. Limeburners Creek is the receiving environment for waste water from the Whangārei waste water treatment plant and Wahiwaka creek is located downstream of discharges from the Maungaturoto waste water treatment plant, the Kaiwaka waste water treatment plant and a discharge from the Fonterra Maungaturoto milk processing plant. In the Bay of Islands the lowest median values were recorded at Te Haumi and Windsor landing (both 7.2 mg/l).

The ANZECC 2002 guidelines do not include a default trigger value for dissolved oxygen concentration (mg/l) although the 1992 ANZECC guidelines recommended that dissolved oxygen should not normally be permitted to fall below 6 mg/l, determined over at least one diurnal cycle. All 42 sites had median values above 6.0 mg/l. It should be noted that samples are collected during the daytime when dissolved oxygen concentrations are likely to be higher than at night because of photosynthesis by aquatic plants.

Table 10: Dissolved oxygen (mg/l) data collected from January 2010 to December 2014. Ranked highest to lowest median.

Site	Count	Minimum	Maximum	Mean	Median	S.E
Otamatea Channel	53	6.7	9.2	8.1	8.0	0.1
Otaika Creek	11	6.1	10.5	8.2	7.9	0.4
Burgess Island	57	6.4	9.6	8.0	7.9	0.1
Kerikeri River	29	5.7	10.1	7.9	7.8	0.2
Waipapa River	29	5.7	10.3	7.9	7.8	0.2
Town Basin	30	3.9	10.6	7.7	7.8	0.3
Five Fathom Channel	57	6.3	9.3	7.9	7.8	0.1
Blacksmith Creek	30	6.6	9.3	7.8	7.7	0.1
Marsden Point	29	6.9	8.9	7.8	7.7	0.1
Oruawharo River	57	6.5	9.8	7.9	7.7	0.1
One Tree Point	30	6.5	9.0	7.7	7.7	0.1
Snake Bank	30	6.7	8.9	7.7	7.6	0.1
Mair Bank	29	7.0	8.9	7.8	7.6	0.1
Hargreaves Basin	57	6.6	9.7	7.8	7.6	0.1
Russell	30	5.0	9.0	7.4	7.5	0.1
Waikare Inlet	30	5.3	9.1	7.4	7.5	0.2
Te Puna	29	5.5	9.1	7.5	7.4	0.2
Waiarohia Canal	29	4.5	10.2	7.4	7.4	0.3
Te Kopua Point	57	6.1	9.4	7.6	7.4	0.1
Paihia North	30	5.1	8.5	7.3	7.4	0.1
Upper Hātea River	30	4.2	10.6	7.4	7.4	0.3
Tamaterau	30	6.4	9.1	7.6	7.4	0.1
Doves Bay	29	5.0	9.1	7.4	7.3	0.1
Ōpua Basin	30	5.2	8.8	7.3	7.3	0.1
Paihia	30	5.2	8.6	7.3	7.3	0.1
Paihia South	29	5.2	9.1	7.3	7.3	0.1
Tapu Point	30	5.3	9.4	7.4	7.3	0.2
Wainui Island	29	5.1	9.0	7.2	7.3	0.2
Waitangi	30	4.9	9.0	7.3	7.3	0.2
Onerahi	30	6.1	9.2	7.5	7.3	0.2
Te Hoanga Point	57	6.1	9.7	7.6	7.3	0.1
Kawakawa River	30	5.5	8.8	7.3	7.3	0.2
Te Haumi	30	5.2	8.8	7.2	7.2	0.1
Windsor Landing	29	5.0	8.8	7.2	7.2	0.1
Kapua Point	58	5.9	9.4	7.4	7.2	0.1
Portland	30	5.9	9.4	7.3	7.2	0.2
Kaiwaka Point	30	5.8	9.0	7.3	7.0	0.2
Kissing Point	30	4.8	9.4	7.1	7.0	0.2
Lower Hātea River	30	5.1	9.3	7.2	7.0	0.2
Limeburners Creek	30	3.9	9.7	6.9	6.8	0.3
Wahiwaka Creek	57	4.8	9.6	7.1	6.7	0.1
Mangapai River	30	4.7	9.4	6.6	6.4	0.2

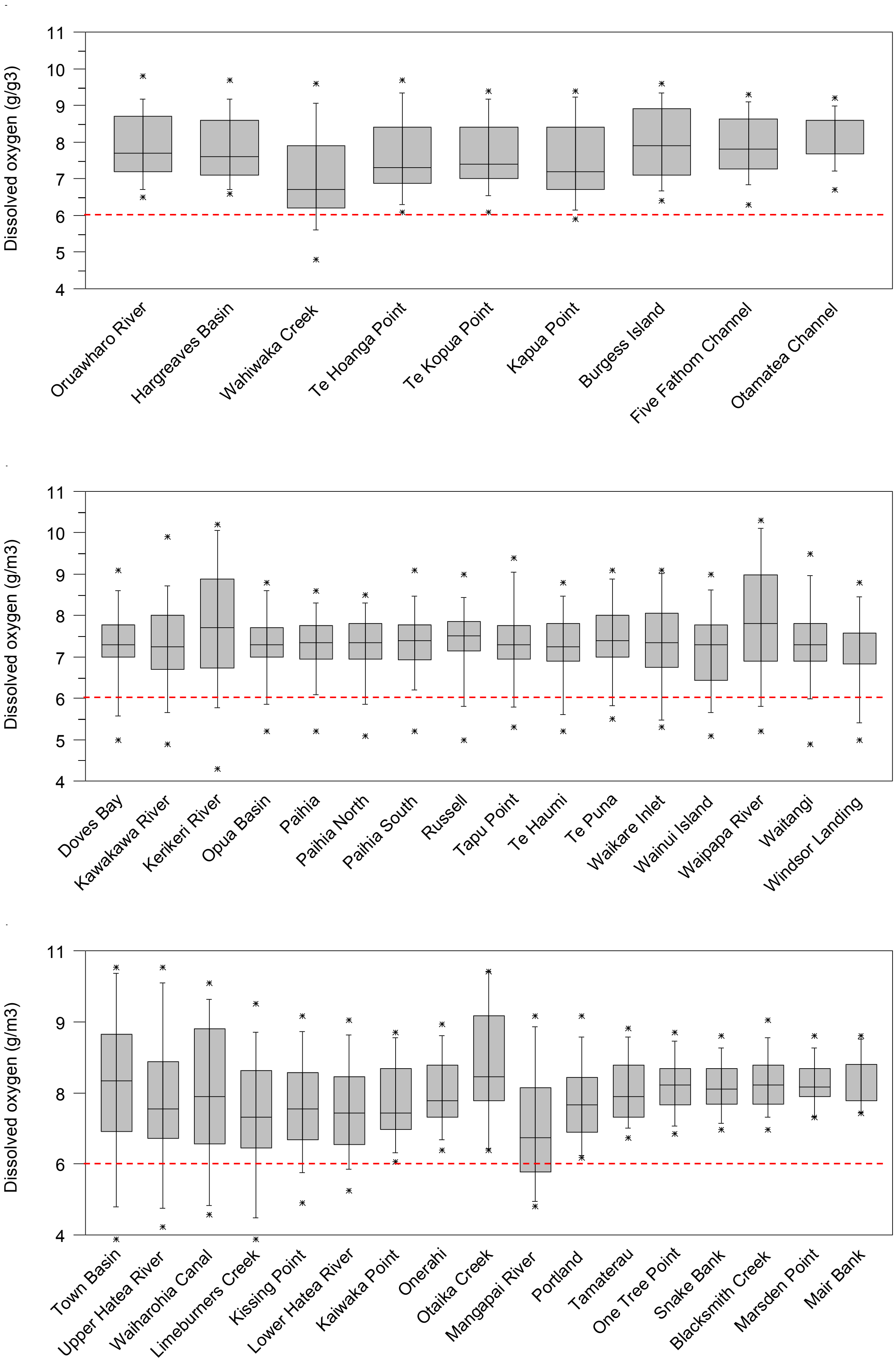


Figure 11: Dissolved oxygen (mg/l) data collected from January 2010 to December 2014. Dash red line = ANZECC 1992 (6mg/l). Note: graphs have different scales.

3.4.2 Dissolved oxygen (% saturation)

Another measure of dissolved oxygen levels is the dissolved oxygen saturation. Dissolved oxygen saturation is a ratio of the concentration of dissolved oxygen in the water to the maximum amount of oxygen that will dissolve in water at that temperature, salinity and pressure under stable equilibrium. As with dissolved oxygen, concentration (mg/l) reduced dissolved oxygen saturation can have adverse effects on marine flora and fauna. It is also possible for water to become supersaturated (that is, exceed 100% saturation). Supersaturation typically occurs either because of photosynthesis by aquatic plants or because of a slow return to equilibrium following a change in atmospheric conditions.

Supersaturation can therefore be an indicator of excess aquatic plant growth, which may in turn cause oxygen depletion issues at night when photosynthesis stops or when the plants break/die and are broken down by bacteria which consume oxygen.

The highest median levels of dissolved oxygen saturation were recorded at the Otamatea Channel (102.7%) and Five Fathom Channel (99.8%) in the Kaipara Harbour (Table 11 and Figure 12). High median dissolved oxygen saturations were also recorded at sites close to the entrance of the Whangārei Harbour (Marsden Point (99.0%), Mair Bank (99.0%) and Snake Bank (98.9%) and Blacksmith Creek 98.8%. In the Bay of Islands, the highest median dissolved oxygen saturations were recorded at Te Puna (97.7%) and Russel (97.1%). These sites are all close to the entrance of the harbours or estuaries or in exposed locations with high water flows where you would expect the water to be well aerated.

The lowest medians were recorded at tidal creek environments in the Mangapai River (79.4%), the Upper Hātea (84.8%), Limeburners Creek (85.7%) and Otaika Creek (85.9%) in Whangārei Harbour and at Wahiwaka Creek (87.0%) in the Kaipara Harbour. In the Bay of Islands the lowest median dissolved oxygen was recorded at the Kawakawa River (87.6%). These sites are all sheltered tidal creek environments. The Limeburners Creek site is the receiving environment for waste water from the Whangārei waste water treatment plant and Wahiwaka creek is located downstream of discharges from the Maungaturoto waste water treatment plant, the Kaiwaka waste water treatment plant and a discharge from the Fonterra Maungaturoto milk processing plant.

The ANZECC guidelines for dissolved oxygen saturation is >80% and <110% for estuarine waters and >90% and <110% for marine waters. The Mangapai River was the only site with a median dissolved oxygen saturation below the ANZECC guidelines value of 80% for estuarine waters. All the sites had median dissolved oxygen saturations well below the upper guideline value of 110%. It should be noted that samples are collected during the daytime when dissolved oxygen concentrations are likely to be higher than at night because of photosynthesis by aquatic plants.

Table 11: Dissolved oxygen (% saturation) data collected from January 2010 to December 2014. Ranked highest to lowest median.

Site	Count	Minimum	Maximum	Mean	S.E	Median
Otamatea Channel	53	94.3	109.5	102.8	0.4	102.7
Five Fathom Channel	57	75.0	108.0	98.8	0.8	99.8
Marsden Point	28	91.0	106.1	98.9	0.7	99.0
Mair Bank	28	91.8	106.9	99.5	0.8	99.0
Snake Bank	29	91.5	105.5	98.7	0.7	98.9
Blacksmith Creek	29	91.3	112.9	98.8	0.8	98.8
One Tree Point	29	90.6	104.0	98.0	0.7	98.5
Oruawharo River	57	79.8	106.0	98.0	0.6	98.3
Te Puna	29	62.4	106.8	96.0	1.5	97.7
Hargreaves Basin	57	77.5	109.0	97.3	0.7	97.2
Russell	30	59.3	106.5	95.3	1.6	97.1
Burgess Island	57	70.2	106.0	96.4	0.8	96.9
Onerahi	29	83.4	106.5	95.6	1.0	96.7
Tamaterau	29	83.0	102.9	95.8	0.7	96.5
Te Kopua Point	58	71.7	106.0	94.6	0.8	95.6
Te Hoanga Point	57	70.0	105.0	93.6	0.9	94.9
Doves Bay	29	59.0	102.1	93.1	1.5	94.5
Paihia South	29	60.8	107.6	92.5	1.5	94.3
Ōpua Basin	30	61.7	101.7	92.0	1.4	93.4
Paihia North	30	60.9	100.8	92.0	1.4	93.1
Paihia	30	61.1	100.8	92.0	1.4	92.5
Windsor Landing	29	59.5	103.7	91.6	1.5	92.5
Te Haumi	30	60.8	101.0	90.7	1.5	92.4
Tapu Point	30	62.2	101.2	91.2	1.3	92.2
Waikare Inlet	30	64.0	102.5	91.9	1.3	91.9
Kapua Point	58	68.1	104.0	91.7	0.9	91.8
Waitangi	30	59.2	100.1	90.7	1.4	91.5
Kerikeri River	29	60.8	100.2	89.4	1.6	91.3
Portland	29	70.4	103.0	91.2	1.1	91.2
Waipapa River	29	61.4	100.4	89.7	1.5	91.0
Kaiwaka Point	29	81.5	99.1	90.7	0.9	90.9
Wainui Island	29	59.2	105.0	90.2	1.5	90.0
Town Basin	29	55.6	103.0	86.0	2.3	87.8
Kawakawa River	30	62.3	96.2	86.5	1.2	87.6
Waiarohia Canal	29	63.0	104.3	85.8	2.2	87.6
Kissing Point	29	67.7	100.9	86.6	1.4	87.5
Lower Hātea River	29	73.2	100.1	88.1	1.3	87.4
Wahiwaka Creek	57	65.4	103.9	85.9	1.0	87.0
Otaika Creek	11	61.2	126.9	90.2	5.2	85.9
Limeburners Creek	29	52.4	101.2	82.5	2.2	85.7
Upper Hātea River	29	59.2	114.4	84.6	2.3	84.8
Mangapai River	29	64.9	100.4	81.3	1.6	79.4

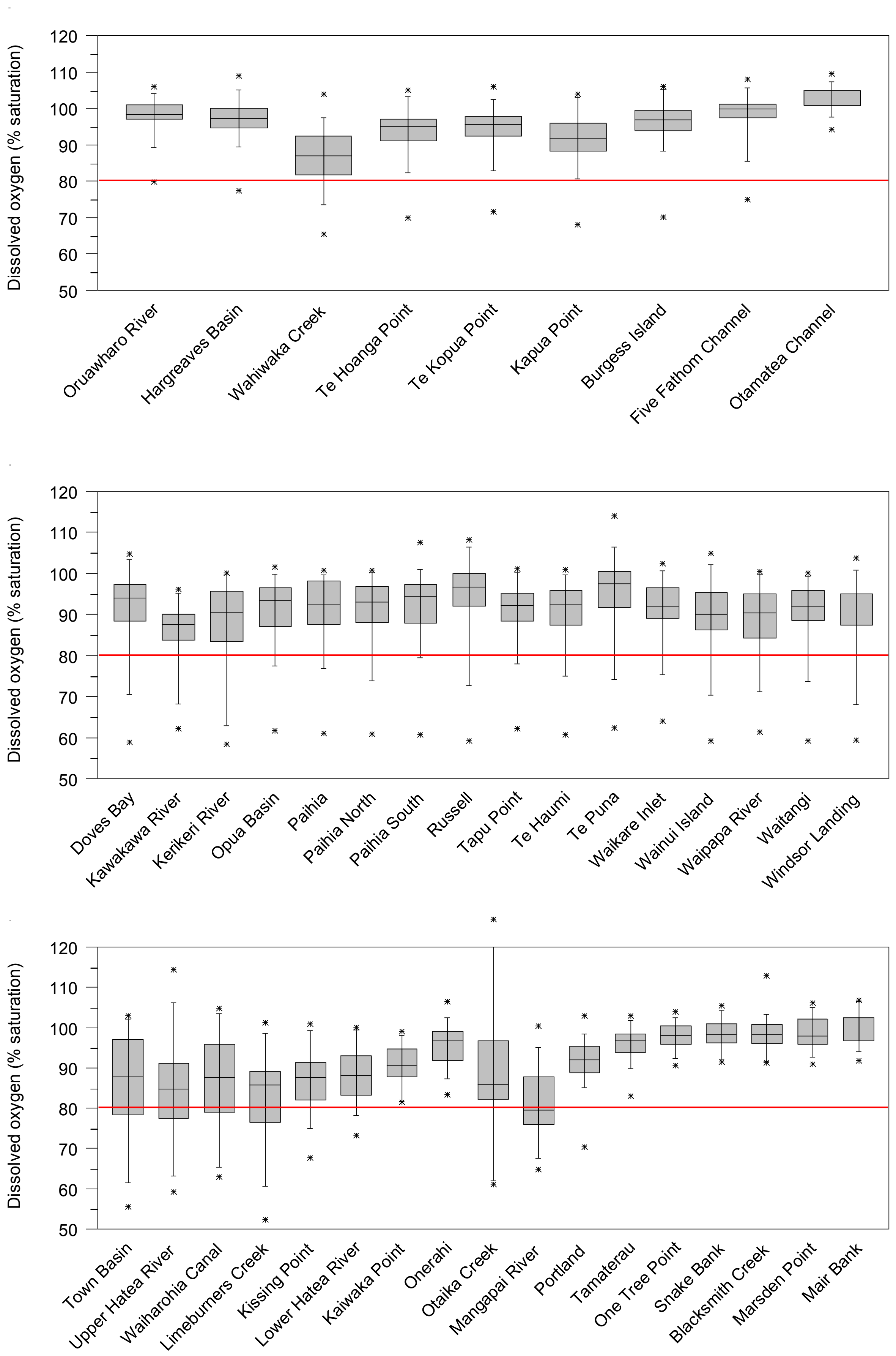


Figure 12: Dissolved oxygen (% saturation) data collected from January 2010 to December 2014. Red line = ANZECC trigger value (80%).

3.4.3 Chlorophyll *a*

Chlorophyll *a* is a green pigment found in plants that is used to absorb sunlight during photosynthesis. Chlorophyll *a* concentrations are therefore an indicator of phytoplankton abundance and biomass in coastal waters, which is in turn an indicator of trophic status.

The highest median chlorophyll *a* concentrations were found at Hargreaves Basin and Burgess Island in the Kaipara Harbour and at Kerikeri River, Waipapa River and Waikare Inlet in the Bay of Islands. These sites are all inner estuarine sites close to freshwater inputs.

The lowest median chlorophyll *a* concentration was recorded at Blacksmith Creek (0.0008 mg/l) in Whangārei Harbour (Table 12 and Figure 13). Other sites in the outer Whangārei Harbour, such as Mair Bank, Marsden Point, Snake Bank and Mair Bank also had low median chlorophyll *a* concentrations. In the Bay of Islands, the lowest concentrations were generally found at more exposed outer estuarine locations such as Paihia North, Paihia South and Russel although a low median chlorophyll *a* concentration was also found at the Waitangi site, which is an estuarine site. In the Kaipara Harbour the lowest medians were also recorded at the two sites closest to the entrance of the harbour (Otamatea Channel and Five Fathom Channel) although all nine sites in the Kaipara Harbour had relatively high concentrations of chlorophyll *a* compared to the sites in the Bay of Islands and Whangārei Harbour.

The ANZECC default trigger value for chlorophyll *a* is 0.004mg/l for estuarine waters and 0.001 for marine waters. All 41 estuarine sites had a median concentration below 0.004 although the median at Hargreaves Basin (0.00395 mg/l), in the Kaipara Harbour was very close to the trigger value. The one open coast site, Mair Bank, had a median of 0.00115 mg/l, which exceeded the trigger value for marine waters.

Table 12: Chlorophyll *a* (mg/l) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site name	N	Minimum	Maximum	Mean	SE Mean	Median
Blacksmith Creek	12	0.00030	0.00270	0.00094	0.0002	0.00083
Mair Bank	12	0.00030	0.00280	0.00132	0.0002	0.00115
Marsden Point	12	0.00030	0.00470	0.00147	0.0004	0.00115
Snake Bank	12	0.00030	0.00240	0.00130	0.0002	0.00130
One Tree Point	12	0.00030	0.00260	0.00132	0.0002	0.00140
Tamaterau	12	0.00030	0.00650	0.00176	0.0005	0.00140
Paihia North	12	0.00060	0.00310	0.00153	0.0003	0.00150
Waitangi	12	0.00060	0.00220	0.00137	0.0001	0.00150
Paihia South	12	0.00060	0.00250	0.00150	0.0002	0.00155
Russell	12	0.00060	0.00390	0.00196	0.0003	0.00165
Kaiwaka Point	12	0.00030	0.00540	0.00212	0.0004	0.00175
Limeburners Creek	12	0.00030	0.00610	0.00233	0.0006	0.00175
Onerahi	12	0.00030	0.00550	0.00183	0.0004	0.00175
Te Haumi	12	0.00068	0.00260	0.00171	0.0002	0.00185
Mangapai River	12	0.00068	0.00440	0.00196	0.0003	0.00190
Paihia	12	0.00060	0.00340	0.00198	0.0003	0.00190
Kissing Point	12	0.00030	0.00520	0.00210	0.0004	0.00200
Waiarohia Canal	12	0.00030	0.00740	0.00243	0.0006	0.00200
Windsor Landing	12	0.00060	0.00330	0.00192	0.0002	0.00200
Kawakawa River	12	0.00078	0.00630	0.00253	0.0004	0.00220
Otaika Creek	12	0.00030	0.13000	0.01390	0.0106	0.00220
Portland	12	0.00068	0.00460	0.00218	0.0003	0.00225
Ōpua Basin	12	0.00060	0.02500	0.00413	0.0019	0.00230
Doves Bay	12	0.00060	0.00330	0.00218	0.0003	0.00240
Lower Hātea River	12	0.00030	0.00510	0.00237	0.0004	0.00250
Town Basin	12	0.00030	0.01000	0.00315	0.0009	0.00250
Te Puna	12	0.00060	0.00560	0.00277	0.0005	0.00255
Wainui Island	12	0.00060	0.00460	0.00260	0.0003	0.00260
Tapu Point	12	0.00060	0.01700	0.00388	0.0013	0.00270
Otamatea Channel	53	0.00030	0.02000	0.00320	0.0004	0.00280
Upper Hātea River	12	0.00068	0.00890	0.00307	0.0006	0.00280
Five Fathom Channel	58	0.00080	0.01580	0.00352	0.0004	0.00290
Te Hoanga Point	59	0.00030	0.00800	0.00342	0.0002	0.00290
Te Kopua Point	59	0.00030	0.01300	0.00334	0.0003	0.00290
Wahiwaka Creek	59	0.00078	0.01010	0.00384	0.0003	0.00300
Waikare Inlet	12	0.00060	0.00870	0.00379	0.0008	0.00300
Waipapa River	12	0.00078	0.00820	0.00356	0.0006	0.00315
Kapua Point	59	0.00030	0.00970	0.00354	0.0003	0.00320
Oruawharo River	57	0.00030	0.01800	0.00408	0.0004	0.00340
Kerikeri River	12	0.00069	0.00840	0.00355	0.0007	0.00360
Burgess Island	59	0.00080	0.01300	0.00430	0.0003	0.00370
Hargreaves Basin	58	0.00030	0.01910	0.00466	0.0004	0.00395

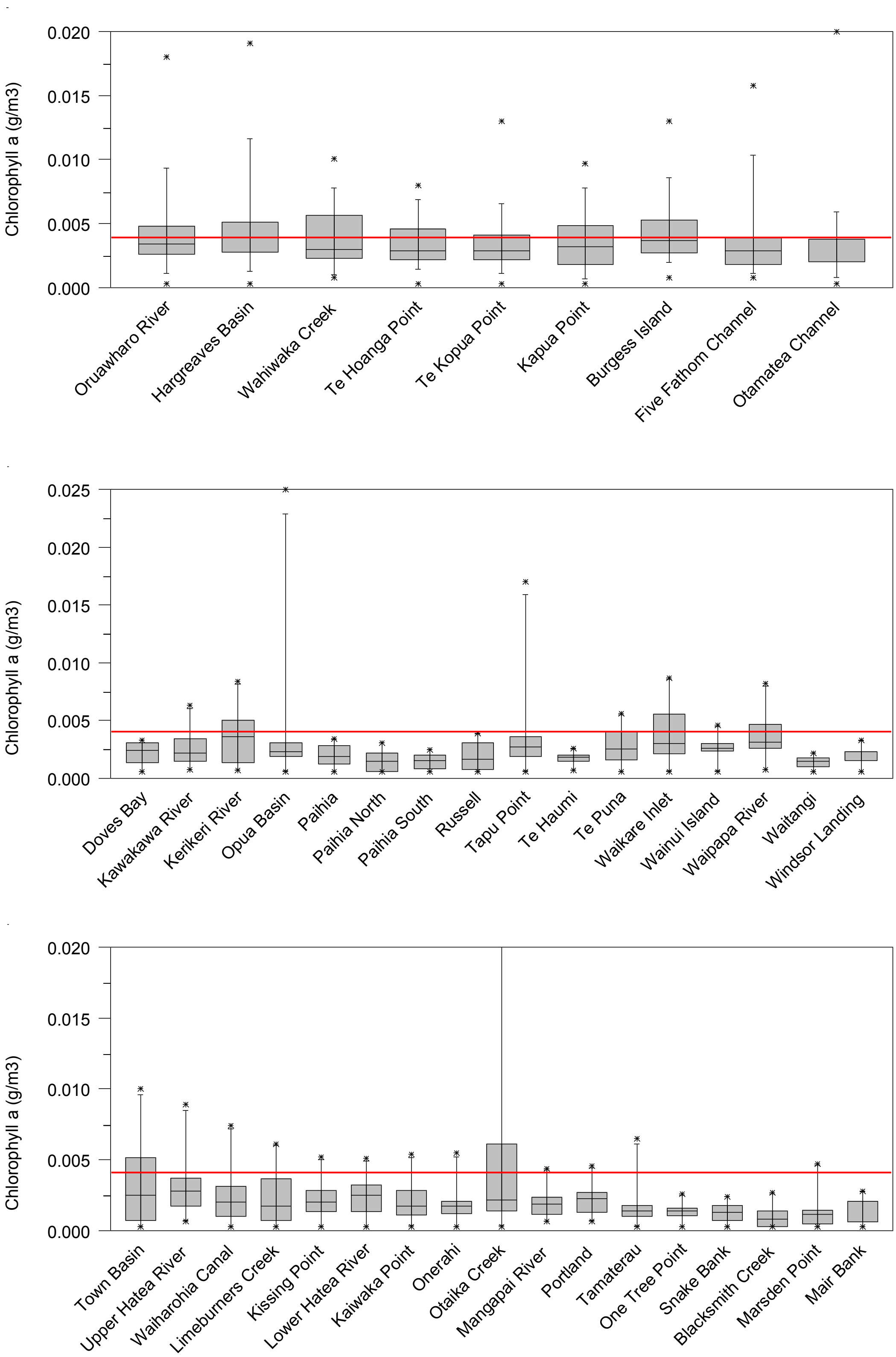


Figure 13: Chlorophyll a data collected from January 2010 to December 2014. Red line = ANZECC trigger value (0.004 mg/l). Note: graphs have different scales.

3.4.4 Ammonium (NH4)

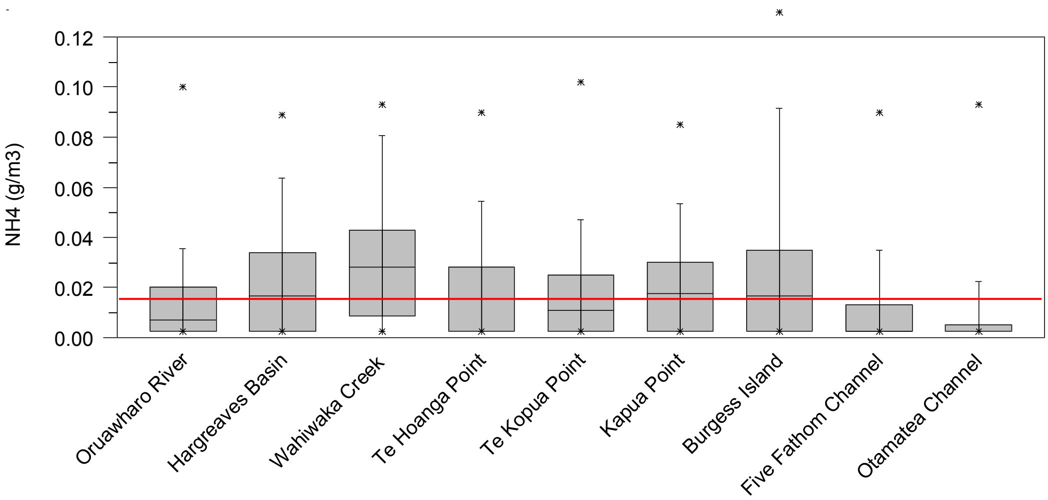
The highest median concentration of NH_4 was found at Limeburners Creek (Table 13 and Figure 14). Limeburners Creek is the receiving environment for discharges from the Whangārei waste water treatment plant. The other five sites in the Hātea River and at Otaika Creek in Whangārei also had high median concentrations. All of these sites had medians above 0.03 mg/l. In the Kaipara Harbour the highest median concentration was recorded at Wahiwaka Creek (0.0280 mg/l) and in the Bay of Islands the highest medians were found at the Waipapa River (0.0245 mg/l) and Kerikeri River (0.0195 mg/l). The Wahiwaka Creek site is located downstream of discharges from the Maungaturoto waste water treatment plant, the Kaiwaka waste water treatment plant and a discharge from the Fonterra Maungaturoto milk processing plant. There are no waste water discharges into either the Waipapa River or Kerikeri River but these are the main fresh water input to the Kerikeri Inlet.

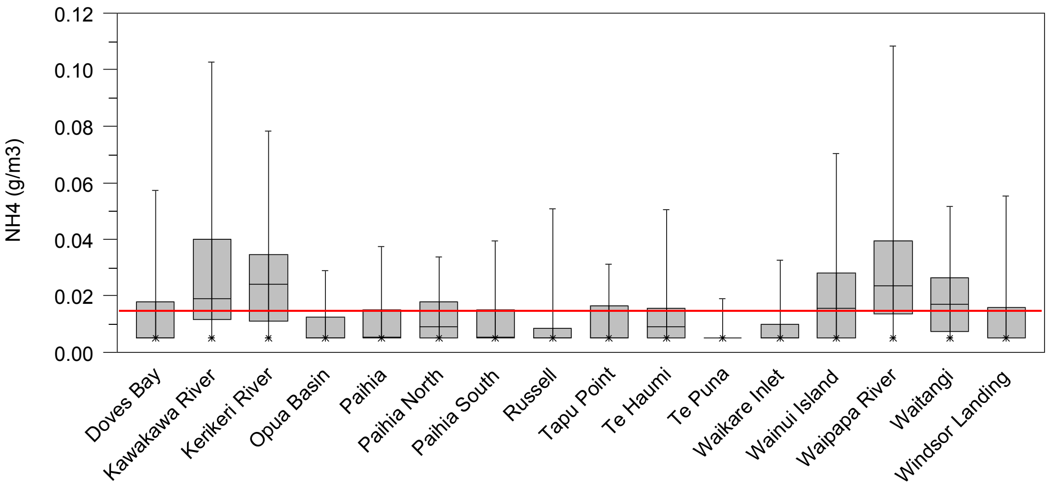
The lowest medians were recorded at outer harbour sites in the Whangārei Harbour (Blacksmith Creek, Mair Bank, Marsden Point, One Tree Point and Snake Bank) and the Kaipara Harbour (Five Fathom Channel and Otamatea Channel). In the Bay of Islands the lowest medians were also generally recorded at outer estuarine locations such as Doves Bay, Russel, Te Puna and Windsor Landing although low medians were recorded at some inner estuarine sites including Waikare Inlet, Ōpua Basin and Tapu Point (all these sites had a median of 0.005 mg/l).

The ANZECC default trigger value for NH_4 is 0.015 mg/l for both estuarine and marine waters. Eighteen of the 42 sites had a median concentration above the trigger value. All of the sites with a median above the ANZECC trigger values were inner estuarine or tidal creek sites.

Table 13: NH4 (mg/L) data collected from January 2010 to December 2014. Ranked lowest to highest median concentration.

Site name	N	Minimum	Maximum	Mean	SE Mean	Median
Blacksmith Creek	30	0.0025	0.1800	0.0131	0.0059	0.0025
Five Fathom Channel	60	0.0025	0.0900	0.0099	0.0018	0.0025
Mair Bank	30	0.0025	0.0250	0.0065	0.0013	0.0025
Marsden Point	30	0.0025	0.0360	0.0065	0.0015	0.0025
One Tree Point	30	0.0025	0.0270	0.0063	0.0012	0.0025
Otamatea Channel	53	0.0025	0.0930	0.0070	0.0018	0.0025
Snake Bank	30	0.0025	0.0200	0.0066	0.0011	0.0025
Doves Bay	30	0.0050	0.3810	0.0251	0.0125	0.0050
Ōpua Basin	30	0.0050	0.3750	0.0215	0.0123	0.0050
Russell	30	0.0050	0.3880	0.0216	0.0128	0.0050
Tapu Point	30	0.0050	0.3750	0.0226	0.0122	0.0050
Te Puna	30	0.0050	0.3800	0.0190	0.0125	0.0050
Waikare Inlet	30	0.0050	0.3870	0.0208	0.0127	0.0050
Windsor Landing	30	0.0050	0.3900	0.0255	0.0128	0.0050
Onerahi	30	0.0025	0.0610	0.0157	0.0031	0.0053
Paihia	30	0.0050	0.3750	0.0232	0.0123	0.0055
Paihia South	30	0.0050	0.4000	0.0241	0.0131	0.0065
Oruawharo River	57	0.0025	0.1000	0.0137	0.0023	0.0070
Paihia North	30	0.0050	0.4000	0.0253	0.0130	0.0090
Tamaterau	30	0.0025	0.0560	0.0150	0.0028	0.0095
Te Haumi	30	0.0050	0.3940	0.0261	0.0129	0.0095
Te Kopua Point	60	0.0025	0.1020	0.0168	0.0026	0.0110
Wainui Island	30	0.0050	0.4000	0.0311	0.0131	0.0130
Portland	30	0.0025	0.0510	0.0168	0.0029	0.0140
Te Hoanga Point	60	0.0025	0.0900	0.0200	0.0025	0.0155
Mangapai River	30	0.0025	0.1900	0.0232	0.0063	0.0160
Burgess Island	60	0.0025	0.1300	0.0255	0.0038	0.0165
Hargreaves Basin	58	0.0025	0.0890	0.0216	0.0027	0.0165
Waitangi	30	0.0050	0.4400	0.0329	0.0142	0.0170
Kapua Point	60	0.0025	0.0850	0.0202	0.0024	0.0175
Kawakawa River	30	0.0050	0.3830	0.0372	0.0127	0.0175
Kerikeri River	30	0.0050	0.3180	0.0328	0.0104	0.0195
Kaiwaka Point	30	0.0025	0.0840	0.0262	0.0041	0.0215
Waipapa River	30	0.0050	0.3720	0.0424	0.0123	0.0245
Wahiwaka Creek	60	0.0025	0.0930	0.0291	0.0030	0.0280
Lower Hātea River	30	0.0025	0.1400	0.0508	0.0068	0.0340
Otaika Creek	12	0.0120	0.0950	0.0485	0.0069	0.0445
Kissing Point	30	0.0150	0.2600	0.0744	0.0101	0.0650
Town Basin	30	0.0140	0.1590	0.0730	0.0080	0.0660
Upper Hātea River	30	0.0190	0.2700	0.0975	0.0123	0.0745
Waiarohia Canal	30	0.0090	0.3200	0.0981	0.0130	0.0790
Limeburners Creek	30	0.0140	2.1000	0.1962	0.0693	0.0835





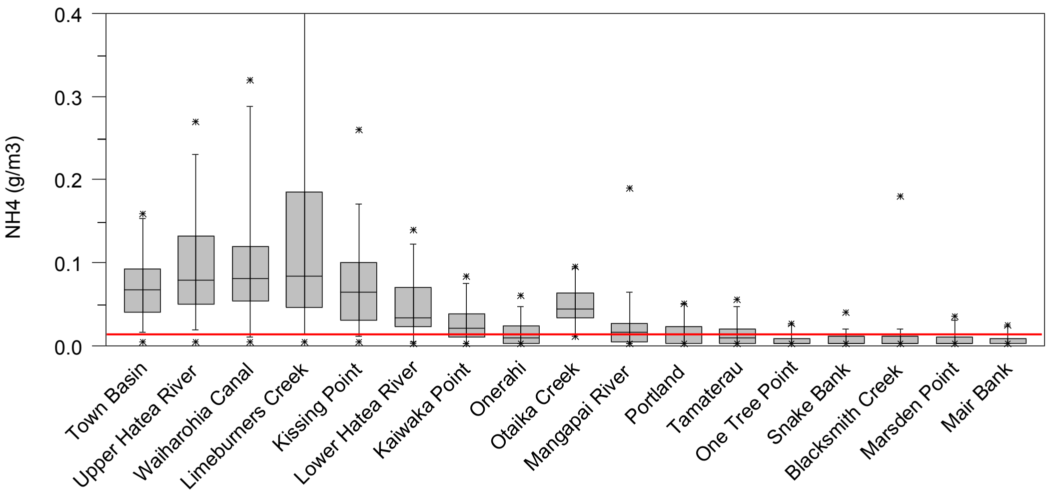


Figure 14: NH4 data collected from January 2010 to December 2014. Red line = ANZECC trigger value (0.015 mg/l). Note: graphs have different scales.

3.4.5 Nitrate-nitrite nitrogen (NNN)

Nitrate-nitrite nitrogen (NNN) 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 highest median concentration of NNN was found at Waiarohia Canal (0.575 mg/l) in Whangārei Harbour (Table 14 and Figure 15). The other five sites in the Hātea River and the Otaika Creek in Whangārei also had high median NNN concentrations. All of these sites had medians >0.1 mg/l. In the Bay of Islands the highest median concentration was found at Kerikeri River (0.145 mg/l), which was double the next highest site in the Bay of Islands. In the Kaipara Harbour the highest median concentrations were recorded at Burgess Island (0.0525 mg/l) and at Wahiwaka Creek (0.0280 mg/l). Like the Otaika Creek and Hātea River sites, Burgess Island, Wahiwaka Creek and Waipapa River are all inner estuarine sites close to fresh water inputs.

The lowest median was recorded at Te Puna (0.001 mg/l) in the Bay of Islands with low medians also recorded at outer harbour sites in the Whangārei Harbour (Blacksmith Creek, Mair Bank, Marsden Point, One Tree Point and Snake Bank).

The ANZECC default trigger value for NNN is 0.015 mg/l for estuarine waters and 0.005 mg/l for marine waters. Twenty of the 42 sites had a median concentration that exceeded the relevant trigger value. Most of the sites with a median above the ANZECC default trigger values were inner estuarine or tidal creek sites. The only outer estuarine sites above the ANZECC default trigger value were Paihia, Paihia South and Paihia North. Six sites (five sites in the Hātea River and the Otaika Creek site) had median NNN concentrations which were an order of magnitude higher than the ANZECC default trigger value.

Table 14: Nitrate-nitrite nitrogen (mg/l) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site name	N	Minimum	Maximum	Mean	SE Mean	Median
Te Puna	30	0.0010	0.0096	0.0026	0.0004	0.0010
Blacksmith Creek	30	0.0010	0.0780	0.0103	0.0030	0.0024
Mair Bank	30	0.0010	0.1010	0.0144	0.0044	0.0028
Marsden Point	30	0.0010	0.0990	0.0120	0.0038	0.0030
One Tree Point	30	0.0010	0.0760	0.0110	0.0030	0.0032
Snake Bank	30	0.0010	0.0890	0.0117	0.0033	0.0035
Waikare Inlet	30	0.0010	0.0660	0.0133	0.0036	0.0045
Russell	30	0.0010	0.0950	0.0156	0.0039	0.0046
Otamatea Channel	53	0.0010	0.1630	0.0158	0.0041	0.0051
Five Fathom Channel	60	0.0010	0.2200	0.0428	0.0082	0.0052
Tapu Point	30	0.0010	0.0750	0.0213	0.0046	0.0069
Ōpua Basin	30	0.0010	0.1250	0.0196	0.0050	0.0073
Tamaterau	30	0.0010	0.0680	0.0139	0.0031	0.0075
Mangapai River	30	0.0010	0.0520	0.0109	0.0022	0.0079
Te Haumi	30	0.0010	0.2000	0.0251	0.0073	0.0082
Portland	30	0.0010	0.0730	0.0163	0.0038	0.0091
Onerahi	30	0.0010	0.0670	0.0185	0.0035	0.0100
Oruawharo River	57	0.0010	0.2400	0.0350	0.0071	0.0100
Te Hoanga Point	60	0.0010	0.2300	0.0451	0.0075	0.0135
Te Kopua Point	60	0.0010	0.2300	0.0445	0.0077	0.0135
Doves Bay	30	0.0010	0.1900	0.0349	0.0081	0.0145
Windsor Landing	30	0.0010	0.1190	0.0304	0.0061	0.0145
Wainui Island	30	0.0010	0.2700	0.0574	0.0140	0.0160
Kapua Point	60	0.0010	0.2200	0.0410	0.0066	0.0165
Paihia	30	0.0010	0.1000	0.0309	0.0060	0.0170
Paihia South	30	0.0010	0.1100	0.0277	0.0054	0.0170
Hargreaves Basin	58	0.0010	0.2300	0.0459	0.0078	0.0175
Kawakawa River	30	0.0010	0.1400	0.0431	0.0083	0.0180
Paihia North	30	0.0010	0.1370	0.0334	0.0072	0.0180
Waitangi	30	0.0010	0.1850	0.0526	0.0112	0.0190
Kaiwaka Point	30	0.0010	0.1700	0.0534	0.0089	0.0430
Wahiwaka Creek	60	0.0010	0.2500	0.0667	0.0083	0.0455
Burgess Island	60	0.0010	0.5040	0.1288	0.0187	0.0525
Waipapa River	30	0.0010	0.4800	0.1557	0.0281	0.0735
Lower Hātea River	30	0.0010	0.8900	0.1684	0.0340	0.1035
Kerikeri River	30	0.0010	0.7500	0.2016	0.0354	0.1450
Kissing Point	30	0.0280	0.9800	0.2867	0.0433	0.2100
Otaika Creek	12	0.0270	0.5300	0.2692	0.0414	0.3000
Town Basin	30	0.0600	0.9800	0.4672	0.0384	0.4100
Limeburners Creek	30	0.0890	4.0000	0.9080	0.2130	0.4400
Upper Hātea River	30	0.0500	0.9100	0.4968	0.0404	0.4450
Waiarohia Canal	30	0.1850	1.4000	0.5714	0.0408	0.5750

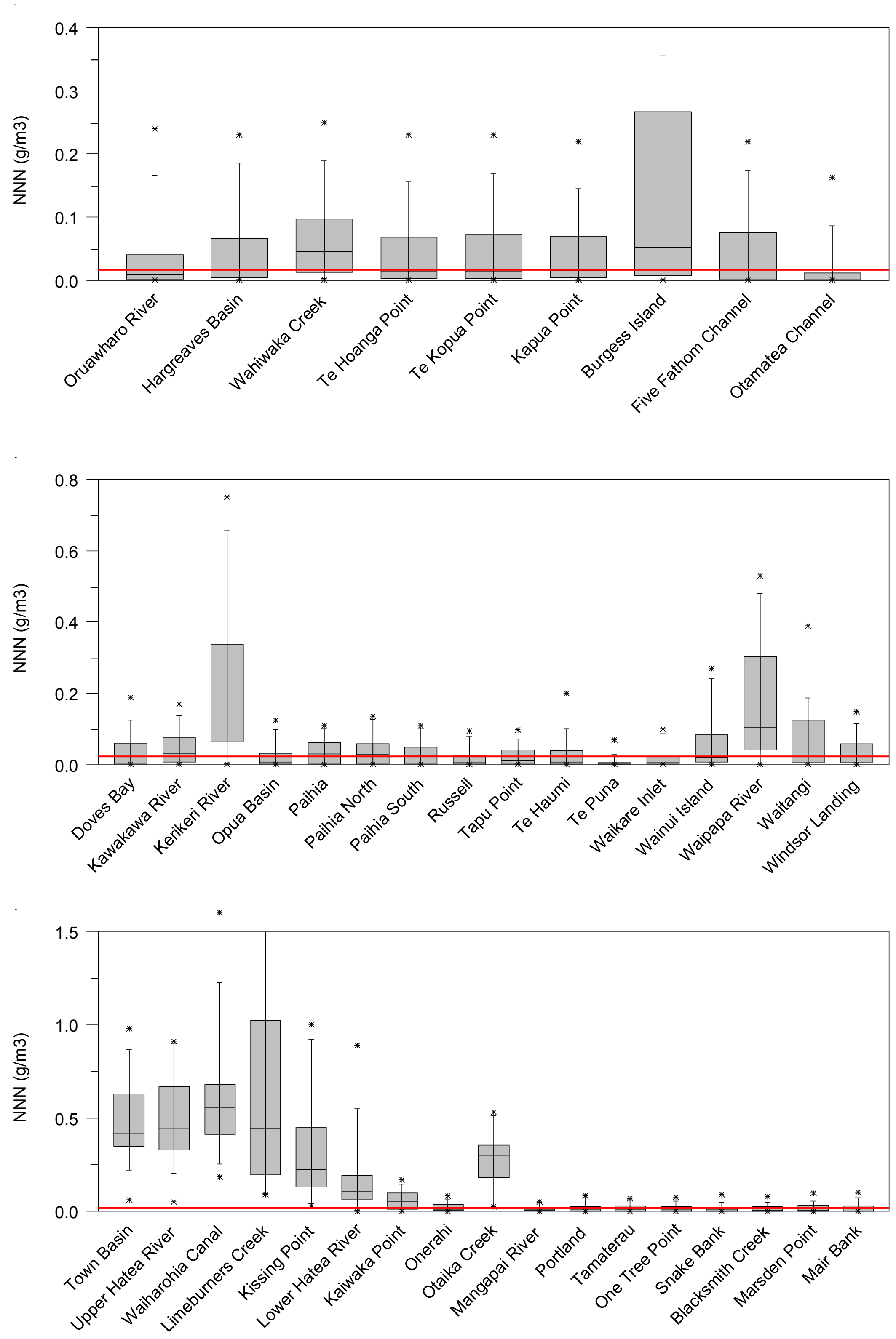


Figure 15: Nitrate-nitrite nitrogen data collected from January 2010 to December 2014. Red line = ANZECC trigger value (0.015mg/l). Note: scales change on graphs.

3.4.6 Total phosphorus

The measurement of total phosphorus (TP) includes the total of all filterable and particulate forms of 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, fertilisers 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.

The highest median concentrations of TP were found at Limeburners Creek (0.1175 mg/l), Waiarohia Canal (0.1150 mg/l) and the Upper Hātea River (0.1020 mg/l) in the Whangārei Harbour (Table 15 and Figure 16). The other three sites in the Hātea River and the Wahiwaka Creek site in the Kaipara Harbour also had high median TP concentrations (>0.05 mg/l). Interestingly, Otaika Creek (0.0275 mg/l), which had high median values for other parameters, had a relatively low median total phosphorus concentration. All of the sites in the Bay of Islands had relatively low median TP concentrations, with the highest median recorded at the Kawakawa River site (0.0255 mg/l).

The lowest median concentrations were recorded at outer estuarine sites in the Whangārei Harbour (Mair Bank, Marsden Point, Blacksmith Creek, Snake Bank and One Tree Point) and the Kaipara Harbour (Otamatea Channel), and at more exposed outer estuarine sites in the Bay of Islands (Russel, Paihia North and Paihia).

The ANZECC default trigger value for TP is 0.03 mg/l for estuarine waters and 0.025 mg/l for marine waters. Thirteen of the 42 sites had a median concentration of TP that exceeded the relevant trigger value and two sites (Burgess Island and Te Hoanga Point) had a median concentration of exactly 0.03 mg/l. All of the sites with a median that exceeded the default trigger value were inner estuarine or tidal creek sites.

Table 15: Total phosphorus (mg/l) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site name	N	Minimum	Maximum	Mean	SE Mean	Median
Mair Bank	30	0.0025	0.0810	0.0126	0.0025	0.0100
Marsden Point	30	0.0050	0.0230	0.0109	0.0008	0.0100
Blacksmith Creek	30	0.0060	0.0200	0.0116	0.0007	0.0105
Snake Bank	30	0.0025	0.0230	0.0115	0.0010	0.0105
One Tree Point	30	0.0025	0.0240	0.0127	0.0009	0.0120
Russell	30	0.0050	0.1500	0.0181	0.0046	0.0135
Otamatea Channel	53	0.0025	0.0630	0.0172	0.0019	0.0140
Paihia North	30	0.0090	0.0470	0.0169	0.0014	0.0150
Paihia	30	0.0080	0.0260	0.0162	0.0008	0.0155
Doves Bay	30	0.0090	0.0300	0.0166	0.0010	0.0160
Five Fathom Channel	60	0.0060	0.0380	0.0182	0.0009	0.0160
Paihia South	30	0.0060	0.0780	0.0185	0.0022	0.0160
Kerikeri River	30	0.0050	0.0380	0.0180	0.0013	0.0180
Te Haumi	30	0.0100	0.0350	0.0191	0.0010	0.0180
Waitangi	30	0.0090	0.0320	0.0183	0.0010	0.0180
Windsor Landing	30	0.0100	0.0280	0.0177	0.0010	0.0185
Te Puna	30	0.0080	0.0470	0.0200	0.0015	0.0195
Ōpua Basin	30	0.0100	0.0350	0.0208	0.0011	0.0200
Tamaterau	30	0.0060	0.0380	0.0192	0.0015	0.0200
Waipapa River	30	0.0050	0.0380	0.0197	0.0014	0.0200
Wainui Island	30	0.0080	0.0390	0.0219	0.0014	0.0205
Tapu Point	30	0.0080	0.3100	0.0332	0.0097	0.0220
Waikare Inlet	30	0.0090	0.0570	0.0262	0.0020	0.0235
Onerahi	30	0.0100	0.0500	0.0263	0.0019	0.0245
Te Kopua Point	60	0.0090	0.0600	0.0272	0.0013	0.0250
Kawakawa River	30	0.0080	0.0650	0.0277	0.0021	0.0255
Oruawharo River	57	0.0080	0.1900	0.0305	0.0032	0.0260
Otaika Creek	12	0.0060	0.1900	0.0543	0.0175	0.0275
Portland	30	0.0120	0.0530	0.0300	0.0019	0.0290
Burgess Island	60	0.0100	0.0560	0.0314	0.0014	0.0300
Te Hoanga Point	60	0.0130	0.0550	0.0307	0.0013	0.0300
Mangapai River	30	0.0100	0.0500	0.0326	0.0020	0.0345
Kapua Point	60	0.0140	0.0750	0.0363	0.0015	0.0350
Kaiwaka Point	30	0.0200	0.0820	0.0372	0.0026	0.0355
Hargreaves Basin	58	0.0150	0.0850	0.0376	0.0016	0.0370
Lower Hātea River	30	0.0190	0.1100	0.0558	0.0048	0.0480
Wahiwaka Creek	60	0.0330	0.1100	0.0569	0.0021	0.0565
Kissing Point	30	0.0290	0.3600	0.0862	0.0119	0.0665
Town Basin	30	0.0120	0.2100	0.0891	0.0097	0.0820
Upper Hātea River	30	0.0150	0.2200	0.1035	0.0093	0.1020
Waiarohia Canal	30	0.0240	0.4000	0.1221	0.0132	0.1150
Limeburners Creek	30	0.0330	0.9700	0.2199	0.0436	0.1175

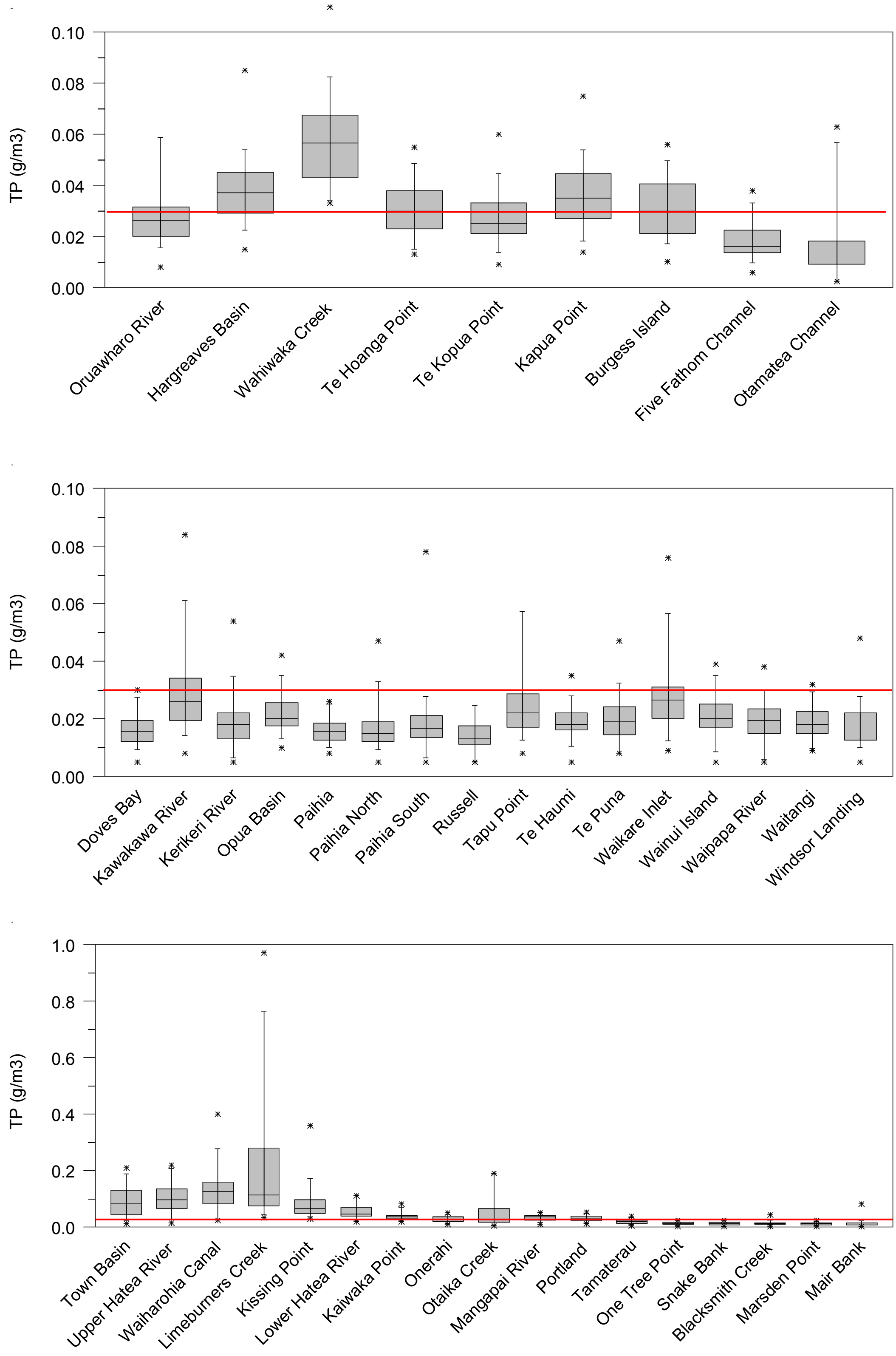


Figure 16: Total phosphorus data collected from January 2010 to December 2014. Red line = ANZECC trigger value (0.03mg/l). Note scales change on graphs.

3.4.7 Dissolved reactive phosphorus

Dissolved reactive phosphorus (DRP) is the fraction of phosphorus that consists largely of the inorganic orthophosphate (PO_4) form of phosphorus. The inorganic orthophosphate fraction is the form of phosphorus 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 highest median concentrations were recorded at the six sites in the Hātea River in Whangārei Harbour and at Wahiwaka Creek in the Kaipara Harbour (Table 16 and Figure 17). These sites all had median values >0.03 mg/l. In the Bay of Islands, the highest median concentration was recorded at the Kawakawa River, which is one of the main fresh water inputs to the Bay of Islands system.

The lowest median concentrations of dissolved reactive phosphorus were recorded at Kerikeri River (0.005 mg/l) and Waipapa River (0.006 mg/l), which are both tidal creek sites located in the upper Kerikeri Inlet in the Bay of Islands (Table 17 and Figure 16). Low median values were also recorded at sites close to the entrance of the Whangārei Harbour (Blacksmith Creek, Mair Bank, Marsden Point) and the entrance of the Kaipara Harbour (Otamatea Channel).

The ANZECC default trigger value is 0.005 mg/l for estuarine waters and 0.010 for coastal waters. Forty of the 42 sites had median concentrations that exceeded the default ANZECC trigger value of 0.005 mg/l for estuarine water. One site (Kerikeri River) had a median value of exactly 0.005 mg/l and the one marine site, Mair Bank (0.007 mg/l) had a median value below the ANZECC default trigger value of 0.010 mg/l for marine waters. Five sites in the Hātea River had median DRP concentrations which were an order of magnitude greater than the default ANZECC trigger value.

Table 16: Dissolved reactive phosphorus (mg/l) data collected from January 2010 to December 2014. Ranked lowest to highest median.

Site name	N	Minimum	Maximum	Mean	SE Mean	Median
Kerikeri River	29	0.0050	0.0140	0.0066	0.0004	0.0050
Waipapa River	30	0.0050	0.0110	0.0065	0.0003	0.0060
Blacksmith Creek	30	0.0025	0.0120	0.0071	0.0005	0.0070
Mair Bank	30	0.0025	0.0150	0.0067	0.0006	0.0070
Marsden Point	30	0.0025	0.0130	0.0066	0.0005	0.0070
Otamatea Channel	53	0.0025	0.0370	0.0083	0.0008	0.0070
Russell	30	0.0050	0.0240	0.0076	0.0007	0.0070
Te Puna	30	0.0050	0.0120	0.0075	0.0003	0.0070
One Tree Point	30	0.0025	0.0120	0.0073	0.0005	0.0075
Doves Bay	30	0.0050	0.0160	0.0088	0.0005	0.0080
Otaika Creek	12	0.0030	0.0590	0.0133	0.0044	0.0080
Paihia North	30	0.0050	0.0130	0.0086	0.0004	0.0080
Paihia South	30	0.0050	0.0140	0.0086	0.0004	0.0080
Snake Bank	30	0.0025	0.0130	0.0072	0.0005	0.0080
Waitangi	30	0.0050	0.0200	0.0088	0.0006	0.0080
Ōpua Basin	30	0.0050	0.0200	0.0094	0.0006	0.0090
Paihia	30	0.0050	0.0130	0.0086	0.0004	0.0090
Tapu Point	30	0.0050	0.0230	0.0097	0.0007	0.0090
Wainui Island	30	0.0050	0.0200	0.0097	0.0007	0.0090
Windsor Landing	30	0.0050	0.0170	0.0091	0.0005	0.0090
Five Fathom Channel	60	0.0025	0.0190	0.0105	0.0004	0.0100
Tamaterau	30	0.0025	0.0340	0.0117	0.0011	0.0100
Te Haumi	30	0.0050	0.0220	0.0101	0.0007	0.0100
Waikare Inlet	30	0.0050	0.0280	0.0105	0.0008	0.0100
Kawakawa River	30	0.0050	0.0180	0.0116	0.0006	0.0115
Onerahi	30	0.0025	0.0320	0.0150	0.0012	0.0135
Portland	30	0.0025	0.0360	0.0166	0.0016	0.0140
Mangapai River	30	0.0060	0.0290	0.0156	0.0011	0.0145
Oruawharo River	57	0.0025	0.0300	0.0157	0.0008	0.0150
Te Kopua Point	60	0.0050	0.0360	0.0171	0.0007	0.0170
Burgess Island	60	0.0060	0.0340	0.0190	0.0008	0.0180
Te Hoanga Point	59	0.0060	0.0320	0.0196	0.0008	0.0190
Kaiwaka Point	30	0.0080	0.0450	0.0225	0.0017	0.0200
Hargreaves Basin	58	0.0025	0.0460	0.0211	0.0012	0.0215
Kapua Point	60	0.0080	0.0440	0.0227	0.0009	0.0215
Wahiwaka Creek	60	0.0120	0.0580	0.0344	0.0012	0.0345
Lower Hātea River	30	0.0170	0.0860	0.0406	0.0037	0.0380
Kissing Point	30	0.0170	0.1500	0.0621	0.0068	0.0585
Town Basin	30	0.0120	0.2000	0.0687	0.0084	0.0650
Upper Hātea River	30	0.0090	0.2000	0.0789	0.0080	0.0735
Waiarohia Canal	30	0.0200	0.3500	0.0954	0.0120	0.0885
Limeburners Creek	30	0.0220	0.9100	0.1887	0.0433	0.0900

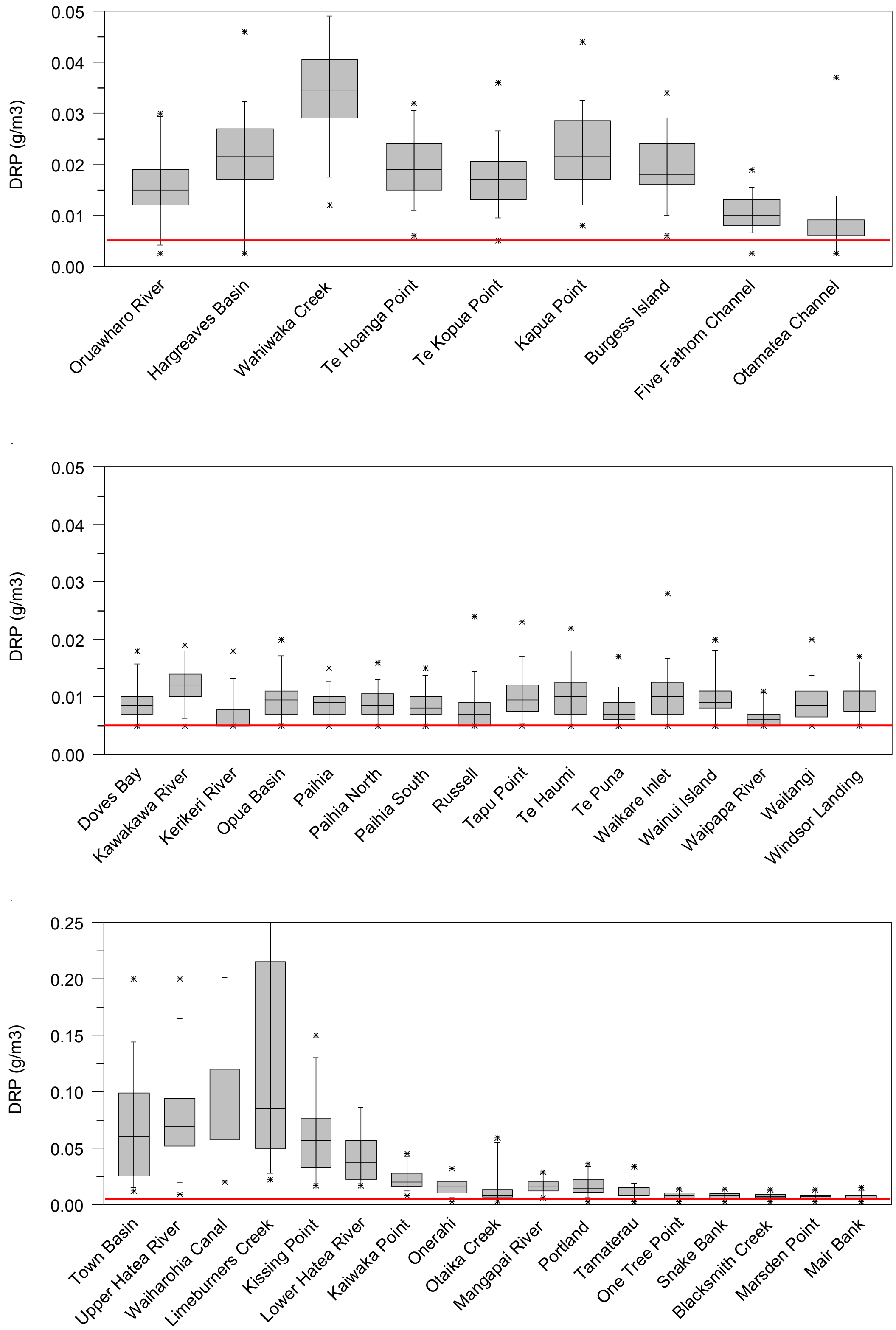


Figure 17: Dissolved reactive phosphorus data collected from January 2010 to December 2014. Red line = ANZECC trigger value (0.005 mg/l). Note scales change on graphs.

3.5 Water quality index

The highest water quality scores were recorded at sites located close to the entrances of the Whangārei Harbour and the Kaipara Harbour, and at Te Puna and Russell in the Bay of Islands (Table 17). These sites are all relatively exposed sites located away from inputs of freshwater. The lowest water quality scores were recorded at sites in the Hātea River and Otaika Creek in Whangārei Harbour and at Wahiwaka Creek in the Kaipara Harbour (Table 17). These sites are all tidal creek sites located close to freshwater inputs.

Table 17: Water quality scores for data collected between January 2010 and December 2014. Ranked highest (best) to lowest index score.

Site	Count	Index	F1 (Scope)	F2 (Frequency)	F3 (Magnitude)	% of tests passed
Marsden Point	30	73.1	42.9	14.6	11.3	85.4
One Tree Point	30	72.6	42.9	16.9	11.2	83.1
Snake Bank	30	65.1	57.1	15.9	11.3	84.1
Mair Bank	30	64.8	57.1	16.5	13.7	83.5
Blacksmith Creek	30	64.2	57.1	18.8	14.6	81.2
Five Fathom Channel	30	58.9	57.1	24.0	34.9	76.0
Te Puna	30	56.6	71.4	16.6	16.8	83.4
Otamatea Channel	27	56.1	71.4	18.5	18.5	81.5
Russell	30	55.3	71.4	18.3	23.8	81.7
Tamaterau	30	53.8	71.4	26.2	24.5	73.8
Windsor Landing	30	52.4	71.4	25.6	32.4	74.4
Doves Bay	30	52.1	71.4	24.6	34.2	75.4
Onerahi	30	51.2	71.4	31.4	32.7	68.6
Ōpua Basin	30	46.3	85.7	23.6	27.2	76.4
Paihia	30	45.1	85.7	25.2	32.4	74.8
Te Kopua	30	41.8	85.7	30.2	43.7	69.8
Oruawharo River	30	41.6	85.7	32.1	42.9	67.9
Burgess Island	30	40.9	71.4	37.7	62.7	62.3
Te Hoanga Point	30	40.8	85.7	33.3	45.4	66.7
Kapua Point	30	38.3	85.7	41.5	48.4	58.5
Hargreaves Basin	30	38.3	85.7	38.8	50.6	61.2
Waikare Inlet	30	38.0	100.0	26.9	28.2	73.1
Paihia South	30	37.5	100.0	26.6	31.7	73.4
Te Haumi	30	37.4	100.0	26.9	32.2	73.1
Paihia North	30	37.0	100.0	27.3	33.9	72.7
Tapu Point	30	37.0	100.0	29.8	31.8	70.2
Kaiwaka Point	30	36.6	85.7	43.5	53.2	56.5
Waipapa River	30	35.8	85.7	31.9	63.2	68.1
Portland	30	35.8	100.0	35.3	33.7	64.7
Waitangi	30	34.7	100.0	31.3	42.5	68.8
Kerikeri River	30	34.4	85.7	32.0	67.4	68.0
Wainui Island	30	34.3	100.0	30.9	44.8	69.1
Mangapai River	30	33.2	100.0	46.9	34.3	53.1
Kawakawa River	30	32.0	100.0	42.3	45.6	57.7
Lower Hātea River	30	27.0	85.7	54.6	75.3	45.4
Otaika Creek	12	25.9	85.7	56.6	76.9	43.4
Wahiwaka Creek	30	23.2	100.0	57.6	66.0	42.4
Kissing Point	30	16.6	100.0	61.8	84.0	38.2
Town Basin	30	15.0	100.0	62.3	88.2	37.7
Upper Hātea River	30	13.8	100.0	65.7	89.4	34.3
Waiarohia Canal	30	13.6	100.0	64.7	90.6	35.3
Limeburners Creek	30	11.7	100.0	66.7	94.5	33.3

3.6 Correlation between variables

In general, weak relationships were observed between most water quality variables (Table 18). TP and DRP had the strongest correlation (0.944). TP and DRP also had strong positive correlations to NNN and NH_4. Turbidity, suspended solids and secchi depth also had reasonably strong correlations.

The concentration of dissolved oxygen and dissolved oxygen saturation had a relatively strong positive correlation with each other (0.696). Concentrations of enterococci and faecal coliforms also had a strong positive correlation (0.703). Interestingly, there were generally weak correlations between chlorophyll *a* and nutrient concentrations and between dissolved oxygen levels and concentrations of nutrients.

Weak negative correlations were found between salinity and most parameters, which indicates that water quality tends to improve with distance from freshwater sources. Secchi depth, which in contrast to most other parameters increases as water quality improves, had a week positive correlation with salinity.

Table 18: Pearson correlations for water quality parameters measured at 42 coastal sites between 2010 and 2014. Bold indicates correlation coefficients >0.7.

	Salinity	Secchi depth	Turbidity	Suspended solids	Chlorophyll *a*	DO (g/m^3)	DO (%)	Enterococci	Faecal coliforms	TP	DRP	NH_4	NNN
Secchi	0.266												
Turbidity	-0.211	-0.548											
Suspended Solids	0.093	-0.583	**0.742**										
Chlorophyll *a*	-0.094	-0.227	0.143	0.117									
DO (g/m3)	-0.431	0.199	-0.154	-0.338	0.069								
DO (%)	0.146	0.343	-0.212	-0.309	0.163	0.696							
Enterococci	-0.195	-0.084	0.373	0.038	0.017	0.011	-0.033						
Faecal coliforms	-0.331	-0.151	0.351	0.156	0.104	0.098	-0.038	**0.703**					
TP	-0.183	-0.229	0.223	0.357	0.065	-0.204	-0.33	0.084	0.234				
DRP	-0.147	-0.165	0.104	0.316	-0.029	-0.191	-0.312	0.041	0.188	**0.944**			
NH_4	-0.26	-0.123	0.15	0.047	-0.052	-0.066	-0.279	0.077	0.185	0.575	0.566		
NNN	-0.418	-0.154	0.093	-0.104	-0.013	0.043	-0.246	0.112	0.335	**0.742**	**0.784**	0.311	
Temperature	0.393	-0.11	0.14	0.205	0.125	-0.679	-0.071	0.03	-0.016	0.102	0.077	-0.061	-0.14

3.7 Trend analysis

3.7.1 Kaipara Harbour

The Mann-Kendall season analysis of the data indicated that there have been a number of improvements in water quality at sites throughout the Kaipara Harbour (Table 19). In particular there were decreases in total phosphorus at six of the nine sites and a decrease in nitrite at seven sites.

Decreases in nitrate-nitrite nitrogen, total nitrogen, ammonium and dissolved reactive phosphorus were also found.

The only negative trends identified were an increase in dissolved reactive phosphorus at Hargreaves Basin and small decreases in dissolved oxygen at three sites.

Table 19: Mann-Kendall seasonal trend analysis of water samples collected between January 2010 and December 2014 in the Kaipara Harbour.

Site name	Parameter	Trend	Magnitude %
Burgess Island	Total phosphorus	Decrease	-10.1
	Total nitrogen	Decrease	-14.4
	Nitrate	Decrease	-13.5
	Nitrite-Nitrate nitrogen	Decrease	-15.8
	Nitrite	Decrease	-16.6
Five Fathom Channel	Dissolved oxygen (% saturation)	Decrease	-0.7
	Total phosphorus	Decrease	-16.1
Hargreaves Basin	Nitrite	Decrease	-18.9
	Dissolved oxygen (g/m^3)	Decrease	-1.4
	Dissolved oxygen (% saturation)	Decrease	-1.5
	Dissolved reactive phosphorus	Increase	12.5
Kapua Point	Total phosphorus	Decrease	-8.6
	Nitrite	Decrease	-50.4
Oruawharo River	Total phosphorus	Decrease	-9.5
Otamatea Channel	Turbidity	Decrease	-23.1
	Dissolved oxygen (% saturation)	Decrease	-0.9
	Dissolved oxygen (g/m^3)	Decrease	-1.2
	Total nitrogen	Decrease	-22.2
	Ammonium	Decrease	-12.5
	Total phosphorus	Decrease	-21.6
Te Hoanga Point	Nitrite	Decrease	-46.3
Te Kopua	Nitrite-nitrate nitrogen	Decrease	-10.8
	Total nitrogen	Decrease	-19.9
	Total phosphorus	Decrease	-4.1
	Nitrite	Decrease	-33.5
Wahiwaka Creek	Nitrite	Decrease	-14.8

3.7.2 Bay of Islands

Mann-Kendall seasonal trend analysis of data collected between 2010 and 2014 identified a number of positive trends throughout the Bay of Islands. Decreases in nitrate-nitrite nitrogen were identified at eight sites and a decrease in total phosphorus was recorded at one site (Table 20). Decreases in enterococci and faecal coliforms at Kerikeri River and a decrease in faecal coliforms at Waipapa River were also detected. Both these sites are located in the upper Kerikeri Inlet and although median concentrations of micro bacteria at these sites were below guideline values, they are elevated compared to other sites in the Bay of Islands (Table 9 and Figure 10) so a decrease at these sites is particularly positive. The only negative trend detected was a decrease in secchi depth (water clarity) in the Waikare Inlet.

Table 20: Mann-Kendall seasonal trend analysis of water samples collected between January 2010 and December 2014 in the Bay of Islands.

Site name	Parameter	Trend	Magnitude %
Doves Bay	Nitrate-nitrite nitrogen	Decrease	-22.3
Kerikeri River	Enterococci	Decrease	-33.4
	Faecal coliforms	Decrease	-33.9
Paihia	Dissolved oxygen mg/L	Increase	1.4
	Nitrate-nitrite nitrogen	Decrease	-18.8
Paihia North	Total phosphorus	Decrease	-9.9
	Temperature	Decrease	-1.2
	Nitrate-nitrite nitrogen	Decrease	-15.9
Paihia South	Nitrate-nitrite nitrogen	Decrease	-16.0
Russell	Nitrate-nitrite nitrogen	Decrease	-65.1
Tapu Point	Nitrate-nitrite nitrogen	Decrease	-65.1
Te Puna	Temperature	Decrease	-25.8
Waikare Inlet	Nitrate-nitrite nitrogen	Decrease	-35.3
	Dissolved oxygen mg/L	Increase	2.3
	Secchi depth	Decrease	-7.6
Waipapa River	Dissolved oxygen mg/L	Increase	2.6
	Faecal coliforms	Decrease	-45.3
Windsor Landing	Nitrate-nitrite nitrogen	Decrease	-19.5

3.7.3 Whangārei Harbour

Mann-Kendall seasonal trend analysis indicates that there have been a number of improvements in water quality at sites throughout the harbour (Table 21). In particular, there were decreases in total phosphorus at 10 sites and decreases in nitrate-nitrite nitrogen at nine sites. Decreases in dissolved reactive phosphorus, ammonium, faecal coliforms and turbidity were also detected.The decreases in ammonium at two sites in the Hātea River (Upper Hātea River and Waiarohia Canal) are particularly positive as both these sites had median ammonium values well above the ANZECC default trigger values. A decrease in faecal coliforms at the Town Basin is also particularly positive as this site had the highest median concentration of faecal coliforms and the median value of (149/100ml) was just below the ANZECC guideline of 150/100ml (Table 9 and Figure 10).

The only negative trends identified were an increase in nitrate-nitrite nitrogen at one site (Limeburners Creek), a decrease in secchi depth (water clarity) at four sites in the upper Whangārei Harbour and an increase in turbidity at one site (Mair Bank). Limeburners Creek is the receiving environment for the Whangārei waste water treatment plant and the median nitrate-nitrite nitrogen level (0.440 mg/l) is well above the ANZECC trigger value of 0.015 mg/l so further increases at this site are a concern. The median turbidity at Mair Bank is 0.6 NTU which is the lowest of all 42 sites and well below the ANZECC limit of 10 so the small increase found at this site is unlikely to be of any concern. The decrease in secchi depth (water clarity) at three sites in the Hātea River (Kissing Point, Limeburners Creek and Waiarohia Canal) is surprising as a decrease in turbidity was simultaneously found at three sites in the Hātea River (Kaiwaka Point, Lower Hātea River and Waiarohia Canal).

Table 21: Mann-Kendall seasonal trend analysis of water samples collected between January 2010 and December 2014 in the Whangārei Harbour.

Site name	Parameter	Trend	p-value	Magnitude %
Blacksmith Creek	Total phosphorus	Decrease	0.003	-15
	Nitrate-nitrite nitrogen	Decrease	0.000	-71
Kaiwaka Point	Turbidity	Decrease	0.034	-6
	Total phosphorus	Decrease	0.021	-6
Kissing Point	Secchi depth	Decrease	0.010	-8
Limeburners Creek	Nitrate-nitrite nitrogen	Increase	0.046	8
	Secchi depth	Decrease	0.031	-9
Lower Hātea River	Turbidity	Decrease	0.022	-8
Mair Bank	Turbidity	Increase	0.046	7
	Total phosphorus	Decrease	0.020	-13
	Nitrate-nitrite nitrogen	Decrease	0.000	-46
Mangapai River	Nitrate-nitrite nitrogen	Decrease	0.012	-24
	Total phosphorus	Decrease	0.008	-8
	Dissolved reactive phosphorus	Decrease	0.006	-10
Marsden Point	Nitrate-nitrite nitrogen	Decrease	0.000	-53
	Total phosphorus	Decrease	0.000	-14
One Tree Point	Total phosphorus	Decrease	0.023	-8
	Nitrate-nitrite nitrogen	Decrease	0.000	-60
	Dissolved reactive phosphorus	Decrease	0.036	-8
	Nitrate-nitrite nitrogen	Decrease	0.004	-25
	Total phosphorus	Decrease	0.001	-13
Portland	Dissolved reactive phosphorus	Decrease	0.036	-10
	Total phosphorus	Decrease	0.031	-9
	Secchi depth	Decrease	0.016	-9
	Nitrate-nitrite nitrogen	Decrease	0.014	-31
Snake Bank	Nitrate-nitrite nitrogen	Decrease	0.000	-45
Tamaterau	Total phosphorus	Decrease	0.023	-5
	Nitrate-nitrite nitrogen	Decrease	0.000	-38
Town Basin	Faecal coliforms	Decrease	0.031	-25
Upper Hātea River	Total phosphorus	Decrease	0.026	-11
	Ammonium	Decrease	0.021	-13
Waiarohia Canal	Turbidity	Decrease	0.014	-14
	Ammonium	Decrease	0.011	-17
	Secchi depth	Decrease	0.009	-7

4. Discussion

4.1 Water clarity

Good water clarity is important for healthy functioning of marine ecosystems. Water clarity can be reduced by 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). Reduced water clarity can also affect the feeding efficiency of visual predators like fish and sea birds and sediment particles can clog the feeding structures and gills of fish and suspension feeding animals like cockles and pipi that filter their food from the water column (Australian New Zealand Environment Conservation Council, 2000). High levels of suspended solids may also protect bacteria from ultraviolet light, (Oliver and Cosgrove, 1975). Water clarity is also an important attribute for recreation and aesthetic values as poor water clarity makes the water less desirable for swimming and recreational activities.

Water clarity can be affected by the amount of sediment in the water column but also algal growth. Reduced water clarity can therefore be an indicator of trophic state. Water clarity may decrease during spring as warmer temperatures stimulate algal growth and increase as cooler weather causes algal growth to decrease. In addition, soil erosion and run-off from rainfall may result in higher concentrations of suspended solids in streams and rivers flowing to the coast, which will decrease secchi depth. In shallow environments, resuspension of sediment from the seabed by wave action of tidal currents may also increase suspended solids in the water column and thus reduce water clarity.

Secchi depth, turbidity and TSS are all essentially measures of water clarity. Secchi depth is a measure of the transparency of the water body. Turbidity is a measure of the degree to which light is scattered in water by particles, such as sediment and algae. TSS is a measure of the amount of suspended material in the water column. Secchi depth, turbidity and TSS all had reasonably strongly Pearson correlations. A similar spatial trend was also observed for both turbidity and secchi depth. TSS was only measured in the Kaipara Harbour but at these sites TSS also displayed a similar pattern to turbidity and secchi depth. Sites with the highest secchi depth and lowest turbidity (highest water clarity) were located near the entrance of the Kaipara Harbour and Whangārei Harbour. Sites with the highest turbidity (Mangapai River, Otaika Creek, Waikare Inlet, Kawakawa and Wahiwaka Creek) and the lowest secchi depth (lowest water clarity) were located in upper estuarine and tidal creek environments. Generally areas that receive freshwater input will have higher turbidity (and lower secchi depth) as freshwater inputs carry 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, so may be susceptible to re-suspension of 'historically' deposited material.

There is currently no ANZECC default trigger value for secchi depth or TSS 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 42 sites had median values below 10 NTU.

4.2 Faecal indicator bacteria

Microbiological indicator organisms are used to measure the faecal contamination of the water and therefore its suitability for recreational activities. Indicator organisms are used because there is such a wide variety of pathogens that may be present in faecal material, it would be difficult and expensive to test for all of them. The New Zealand Marine Bathing Study showed that enterococci are the indicator most closely correlated with health effects in New Zealand marine waters, while faecal coliforms and *E.coli* were not as well correlated with health risks. The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas recreational guidelines (Ministry for the Environment and the Ministry of Health, 2003) therefore recommends that enterococci are used as the faecal indicator in marine waters. However, enterococci may be present in the environment from other sources under certain conditions. For example, enterococci can occur naturally in mangroves so sites with a lot of mangroves nearby may naturally have elevated levels of enterococci. For this reason, in estuarine and brackish environments it may be necessary to use a combination of indicators to assess the risk of faecal contamination. Enterococci are measured at all of council's 42 coastal sites and faecal coliform concentrations are also monitored at sites in the Whangārei Harbour and the Bay of Islands, but not at the nine sites in the Kaipara Harbour.

Similar spatial patterns were observed for both enterococci and faecal coliforms, with the highest numbers of both micro-bacteria recorded at sites in tidal creek locations and lower concentrations at outer estuarine sites. The concentration of enterococci and faecal coliforms also had a reasonably strong positive correlation ($r = 0.703$). The highest median concentrations of both enterococci and faecal coliforms were recorded at sites in the Hātea River and at Otaika Creek in Whangārei Harbour. The Hātea River receives freshwater input from the surrounding catchment (which may carry bacteria entrained in run-off from the land), and receives treated waste water discharges from the Whangārei waste water treatment plant. The Otaika Creek is a rural catchment with a high proportion of pasture used for both beef and dairy farming.

The Microbiological Guidelines for Marine and Freshwater Recreational Areas (Ministry for the Environment and the Ministry of Health, 2003) set concentrations of enterococci for different levels of action. This three-tier system is analogous to traffic lights with a green (surveillance mode), amber (alert mode) and a red (action mode). For the surveillance/green mode (highly likely to be uncontaminated – 'suitable' for bathing) no single sample should exceed 140 enterococci/100ml. The MfE guidelines also detail concentrations of enterococci for different microbiological assessment categories, which are used to grade beaches according to their suitability for recreation. For grade A (the highest grade) waters the 95th percentile should be ≤ 40 enterococci/100ml.

Apart from the tidal creek sites in the Hātea River and Otaika Creek, the enterococci concentrations were generally very low and the median concentration of enterococci at 32 of the 42 sites (or 76% of all sites) was the same as the laboratory detection limit. The median number of enterococci was below 140 per 100ml at all 42 sites and at 17 sites all of the samples collected were below 140/100ml. Twenty-one of the 42 sites had a 95th percentile that was ≤ 40 enterococci/100ml, which equates to a Grade A. Twelve sites had a 95th between 41 and 200, which is equivalent to a Grade B and seven sites had a 95th percentile between 201 and 500, which is a Grade C. Two sites (Limeburners Creek in Whangārei and Wahiwaka Creek in Kaipara) had 95th percentiles above 500 enterococci/100ml, which is a Grade D.

The MfE guidelines has not set a 'safe' limit for faecal coliforms in marine recreational swimming water but the ANZECC 2000 guidelines set a limit of 150/100ml (Australian New Zealand Environment Conservation Council, 2000). None of the 33 sites, where faecal coliforms data is collected, had median values that exceeded 150/100ml (faecal coliforms are not measured at the nine Kaipara Harbour sites).

4.3 Nutrients and trophic state

While nutrients are essential for all forms of life, nutrients that enter the environment from anthropogenic sources, such as fertiliser, storm water run-off 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.

Concentrations of different nutrients (for example, phosphorus and ammonium) are direct measures of the nutrient levels, which may be responsible for over-enrichment, while chlorophyll *a* and dissolved oxygen are 'response indicators' of nutrient enrichment. Water clarity can also be a 'response indicator' of nutrient enrichment as phytoplankton can reduce light transmission. However, as sediment run-off from the land also influences water clarity we have treated this parameter separately (see section 4.1).

Results of the response indicators (chlorophyll *a* and dissolved oxygen) were generally within ANZECC guideline values. However, nutrient concentrations were often outside of the ANZECC trigger values. In many cases nutrient concentrations exceeded trigger values, at well flushed outer estuarine sites where water quality is considered to be very good. In the case of dissolved reactive phosphorus for example, 40 of the 42 sites had a median concentration which exceeded the trigger value. It therefore appears that the ANZECC trigger values are too conservative for Northland waters.

4.3.1 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% (supersaturation) can also be harmful and fish may suffer from 'gas bubble disease' in water containing excessive dissolved oxygen, although this is very rare. Supersaturation can be an indicator of excess aquatic plant growth, which may in turn cause oxygen depletion issues at night when photosynthesis stops or when the plants die and are broken down by bacteria that consume oxygen.

Oxygen enters estuaries and marine waters from streams 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.

The relevant ANZECC default trigger value for dissolved oxygen (% saturation) is between 80 and 110% saturation (Australian New Zealand Environment Conservation Council, 2000). The ANZECC 2000 guidelines do not include a default trigger value for dissolved oxygen concentration (mg/l) although the 1992 ANZECC guidelines recommended that dissolved oxygen should not normally be permitted to fall below 6 mg/l, determined over at least one diurnal cycle, while Newcombe and Gillespie (2015) have counselled that in general a drop to below 5.0 mg/l is considered to be detrimental to aquatic life.

All 42 sites had median dissolved oxygen concentrations above 6 mg/l and 41 sites had median dissolved oxygen percentage saturation above 80%. The lowest median dissolved oxygen saturation was at the Mangapai River, in Whangārei Harbour, which had a median of 79.4%, which is just below the default trigger value.

A similar spatial pattern was observed for both the concentration of dissolved oxygen and dissolved oxygen saturation. Sites in tidal creek locations generally had lower dissolved oxygen levels than outer estuary sites. Otaika Creek was a noticeable exception to this, with a high median dissolved oxygen concentration (7.9 mg/l) but a low median dissolved oxygen saturation (85.9%). Tidal creek sites are less exposed than outer estuarine sites, which have more mixing of surface waters by wind and wave, which increases the rate at which oxygen from the air can be absorbed into the water.

4.3.2 Chlorophyll a

Chlorophyll *a* is a green pigment found in plants that is used to absorb sunlight during photosynthesis. Chlorophyll *a* concentrations are therefore an indicator of phytoplankton abundance and biomass in coastal waters, which is in turn an indicator of trophic status.

The lowest median chlorophyll *a* concentrations were recorded at exposed outer estuarine sites towards the entrance of the Whangārei Harbour. The highest median chlorophyll *a* concentrations were found at Hargreaves Basin and Burgess Island in the Kaipara Harbour and at Kerikeri River, Waipapa River and Waikare Inlet in the Bay of Islands. These sites are all inner estuarine sites. The nine sites in the Kaipara Harbour all appeared to have relatively high concentrations of chlorophyll *a* compared to the sites in the Bay of Islands and Whangārei Harbour. It is worth noting that chlorophyll *a* has only been sampled in the Whangārei Harbour and Bay of Islands for two years (12 data points per site) and the sites are only sampled bi-monthly as opposed to the sites in the Kaipara, which were sampled monthly (59 samples), so there could be some temporal bias in the data.

The ANZECC default trigger value for chlorophyll *a* is 0.004 mg/l for estuarine waters and 0.001 mg/l for marine waters. All 41 estuarine sites had a median concentration below 0.004 mg/l although the median at Hargreaves Basin in the Kaipara Harbour was very close to the trigger value. The one open coast site, Mair Bank, had a median of 0.00115 mg/l, which exceeded the trigger value for marine waters.

In a trophic status classification developed by Bricker *et al*. (1999) chlorophyll *a* concentrations below 0.005 mg/l are deemed to have a 'low' degree of eutrophication. Under this classification system, using the median values, all 42 sites would be classified as having a 'low' level of eutrophication. Under another trophic index proposed by Vollenweider (1998) concentrations <0.001 mg/l are classified as 'oligotrophic', ≥ 0.001-0.003 mg/l as 'mesotrophic', ≥ 0.003-0.005 mg/l as 'eutrophic' and >0.005 mg/l as 'hypereutrophic'. Using this classification and the median concentrations for the 42 sites, one site would be classified as ‘oligotrophic’, 33 sites as ‘mesotrophic’ and eight sites as ‘eutrophic’.

4.3.3 Ammonium (NH_4)

Ammonium is reported as a combination of un-ionised ammonia (NH_3) and the ammonium ion (NH_4). The proportion of the different forms is dependent on pH, temperature and salinity. At the average pH of seawater approximately 95% of ammonia is in the ammonium (NH_4+) form. Ammonium is the form of nitrogen taken up most readily by phytoplankton and assimilated into amino acids. Un-ionised ammonia (NH_3) is the more toxic form to aquatic life. Ammonium (NH_4 plus NH_3) occurs in a number of waste products. 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. Synthetically produced ammonia is also an important fertiliser.

The highest median concentration of NH_4 was found at Limeburners Creek, which was almost double the median at the next highest site. Limeburners Creek is the receiving environment for discharges from the Whangārei waste water treatment plant. High concentrations were also found at other sites in the Hātea River, at Otaika Creek in Whangārei Harbour and at Wahiwaka Creek in the Kaipara Harbour. The Wahiwaka creek site is located downstream of discharges from the Maungaturoto waste water treatment plant, the Kaiwaka waste water treatment plant and a discharge from the Fonterra Maungaturoto milk processing plant. The lowest medians were recorded at outer harbour sites in the Whangārei Harbour and the Kaipara Harbour.

The ANZECC default trigger value for NH_4 is 0.015 mg/l for both estuarine and marine waters. Twenty-four of the 42 sites had a median concentration below the trigger value. All of the sites with a median above the ANZECC trigger values were inner estuarine or tidal creek sites.

4.3.4 Nitrate-nitrite nitrogen (NNN)

Nitrate-nitrite nitrogen (NNN) 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.

Similar spatial patterns were observed for both ammonium and nitrate-nitrite nitrogen with the lowest concentrations generally recorded at more exposed outer estuarine sites and the highest concentrations recorded in the Hātea River and Otaika Creek and at other tidal creek sites.

The ANZECC default trigger value for NNN is 0.015 mg/l for estuarine water and 0.005 mg/l for marine waters. Twenty-two of the 42 sites had a median concentration below the relevant trigger value. Most of the sites with a median above the ANZECC default trigger values were inner estuarine or tidal creek sites. Six sites (five sites in the Hātea River and the Otaika Creek site) had median concentrations which were an order of magnitude higher than the ANZECC default trigger value.

4.3.5 Total phosphorus (TP)

The measurement of total phosphorus (TP) includes the total of all filterable and particulate forms of 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, fertilisers 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.

The lowest median concentrations of TP were recorded at outer estuarine sites in the Whangārei Harbour and the Kaipara Harbour, and at exposed sites in the Bay of Islands. The highest median concentrations were found at sites in the Hātea River in the Whangārei Harbour and the Wahiwaka Creek site in the Kaipara Harbour. All of the sites in the Bay of Islands had relatively low median TP concentrations, with the highest median recorded at the Kawakawa River site (0.0255 mg/l).

The ANZECC default trigger value for TP is 0.03 mg/l for estuarine waters and 0.025 mg/l for marine waters. Twenty-nine of the 42 sites had a median concentration below the relevant trigger value and two sites (Burgess Island and Te Hoanga Point) had a median concentration of exactly 0.03mg/l. All of the sites that had a median that exceeded the default trigger value were inner estuarine tidal creek sites in either the Whangārei Harbour or Kaipara Harbour (all sites in the Bay of Islands had a median below the trigger value).

Using a trophic index proposed by Vollenweider (1998) concentrations of TP <0.01 mg/l are classified as ‘oligotrophic’, ≥ 0.01-0.03 mg/l as ‘mesotrophic’, ≥ 0.03-0.04 mg/l as ‘eutrophic’ and >0.04 mg/l as ‘hypereutrophic’. Using this classification and the median values for council's coastal sites, 29 sites would be classified as 'mesotrophic', six sites as 'eutrophic' and seven sites as 'hypereutophic'. The seven hypereutophic sites were the six sites in the Hatea River and Wahiwaka Creek in the Kaipara Harbour.

4.3.6 Dissolved reactive phosphorus

Dissolved reactive phosphorus (DRP) is the fraction that consists largely of the inorganic orthophosphate (PO_4) form of phosphorus. The inorganic orthophosphate fraction is the form of phosphorus 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 lowest median concentrations of dissolved reactive phosphorus were recorded at the Kerikeri River and the Waipapa River, which are both tidal creek sites located in the upper Kerikeri Inlet in the Bay of Islands. Low median values were also recorded at sites close to the entrance of the Whangārei Harbour and the entrance of the Kaipara Harbour. The highest median concentrations were recorded at the six sites in the Hātea River in Whangārei Harbour and at Wahiwaka Creek in the Kaipara Harbour.

The ANZECC default trigger value is 0.005 mg/l for estuarine waters and 0.010 mg/l for coastal waters. Forty of the 42 sites had median concentrations that were greater than the default ANZECC trigger value of 0.005 mg/l for estuarine water. One site (Kerikeri River) had a median value of exactly 0.005 mg/l and the one marine site, Mair Bank (0.007 mg/l) had a median value below the ANZECC default trigger value of 0.010 mg/l for marine waters. Five sites in the Hātea River had a median DRP concentration which was an order of magnitude greater than the default ANZECC trigger value.

4.4 Water quality index

The highest water quality scores were recorded at sites close to the entrances of the Whangārei and Kaipara Harbour and at outer estuarine sites in the Bay of Islands. The lowest water quality scores were recorded at sites in the Hātea River and Otaika Creek in Whangārei Harbour and at Wahiwaka Creek in the Kaipara Harbour. The Hātea River has a predominantly urban catchment, with some agriculture and forestry in the north of the catchment. The Whangārei waste water treatment plant discharges into the Limeburners Creek, which itself flows into the Hātea River. The Otaika Creek is a rural catchment with a high proportion of pasture used for both beef and dairy farming. The Wahiwaka Creek site is located in the Otamatea River, a rural catchment with a high proportion of pasture sheep, beef and dairy farming. It is also downstream of discharges from the Kaiwaka and Maungaturoto waste water treatment plants and Fonterra's Maungaturoto dairy processing plant.

4.5 Relationship between parameters

In general, weak relationships were observed between most water quality variables. TP and DRP had the strongest correlation and they also had strong positive correlations to NNN and NH_4. Turbidity, suspended solids and secchi depth also had reasonably strong correlations. The concentration of dissolved oxygen and dissolved oxygen saturation had a relatively strong positive correlation, as would be expected, while enterococci and faecal coliforms also had a relatively strong positive correlation. Interestingly, there were generally weak correlations between chlorophyll *a* and nutrient concentrations and between dissolved oxygen levels and concentrations of nutrients.

Weak negative correlations were found between salinity and most parameters, which indicates that water quality tends to improve with distance from freshwater sources. Secchi depth, which in contrast to most other parameters increases as water quality improves, had a week positive correlation with salinity. These relationships between salinity and water quality parameters reflect the patterns described for the different parameters and the results of the water quality index (Section 4.4), which showed lower water quality in tidal creek environments and better water quality towards the entrance of estuaries and harbours.

4.6 Trend analysis

Trend analysis found a number of positive trends at sites throughout all three harbours. Of the 78 trends identified, 67 were positive trends indicating improving water quality. In particular, decreases in the concentrations of nutrients were identified at a number of sites throughout the three harbours. Another notable trend was a decrease in faecal indicator bacteria at the Kerikeri Inlet and Waipapa River sites in the upper Kerikeri Inlet. These sites have elevated concentrations of micro bacteria so decreases at both these sites are particularly positive. In contrast, relatively few negative trends were identified. Most negative trends were reductions in water clarity or increases in dissolved oxygen.

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6 Appendices

Appendix 1: site co-ordinates (NZGD 2000, New Zealand Transverse Mercator).

Site name		x	y
Mangapai River	Whangārei Harbour	1719865	6033523
Town Basin	Whangārei Harbour	1719871	6045912
Upper Hātea River	Whangārei Harbour	1720380	6045570
Portland	Whangārei Harbour	1721786	6037296
Limeburners Creek	Whangārei Harbour	1720611	6044292
Lower Hātea River	Whangārei Harbour	1721994	6043396
Kissing Point	Whangārei Harbour	1721885	6044481
Kaiwaka Point	Whangārei Harbour	1722500	6040598
Tamaterau	Whangārei Harbour	1727464	6037880
One Tree Point	Whangārei Harbour	1731336	6035303
Blacksmiths Creek	Whangārei Harbour	1733188	6033389
Marsden Point	Whangārei Harbour	1735580	6032934
Mair Bank	Whangārei Harbour	1736610	6032428
Onerahi	Whangārei Harbour	1724164	6040654
Snake Bank	Whangārei Harbour	1733359	6035404
Waiarohia Canal	Whangārei Harbour	1720529	6045073
Otaika Creek	Whangārei Harbour	1718363	6039770
Russell	Bay of Islands	1701888	6097331
Doves Bay	Bay of Islands	1694300	6104732
Windsor Landing	Bay of Islands	1693649	6103601
Te Puna Inlet	Bay of Islands	1690999	6109039
Paihia North	Bay of Islands	1699171	6095533
Paihia South	Bay of Islands	1699765	6094870
Te Haumi	Bay of Islands	1700137	6093454
Paihia	Bay of Islands	1699668	6095520
Ōpua Basin	Bay of Islands	1701677	6091826
Tapu Point	Bay of Islands	1702577	6091929
Wainui Island	Bay of Islands	1691548	6104195
Waikare Inlet	Bay of Islands	1706238	6092261
Waitangi River	Bay of Islands	1698190	6096284
Waipapa River	Bay of Islands	1688786	6103513
Kerikeri River	Bay of Islands	1688797	6103181
Kawakawa River	Bay of Islands	1701646	6089648
Oruawharo River	Kaipara Harbour	1716739	5981218
Hargreaves Basin	Kaipara Harbour	1724856	5982210
Wahiwaka Creek	Kaipara Harbour	1724505	5997524
Te Hoanga Point	Kaipara Harbour	1719737	5991165
Te Kopua Point	Kaipara Harbour	1714843	5992950
Kapua Point	Kaipara Harbour	1710941	5995981
Burgess Island	Kaipara Harbour	1694354	5995293
Five Fathom Channel	Kaipara Harbour	1703620	5986591
Otamatea Channel	Kaipara Harbour	1708870	5979607

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