Coastal and Estuarine Water Quality: 2019 Annual Data Report

R Ingley

August 2020

Technical Report 2020/016

Research and Evaluation Unit

RIMU

Auckland Council

Te Kaunihera o Tāmaki Makaurau

Coastal and Estuarine Water Quality: 2019 Annual Data Report

August 2020 Technical Report 2020/016

R Ingley

Research and Evaluation Unit (RIMU)

Auckland Council
Technical Report 2020/016

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

ISBN 978-1-99-002254-8 (Print)
ISBN 978-1-99-002255-5 (PDF)

This report has been peer reviewed by the Peer Review Panel.
Review completed on 31 August 2020 Reviewed by two reviewers
Approved for Auckland Council publication by: Name: Eva McLaren Position: Manager, Research and Evaluation (RIMU)
Name: Jonathan Benge Position: Manager, Water Quality (RIMU)
Date: 31 August 2020

Recommended citation
Ingley, R (2020). Coastal and estuarine water quality: 2019 annual data report. Auckland Council technical report, TR2020/016

Cover photograph credit: Tamaki Estuary, photograph taken by Sheldon Benito

Executive summary

Auckland Council monitors the state of the environment in the region as required under section 35 of the Resource Management Act 1991 (as amended, RMA). The collection of long-term data is necessary to understand natural variability so that we can detect trends that may be attributed to land use and/or climate change and to subsequently assess the efficiency of council initiatives, policies and strategies.

Auckland Council operates a long-term, region-wide coastal and estuarine water quality monitoring programme. The programme includes 31 sites, representative of Auckland's three main harbours (Kaipara, Waitematā and Manukau) and the east coast of the Hauraki Gulf.

This annual report summarises the results for 16 water quality parameters collected monthly during 2019; and provides a summary of the state of water quality at each site using a Water Quality Index.

The period of January to June 2019 had below normal rainfall and the annual water quality results are generally representative of median, to lower flow conditions (and associated freshwater contaminant discharge). However, individual parameters assessed were generally consistent with patterns previously reported. High concentrations of nutrients, turbidity, and suspended sediment were observed at several sites when monitoring coincided with high river flows in the upstream catchments. Nationally, a 'marine heatwave' of unusually warm sea surface temperatures was recorded in 2019.

Using a Water Quality Index, 55 per cent of sites assessed had 'good' to 'fair' water quality. There is a spatial gradient in freshwater influence from tidal creeks, to estuaries, to the coast and water quality class generally follows this gradient from 'poor' to 'good'. Several sites within the Manukau Harbour, one site within the Kaipara Harbour, and one site in the Tāmaki Estuary had water quality that was poorer than would be expected given this typical spatial pattern.

Regional water quality state, compared to water quality index guideline values, has been relatively consistent over the recent time period. Twenty-three sites had the same water quality class in the 2017-2019 period as in 2014-2016. Six sites declined in water quality class, although four of these appear to be primarily due to an artefact of changes in laboratory analysis methods. Two sites improved in water quality class. Long-term trend analysis is critical to identify where improvements to water quality are being made, and where water quality is degrading. Trend analysis is anticipated to be completed later in 2020.

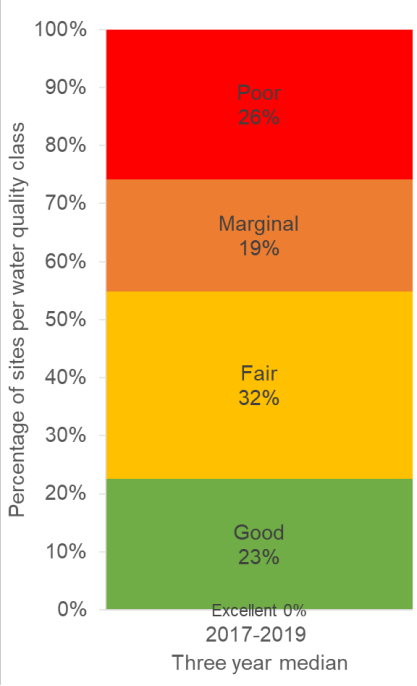

Table of contents

List of figures

List of tables

1.0 Introduction

The marine environment in the Auckland region encompasses two oceans, three major harbours and numerous estuaries. Within these are a wide variety of marine habitats which support a diverse range of plants and animals, including seaweeds, invertebrates, mangroves, seagrass, shellfish, marine mammals, fish and sea birds. The coastal and marine environment also provides many options for recreational activities across the region.

The aesthetics, use and health of coastal waters are influenced by the quality of surface water that runs from the land through streams, rivers, overland flow paths and stormwater, and point source discharges directly to the coastal environment. Land use both inside and outside of the Auckland region also impacts coastal water quality, particularly in the Hauraki Gulf, and Kaipara Harbour. Water quality is also influenced by natural seasonal and decadal variation as well as climatic changes.

Auckland Council operates long-term state of the environment programmes that include monitoring of river water quality and ecology, coastal and estuarine water and sediment quality and benthic ecology. Microbiological contamination of beaches and recreational water quality are monitored through the Safeswim programme, www.safeswim.org.nz

Long-term data is necessary to understand what natural variability looks like so that we can detect real trends that may be attributed to land use and/or climate change. Combining analysis of river and coastal water quality and ecological monitoring is also important to provide an integrated overview of the physical, chemical and biological condition of the region. Results across monitoring programmes are collated on a five-yearly basis in the *State of the Environment* report as required under the section 35, RMA 1991 (e.g. Auckland Council, 2015).

The purpose of this report is to communicate the state of our coastal and estuarine water quality based on council's coastal and estuarine water quality monitoring programme for 2019.

Water holds special significance to Māori. Mana whenua whakapapa to significant water bodies and have kaitiaki obligations to protect them. This is part of the customary practice of taonga tuku iho (protecting treasures or taonga passed down from previous generations). The results of the coastal and estuarine water quality monitoring programme can be added to matauranga Māori knowledge to support Māori in their role as kaitiaki to protect and enhance te mauri o te wai (the life supporting capacity of water).

Auckland Council's coastal and estuarine water quality monitoring programme focuses on nutrient and water clarity parameters that can be altered by differences in land use, point source discharges direct to the coast, land erosion and activities in the coastal environment. These parameters also fluctuate naturally due to changes in ocean hydrodynamics, seasonal and climatic variation. Other contaminants associated with urban land use and stormwater contamination, such as metals, are monitored in Auckland Council's river water quality (Buckthought, 2019) and estuarine sediment and ecology monitoring programmes (Mills, 2016; Hewitt, *et al.,* 2012) and are not assessed here.

In general, for long-term monitoring programmes, chronically high levels of contamination (those existing for a long time or constantly recurring) are of more concern than a single exceedance, depending on the magnitude (Griffiths, 2016). Short-term, high magnitude events may be the result of natural variation, an unusual climatic event, or a one-off incident (e.g. sewage overflow). This does not discount the possibility that acute, short-term exposure to high concentrations of contaminants can have an adverse ecological effect. However, the chance of intercepting short-term events is limited due to the monthly sampling design required to support long-term environmental change monitoring.

This report presents the results for individual water quality parameters, and also provides a summary of the overall state of water quality at each site by incorporating key parameters into a single score using a regional Water Quality Index (WQI). The index represents the deviation from reference coastal or estuarine conditions (as reflected by the guideline values) in the Auckland region, rather than indicating whether the water quality is suitable for a particular purpose or activity.

In summary, the Auckland regional coastal and estuarine water quality monitoring programme supports the following objectives:

- Satisfy Auckland Council's obligations under section 35 of the Resource Management Act 1991 with respect to the state of the environment monitoring and reporting.
- Contribute to our ability to maintain and enhance the quality of the region's coastal environment (Local Government Act 2002). Provide evidence for the "Environment and Cultural Heritage" component of the Auckland Plan 2050. A key issue for the region is to manage the effects of growth and development on our natural environment.
- Help inform the effectiveness of policy initiatives and strategies and operational delivery.

- Assist with the identification of large scale and/or cumulative impacts of contaminants associated with varying land uses and disturbance regimes and links to particular activities.
- Provide baseline, regionally specific data to underpin sustainable management through resource consenting and associated compliance monitoring for coastal and estuarine environments.
- Continuously increase the knowledge base for Aucklanders and promote awareness of regional coastal and estuarine water quality issues and their subsequent management.

1.1 Supporting reports

Previous annual data reports can be obtained from Auckland Council's Knowledge Auckland website www.knowledgeauckland.org.nz.

Coastal and estuarine water quality data can be accessed at council's Environmental Data Portal, https://environmentauckland.org.nz/. For further enquiries and data supply, please email environmentaldata@aucklandcouncil.govt.nz

For the most recent comprehensive trend analysis, please refer to *Marine water quality state and trends in the Auckland region from 2007 to 2016* (Foley, *et al*., 2018 TR2018/015). Recommendations are made in this report along with analyses of historic long-term changes in water quality for the Auckland region.

A snapshot of the status can be found in Auckland Council's *The health of Auckland's natural environment in 2015* report which briefly summarises marine water quality issues and the pressures facing the Auckland region and its ecological health (Auckland Council, 2015).

2.0 Methods

2.1 Programme design

Auckland Council collects coastal and estuarine water quality samples monthly from surface waters by helicopter, boat and from land. Collection of water samples by helicopter enables sites spread over the region to be sampled within a narrow time window created by tidal constraints, making comparison between sites more robust.

Natural temporal variation in water quality is avoided as much as possible by maintaining a consistent sampling time relative to the tidal cycle. Samples are collected approximately 10 minutes to 2.5 hours after high tide for the Kaipara Harbour, Waitematā Harbour and Hauraki Gulf sites and 2.5 to 4 hours after high tide for the Manukau Harbour. Maintaining a consistent sample time improves the power of long-term trend detection.

Sites in the inner Hauraki Gulf, Kaipara Harbour, Tāmaki Strait and Manukau Harbour are collected by helicopter, sites in the upper and central Waitematā Harbour are collected by boat and Tāmaki Estuary sites are collected from land.

2.2 Site locations

Sites are representative of six geographically distinct areas. Monitored site locations are summarised in Table 2-1 and illustrated in Figure 2-1.

- Six sites in the inner Hauraki Gulf, including two sites in the Mahurangi Harbour (East Coast)
- Six sites in the Kaipara Harbour
- Eight sites in the Waitematā Harbour
- Two sites in the Tāmaki Estuary
- One site in the Tāmaki Strait (at the mouth of the Wairoa River)
- Eight sites in the Manukau Harbour.

Each monitoring site was selected to provide information on,

- A range of exposure levels including open coast, harbours, large estuaries, and tidal creeks.
- The three main harbours and large estuaries.
- Areas with a variety of contributing catchment land uses, ranging from urban to rural[1].

[1] Open coast sites are less subject to direct influences from adjacent land use due to greater exposure and oceanic influences.

Table 2-1: Current coastal and estuarine water quality monitoring sites grouped by location.

	Site	NZTM Easting	NZTM Northing	Year initiated	Exposure Level	Dominant catchment land use*
East Coast	Goat Island	1761787	5984944	1993	Open Coast	N/A
	Ti Point	1760058	5978931	1991	Open Coast	N/A
	Mahurangi Heads	1754225	5960548	1993	Estuary	Rural
	Dawsons Creek	1753782	5966175	1993	Estuary	Rural
	Orewa	1753660	5949837	1991	Open Coast	N/A
	Browns Bay	1757497	5935771	1991	Open Coast	N/A
Kaipara Harbour	Shelly Beach	1723871	5952426	1991	Estuary	Rural
	Kaipara River	1725504	5947101	2009	Estuary	Rural
	Makarau Estuary	1727396	5953730	2009	Estuary	Rural
	Kaipara Heads	1708534	5970421	2009	Estuary	Rural
	Tauhoa Channel	1717821	5970063	2009	Estuary	Rural
	Hoteo River	1726691	5967495	2009	Estuary	Rural
Waitematā Harbour	Chelsea	1753721	5922776	1991	Estuary	Urban
	Whau Creek	1748588	5920563	1991	Estuary	Urban
	Henderson Creek	1746715	5923855	1991	Estuary	Urban
	Hobsonville	1749453	5927353	1993	Estuary	Urban
	Paremoremo	1745717	5930201	1993	Tidal Creek	Lifestyle/Native
	Rangitopuni Creek	1742734	5930626	1993	Tidal Creek	Rural
	Brighams Creek	1742829	5928227	1996	Tidal Creek	Urban
	Lucas Creek	1749892	5932176	1993	Tidal Creek	Urban
Tāmaki Estuary	Tāmaki	1769303	5916944	1992	Estuary	Urban
	Panmure	1765553	5913693	1992	Estuary	Urban
Tāmaki Strait	Wairoa River	1786561	5910769	2009	Estuary	Rural
Manukau Harbour	Grahams Beach	1749431	5897517	1987	Estuary	Rural
	Clarks Beach	1749746	5888100	1987	Estuary	Rural
	Waiuku Town	1752923	5879195	2012	Estuary	Rural
	Shag Point	1748335	5908549	1987	Estuary	Urban/Rural
	Puketutu Point	1753938	5908791	1987	Estuary	N/A*
	Weymouth	1764080	5897952	1987	Estuary	Urban/Rural
	Māngere Bridge	1758048	5910932	1987	Estuary	Urban
	Manukau Heads	1741520	5900335	2009	Estuary	Urban/Rural

** Site is adjacent to the Māngere Wastewater Treatment Plant discharge "non-compliance zone" and may be less subject to the direct influence of diffuse land derived contaminants*

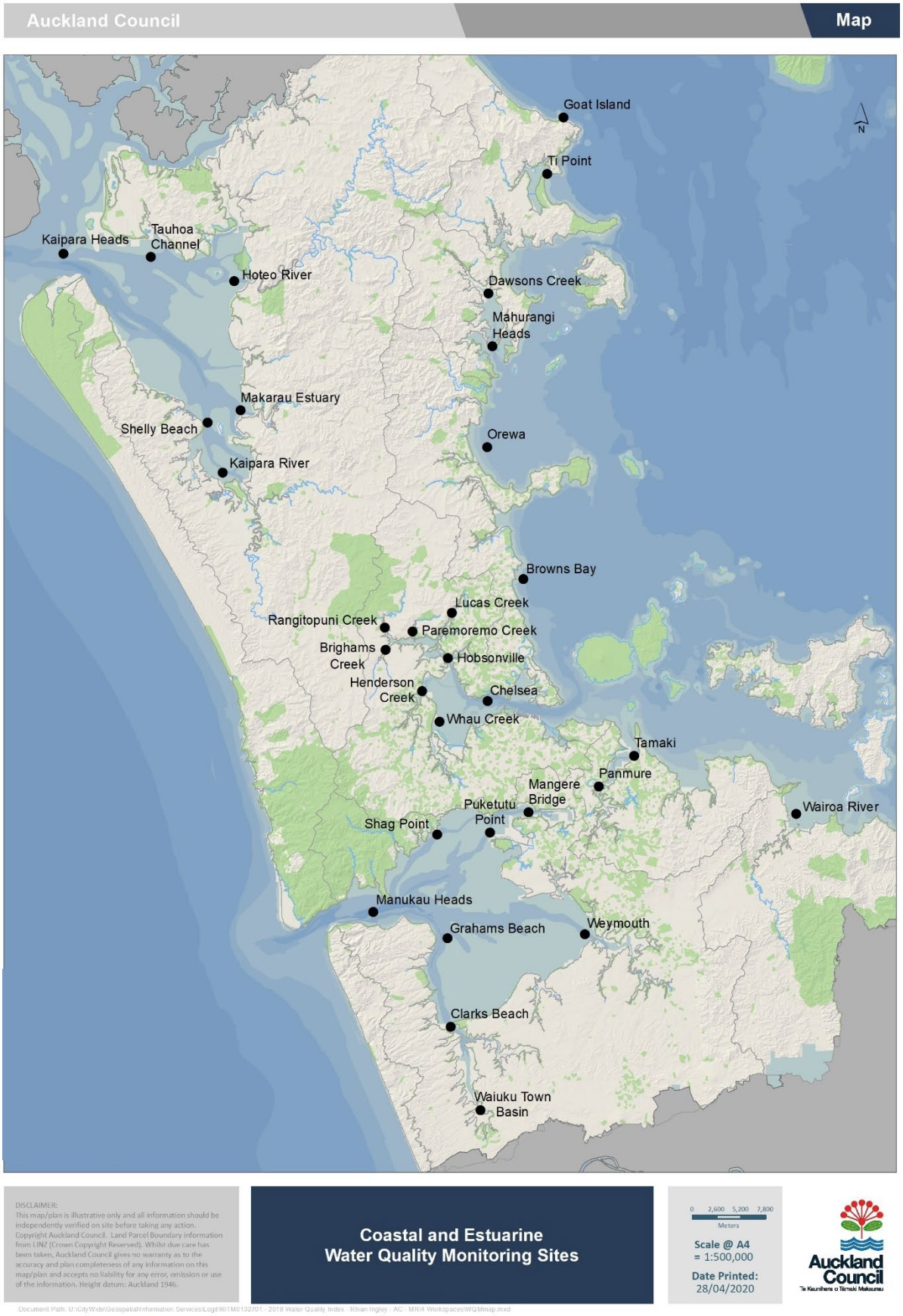

Figure 2-1: Location of the 31 coastal and estuarine water quality monitoring sites

2.3 Data collection

Sample collection was undertaken by council staff on a monthly basis. The quality of coastal water around the region is determined by measuring 16 parameters. A summary of all parameters monitored is provided in Table 6-19 in Appendix B.

Six parameters are determined in the field using an EXO Sonde portable water quality meter (Xylem Analytics), and the remainder are determined by laboratory analysis (see Appendix B). At each site, water samples were collected from the surface (top 1m) by lowering two 1 litre plastic bottles into the water.

All field measurements collected in 2019 were consistent with equipment accuracy specifications and were operated in accordance with in-house procedures and calibration requirements (see Appendix B). Over the course of 2019, calibration and validation procedures were reviewed to improve alignment with draft National Environmental Monitoring Standards (NEMS) (Part 4 – Coastal Waters) (released in April 2019).

Samples were analysed under contract by R J Hill Laboratories Ltd (Hills), an IANZ accredited laboratory. Analytical methods follow the "Standard Methods for the Examination of Water and Wastewater" 22nd Edition (APHA, 2012). It is noted that not all methods for all parameters are IANZ accredited, however this is a common issue across service providers and Hills are actively working towards achieving accreditation.

All field and laboratory data were stored in Auckland Council's archiving database, HYDSTRA (Kisters Pty Ltd). In November 2019, all water quality data (including historic data) were migrated from HYDSTRA to a specialised water quality database, KiWQM (Kisters Pty Ltd).

2.4 Data processing

Quality control was undertaken in accordance with Auckland Council's internal standards, including procedures for the collection, transport and storage of samples, and methods for data verification and quality assurance to ensure consistency across the monitoring programme. Quality coding was also undertaken in accordance with internal standards, these are not directly comparable with NEMS quality codes (final version published February 2020).

Data collected for each variable is analysed for each site and initially compared to data previously collected over a ten-year period. This data is used to obtain the 5th and 95th percentiles and if any new data falls outside of these boundaries, it is flagged. This allows the processor to check for erroneous data and repair (if data is incorrect) or

comment as appropriate. Prior to any analysis, any data points that were assigned a quality assurance code of questionable quality were removed from the dataset.

2.4.1 Censored data and substituted values

For some water quality parameters, censored values are used when true values are too low or too high to be measured with precision by the analytical method used by the laboratory. For very low values of a specific water quality parameter, the minimum acceptable precision corresponds to the "detection limit" for the analytical method for that parameter; for very high values, the minimum acceptable precision corresponds to the "reporting limit" of the analytical method for that variable.

Values that were below the detection limit were substituted with a value of half the detection limit prior to any analysis being undertaken. There were no instances of data reported above the high end "reporting limit".

Previous national water quality reporting excluded sites from analyses where more than 50 per cent of the values for a variable were below the detection limit (Dudley, *et al.,* 2017; Larned, *et al.,* 2018).

Three parameters were affected by a high proportion of left censored values (below the detection limit) within the 2019 calendar year. Fourteen sites had more than 50 per cent of values below the detection limit for nitrite, and six sites that had more than 50 per cent of values below the detection limit for total oxidised nitrogen (and nitrate). Two sites also had more than 50 per cent of values below the detection limit for total suspended solids. These sites and parameter combinations have been excluded, and are noted as such in the annual data summary and associated data tables in Appendix A.

2.5 Data analysis

The data summary section presents the variability of the data across all parameters measured during 2019. Data from 2019 is presented in box plots (section 3.2) to display the ranges over which marine water quality parameter results were recorded. Sites are grouped by location and then listed based on increasing median salinity. These summary statistics are also provided in data tables in Appendix A.

- Box plots (see Figure 2-2) were produced using the software package SigmaPlot version 14.0, using the default percentile functions. The boxes represent the inter-quartile range (25^{th} and 75^{th} percentiles) and the whiskers represent the 10^{th} and 90^{th} percentiles. The median is shown as a line within each box.

- Summary tables which provide a statistical analysis for each parameter at each site have been produced using Sigmaplot version 14.0.

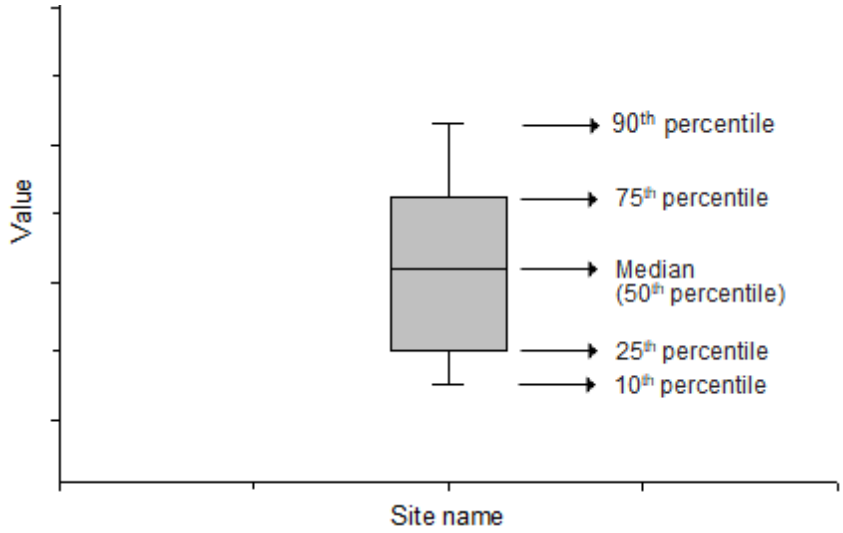

Figure 2-2: The different statistical measures shown within a box plot

2.5.1 Water Quality Index

A Water Quality Index (WQI) is used to simplify how we communicate the state of complex water quality data by incorporating multiple factors (parameters) into a single number or score and overall water quality class (Table 2-2). These guidelines are not regulatory triggers or thresholds and are only used to enable comparison between sites and to identify potential directions for further investigation.

The water quality index used in this report is based on that developed by the Canadian Council of Ministers for the Environment (CCME, 2001) with some modifications. The CCME index framework has been utilised by other regional councils (e.g. Greater Wellington Regional Council and Northland Regional Council) in New Zealand and is used internationally in both freshwater and saline water quality reporting (Ballantine, 2012).

Our approach is based on exceedances of defined water quality guidelines for a subset of six parameters. Guidelines are derived from the 80th percentile of 10 years of data (2007-2016) at reference sites within the Auckland region, or Australia and New Zealand default guidelines (Table 2-3). Separate guidelines were defined for open coast, and estuarine sites resulting from expected differences in water quality due to hydrodynamics and flushing times (Foley, 2018).

This report follows the water quality index methodology outlined in Foley (2018) with modifications as per Ingley (2019). See Appendix C for further detail on Auckland Council's application of the CCME water quality index methodology.

A three-year rolling median was used to calculate the final 2019 water quality index score (monthly median values from 2017 to 2019). Three year rolling medians and associated water quality index scores were also calculated for 2016, 2017, and 2018 (monthly medians from 2014 to 2016, 2015 to 2017, and 2016 to 2018 respectively) for direct comparison.

The 2018 annual coastal water quality reporting suggested that separate guidelines should also be defined for tidal creek environments (Ingley, 2019). While guidelines can be aspirational, it is important that they are achievable under natural or reference conditions and, further, can be achieved under best case management conditions. The established 'estuary' guidelines may not be suitable for tidal creek environments due to differences in coastal hydrodynamics, flushing times, and proximity to freshwater inputs, and may therefore not identify when improvements in water quality are being achieved (or vice versa) in tidal creek environments.

Four monitored sites in the upper Waitematā Harbour were defined as 'tidal creeks'. For the purposes of this assessment, these were sites that were located in narrow channels upstream of the creek 'mouth' or confluence with the main estuary or harbour body and where median salinity over 2007-2016 was <30 ppt (polyhaline). Whilst the 80th percentile of reference sites is commonly used to set water quality guidelines, the ANZ 2018 framework acknowledges that in highly disturbed systems, the 90th percentile of reference sites may be more appropriate. Tidal creeks could be considered 'highly disturbed' in relation to the greater freshwater (and associated contaminant) inputs at these sites relative to estuarine reference sites. Guidelines developed for tidal creeks by Northland Regional Council (NRC) based on tidal creek reference data from its regional monitoring network (including sites in the northern Kaipara Harbour) were also considered (Griffiths, 2016).

Preliminary guidelines have been proposed in this report, based on the guidelines developed for tidal creeks by NRC, or the 90th percentile of Auckland estuary reference sites where the NRC guidelines appeared to be overly generous for Auckland tidal creeks (i.e. a conservative approach was adopted). It is recommended further review is undertaken if/when additional tidal creek sites in the Kaipara or Manukau harbours are monitored in the future.

Table 2-2: Water quality index categories and scoring ranges used by Auckland Council (CCME, 2001)

WQI Class	Score range	Meaning
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment, conditions very close to natural or pristine levels. These index values can only be obtained if **all measurements** are within guidelines **all the time**.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels or water quality guidelines.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels or water quality guidelines.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels or water quality guidelines.
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels or water quality guidelines.

Table 2-3: Water quality index guidelines for the Auckland region

Parameter	Open Coast Guideline	Estuary Guideline	Preliminary Tidal Creek Guideline
Dissolved oxygen (% saturation)	90-110%[1]	90-110%[1]	80-110% [3]
Turbidity (NTU) [1]	<1	<10	<10
Chlorophyll α (mg/L)	<0.0023	<0.0031	<0.0039 [2]
Soluble reactive phosphorus (mg/L)	<0.012	<0.021	<0.021 [3]
Nitrate + nitrite nitrogen (mg/L)	<0.027	<0.029	<0.047 [2]
Ammoniacal nitrogen (mg/L)	<0.015 [4]	<0.015 [4]	<0.018 [2]

[1] Based on ANZ default guidelines, not 80th percentile of reference sites from Auckland region.
[2] Based on the 90th percentile of estuary reference sites from the Auckland region
[3] Based on Northland Regional Council Tidal Creek Guidelines (Griffiths, 2016)
[4] Based on ANZ default guideline for ammonium (NH4+) not ammoniacal nitrogen (NH3+NH4). At the average pH of seawater, approximately 95% of ammoniacal nitrogen is in the ammonium form.

2.6 Limitations

2.6.1 Programme changes

The number of sites within the programme has varied over time primarily to improve the regional coverage. Some sites have also been discontinued due to budget and resources constraints.

The number and type of water quality parameters measured has varied since the programme's inception as new technology has become more affordable, instrument sensitivity has improved, and the programme objectives modified. Refer to Appendix D for a history of changes over time.

2.6.2 Data continuity

Baseline monitoring aims to build a consistent dataset to improve the confidence in state and trend assessments over time, to better assist our understanding of management outcomes. Due to logistical requirements, changing priorities, and improvements to methodologies, some discontinuities exist within the dataset.

The service provider for laboratory analysis changed in July 2017 from Watercare Services Ltd to Hill Laboratories Ltd (Hills). This changeover coincided with some minor changes to analytical methodologies, and detection limits for select parameters. All samples collected in 2019 were analysed by Hills and are comparable between sites within the year.

Some discrepancies have been observed in long-term trends particularly for:

- Ammoniacal nitrogen, where a step increase was observed coinciding with the change in service provider.
- Total nitrogen, where a series of step increases has been observed dating to January 2016 and July 2017.
- Chlorophyll α, where a higher detection limit between July 2017 and June 2018 resulted in poor resolution of the data and a high percentage of values below the detection limit (e.g. 71 per cent of values from January to May 2018 compared to four per cent of values from June to December 2018). This has since been resolved by substitution to a laboratory method with a more sensitive detection limit.

3.0 Results

3.1 2019 Annual climate summary

New Zealand's climate varies significantly from year to year and over the long-term. This is associated with decadal circulation and climate variations such as the Interdecadal Pacific Oscillation (IPO) and El Niño Southern Oscillation (ENSO). These cycles affect average sea surface temperature, prevailing winds, and rainfall patterns. This drives differences in nutrients and sedimentation, such as through changes to oceanic upwelling of nutrient rich waters, and soil erosion and nutrient leaching.

Scarsbrook (2008) has previously found that within the Manukau Harbour, temperature, nitrate, and ammoniacal nitrogen all tend to be higher during La Niña phases and lower during El Niño phases. ENSO typically accounts for less than 25 per cent of variance in seasonal rainfall and temperature patterns at most sites in New Zealand (NIWA, n.d.) and was found to account for <15 per cent of the variance in nitrogen concentrations within the Manukau (Scarsbrook, 2008).

In 2019, the early part of the year approached El Niño conditions reverting to neutral conditions in July through to December (NIWA, 2019). The period of January to June 2019 had below normal rainfall (62 per cent of normal rainfall) (NIWA, 2019).

Anomalously warm ocean waters or a 'marine heatwave' persisted around the country for the duration of 2018, and above average sea surface temperatures continued into the summer and autumn of 2019 within the Auckland region (NIWA, 2019).

Collectively, we would expect coastal nutrient concentrations to generally be lower in 2019 due to the El Niño phase, and reduced freshwater inflows to estuarine environments, particularly in the early part of the year (Scarsbrook, *et al*., 2003; Scarsbrook, 2008). Soil nitrogen accumulates over dry weather conditions and substantial amounts of nitrogen (particularly as nitrate), can be released through soil leaching after a significant rain event following a dry period (Lucci, *et al*., 2013).

3.1.1 2019 Regional river flows and hydrology

Coastal and estuarine water quality is influenced by the quality of surface water that runs from the land through streams, rivers, overland flow paths and stormwater. Regular monitoring is undertaken at monthly intervals and is not targeted to episodic rainfall events, such as floods, which may deliver high quantities of contaminants to the coastal environment over a relatively short duration. We expect variation in the range of river flows experienced both within sites over time, and between sites.

Auckland Council operates a network of river hydrology monitoring stations across the region. Several of these stations that were located upstream of tidal creek or estuary water quality monitoring sites were selected for analysis. The river hydrology stations, and coastal water quality monitoring stations are not explicitly paired, and the hydrology stations vary in their distance upstream, and size or order of the contributing river.

Long-term flow conditions or flow duration curves (i.e. the range of flows that can be expected to occur at that hydrology station[2]) were compared to the flow conditions experienced at that river hydrology monitoring station on the days that we undertook the coastal and estuarine water quality monitoring during 2019. This information is used only to characterise variation between years, between sites, and to identify any notable high flow events that may help explain observations of high concentrations of contaminants in the downstream receiving environment.

An example of a flow duration curve is provided in Figure 3-1. This shows that the monthly monitoring undertaken in the Waitemata Harbour was generally representative of the 18th to 86th percentage of flows experienced at the upstream Rangitopuni River hydrology site (interquartile range). The highest flow conditions intercepted were up to the 6th percentile, i.e. only six per cent of flows recorded are ever higher than this volume.

Figure 3-2 summarises the range of flows that occurred at each of the selected hydrology stations, on the coastal water quality monitoring days in 2019, standardised by the per cent exceedance of flows. This shows that coastal and estuary water quality monitoring days in 2019 were generally representative of median, to lower, long-term river flow conditions (the interquartile range typically spans approximately 20th to 80th per cent of flows). In 2018, the interquartile range typically spanned approximately the 20th to 60th percentile of flows (Ingley, 2019). Lower flow conditions were sampled in 2019 than in 2018.

The monitoring programme is not specifically designed to capture high river flow events. However, in 2019, at least one coastal monitoring event coincided with flows in the highest 10 per cent of long-term flows in contributing rivers, except for sites within the wider Manukau Harbour watershed. Rain events resulting in river flows higher than the highest four per cent of flow conditions at hydrology monitoring stations within each watershed coincided with the following coastal water quality sampling events:

- Mahurangi Harbour – June
- Wairoa River – June and August
- Tāmaki Estuary – August
- Waitematā Harbour – October

[2] Based on the maximum data range available, with a minimum of 10 years of records.

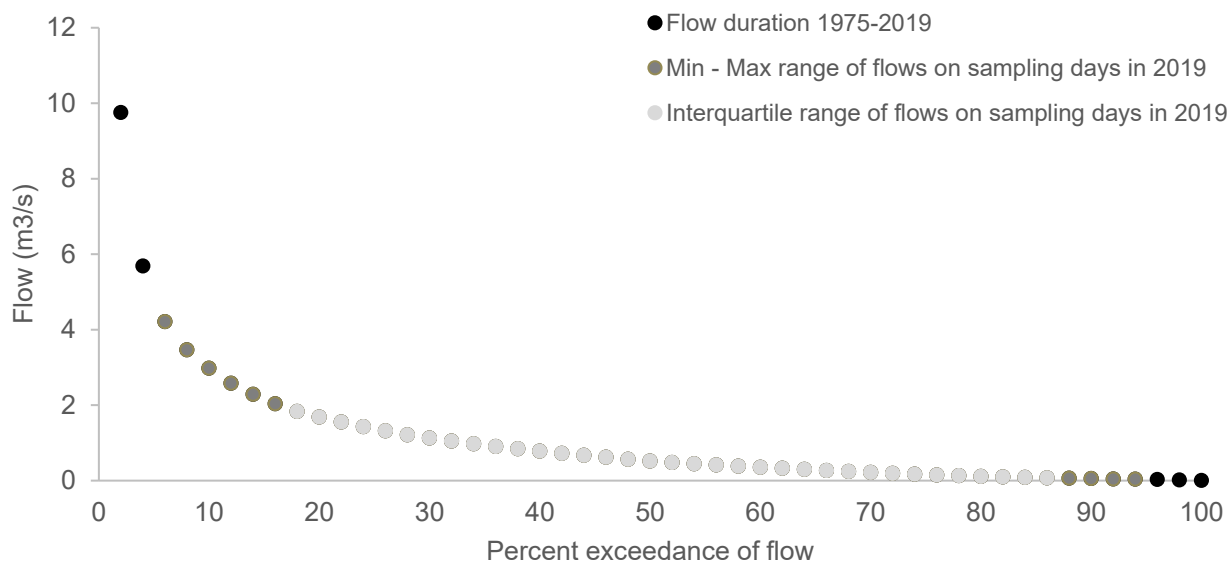

Figure 3-1: Example of the long-term flow duration curve at Rangitopuni River hydrology site compared with river and flow conditions at that site coinciding with the downstream estuary water quality monitoring days sampled in 2019.

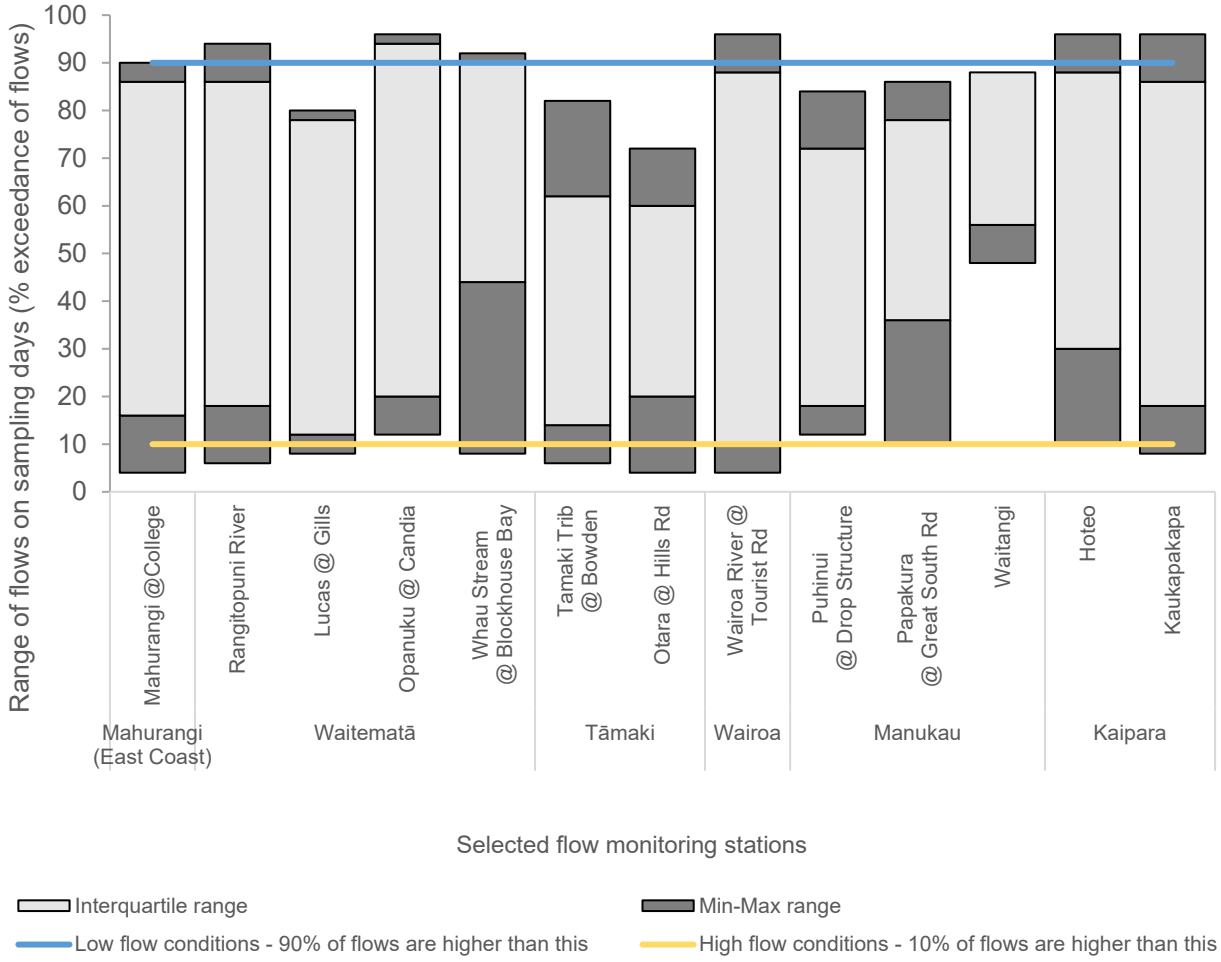

Figure 3-2: Summary of flow duration analysis based on the long-term records (min 10 years) for selected river hydrology flow monitoring sites compared to flow conditions experienced at that site on the 2019 monthly coastal water quality sample days.

3.2 Annual data summary

Sites within the coastal and estuarine water quality programme are representative of a range of physical conditions ranging from open coast to estuaries/harbours and tidal creeks. Salinity (and conductivity) is reflective of these conditions with open coastal sites close to oceanic values of 35ppt (Figure 3-4). Tidal creek sites are typically more variable due to varying freshwater inflows; this is further exacerbated in upper tidal creeks (such as Rangitopuni Creek) where, following heavy rain events, surface waters can be very fresh.

The range of values recorded for each parameter at each site was similar to what has been previously reported, see Figure 3-4 to Figure 3-9 and associated data tables in Appendix A. In these plots, sites are ordered for each harbour or estuary grouping by increasing median salinity.

Anomalous results recorded in 2019, and potential causes of these anomalies, are outlined below.

Anomalous results associated with high flow events:

- Dawsons Creek and Mahurangi Heads – high rainfall event in June (highest two per cent of flows on record), associated with very high total oxidised nitrogen concentrations for the site (up to double the concentration recorded in the past five years), as well as elevated turbidity and soluble reactive phosphorus.
- Wairoa – high rainfall event (highest four per cent of flows on record) in August associated with very high total oxidised nitrogen (nitrate) and total nitrogen, and turbidity and, elevated total phosphorus concentrations for the site.
  While high flow events had also been recorded in June, higher flow conditions (>20 per cent of flows) had been sustained for over three weeks prior to the August sample whilst the weeks preceding the June rain event had been below median flow.
- Kaipara River and Makarau Estuary – higher ammoniacal nitrogen and soluble reactive phosphorus concentrations were recorded at both sites in April. It was noted that a heavy rain event had occurred the day prior to sampling however nearby river hydrology sites recorded flows that were less than the top 10 per cent of flows.

Other:

- The majority of monitored sites had maximum temperatures higher than the 98th percentile of each site over the 10 years 2007-2016. This is consistent with the ‘marine heatwave’ conditions experienced in early 2019.

- Māngere Bridge and Puketutu Point – at both of these sites higher than typical nitrite concentrations were recorded on multiple occasions. This does not appear to be associated with specific flow events.
- Dawsons Creek – higher total suspended sediments were recorded at this site in November. A sediment plume was observed at the time, with sediment discharging from all three tidal creeks upstream of the Dawsons Creek estuary site (Figure 3-3). Only moderate rain and river flow conditions were recorded prior to this event.

Figure 3-3: Sediment plume visible at Dawsons Creek confluence in the Mahurangi Harbour in November 2019 (Image from: H. Allen, RIMU)

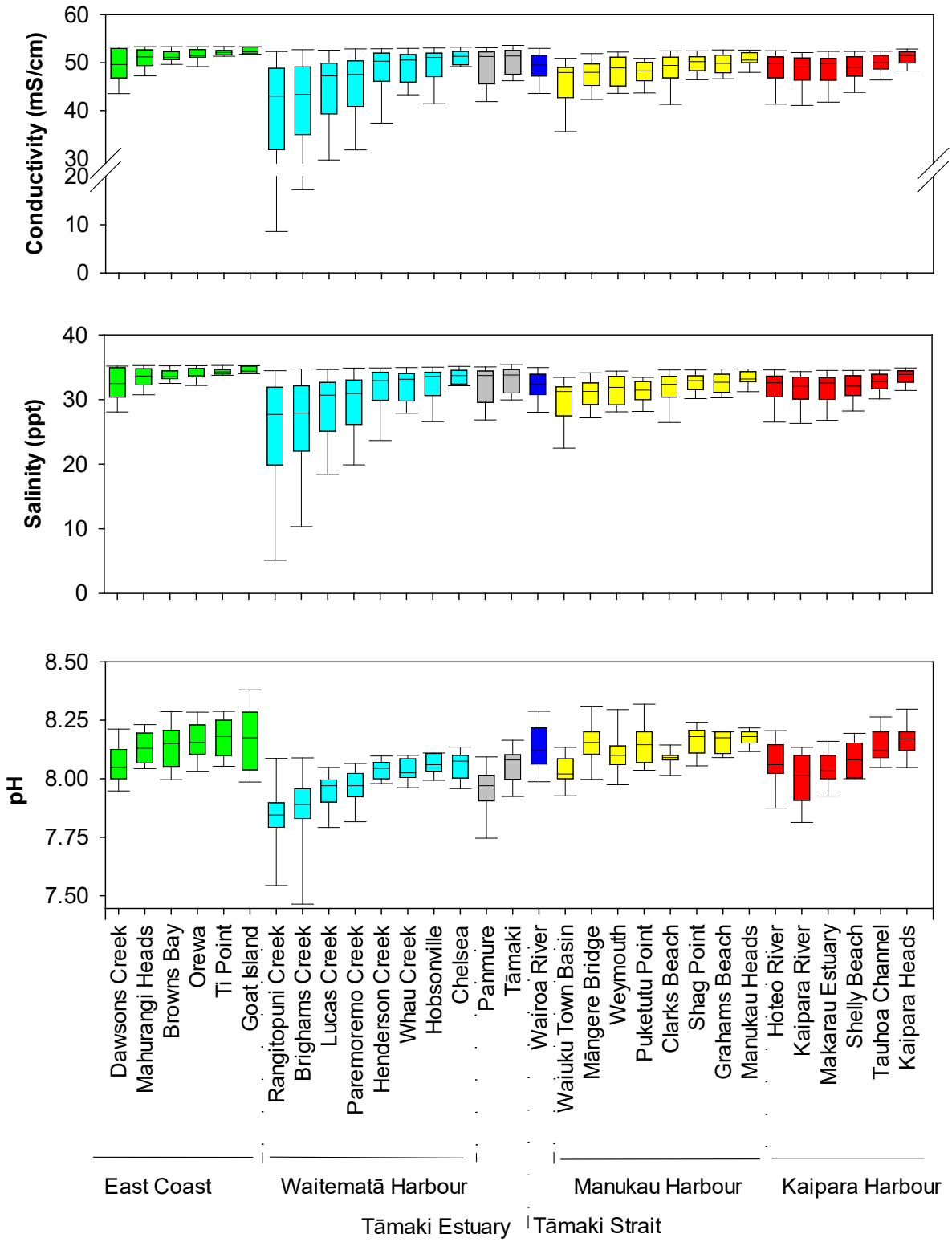

Figure 3-4: Spatial patterns in conductivity, salinity and pH.

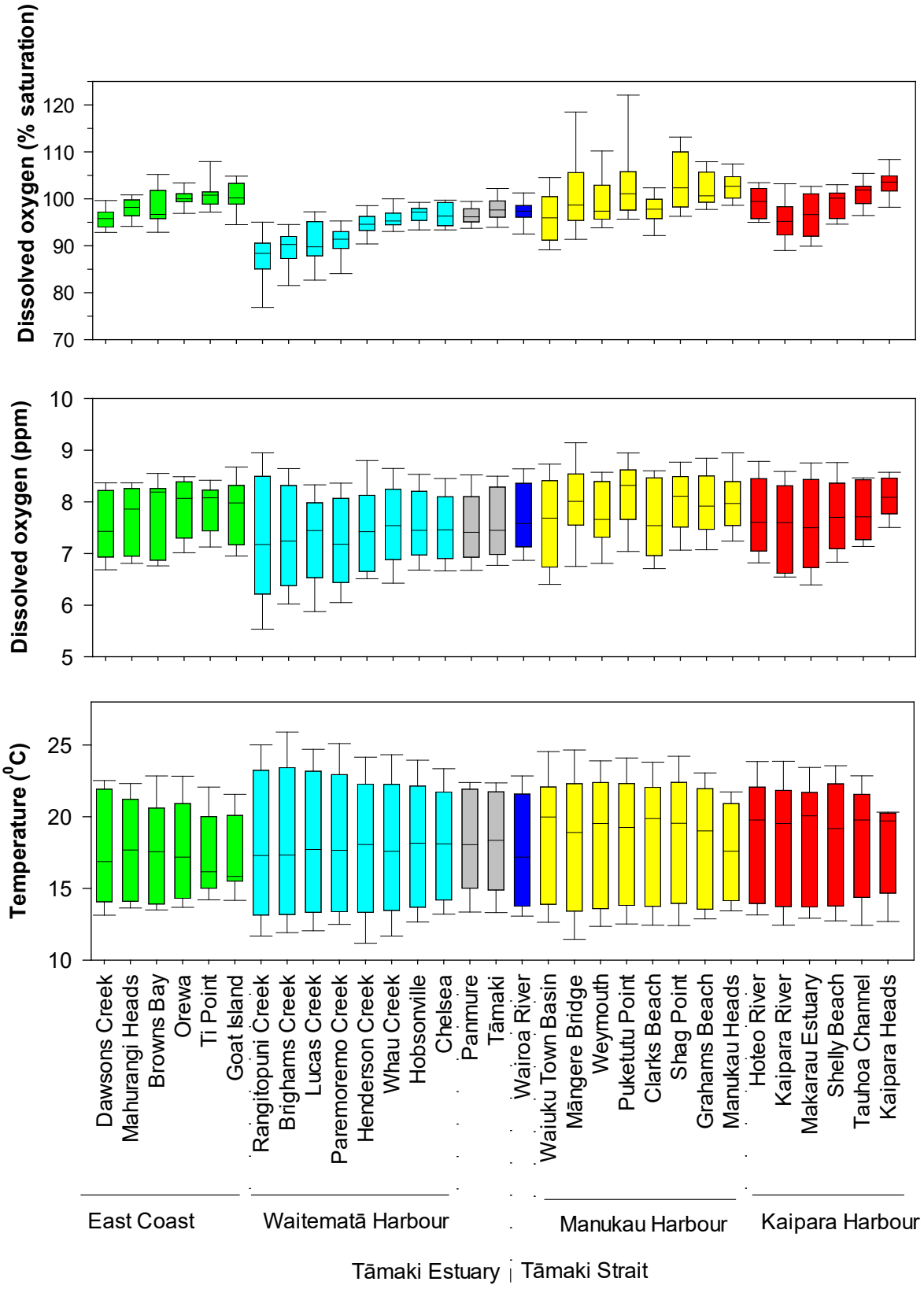

Figure 3-5: Spatial patterns in two indices of dissolved oxygen (ppm and % saturation) and sea surface temperature.

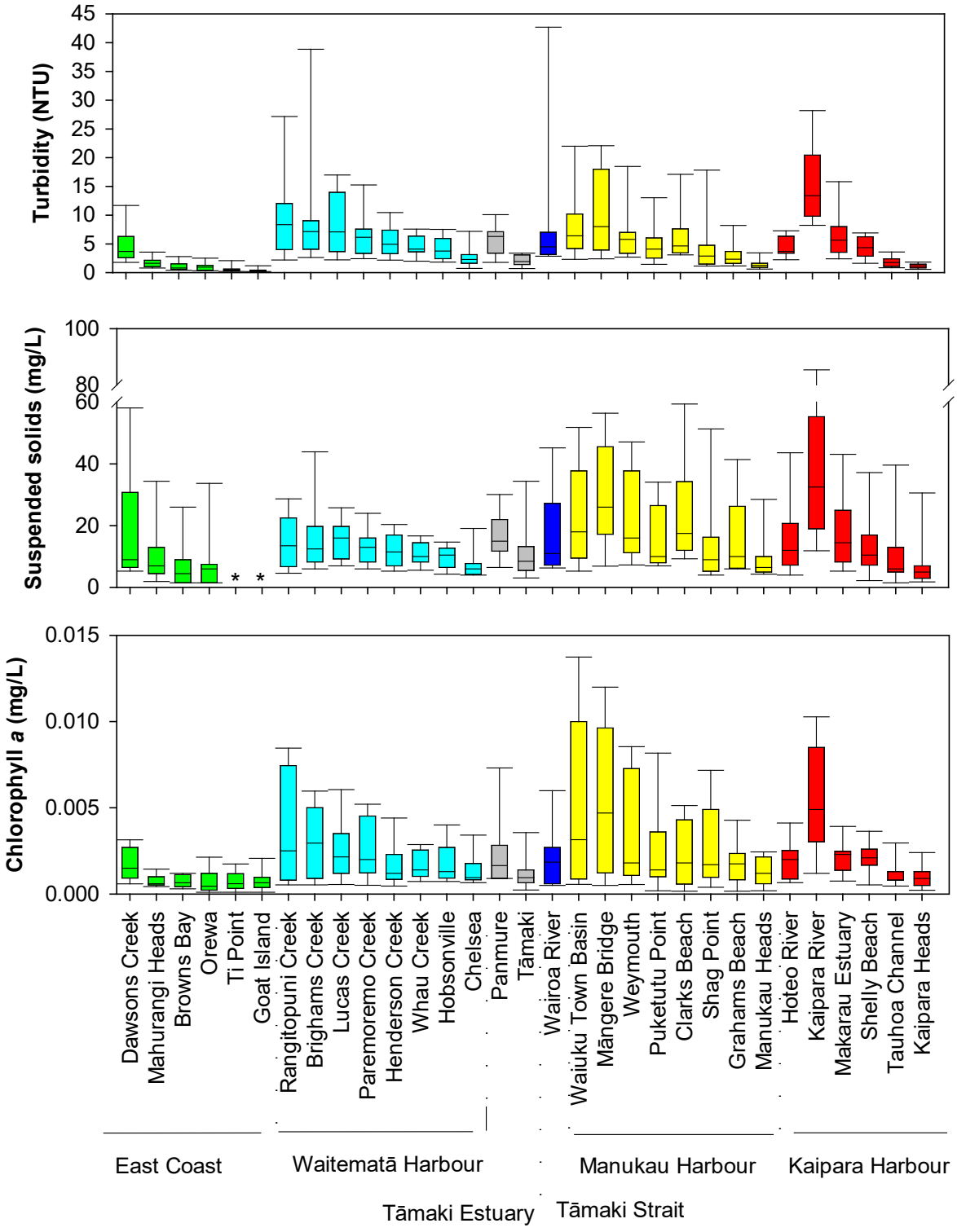

Figure 3-6: Spatial patterns in turbidity, suspended sediment, and chlorophyll α.

** Sites have been excluded from analyses where >50% of values were below the detection limit for that parameter*

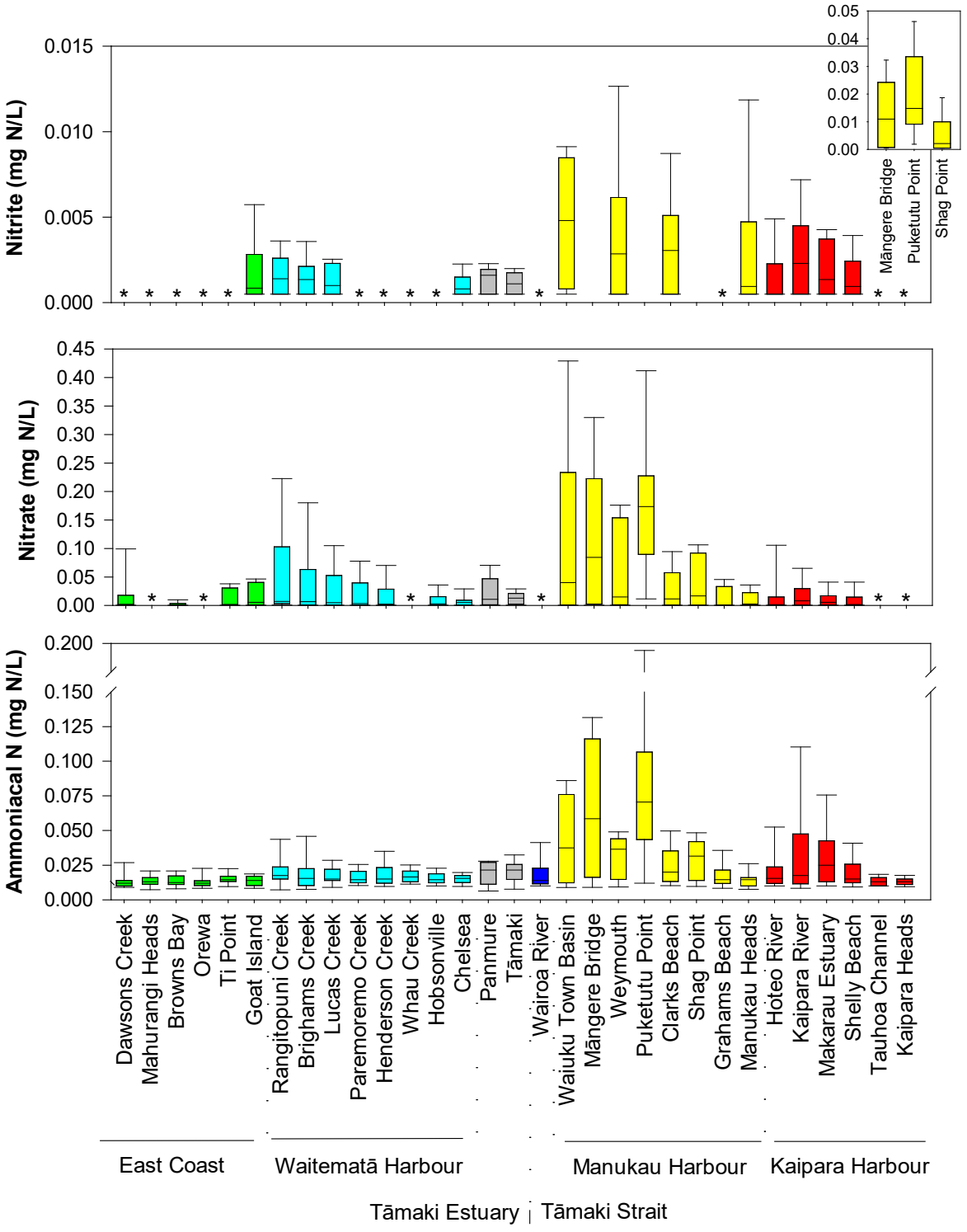

Figure 3-7: Spatial patterns in nitrite, nitrate and ammonia.

** Sites have been excluded from analyses where >50% of values were below the detection limit for that parameter*

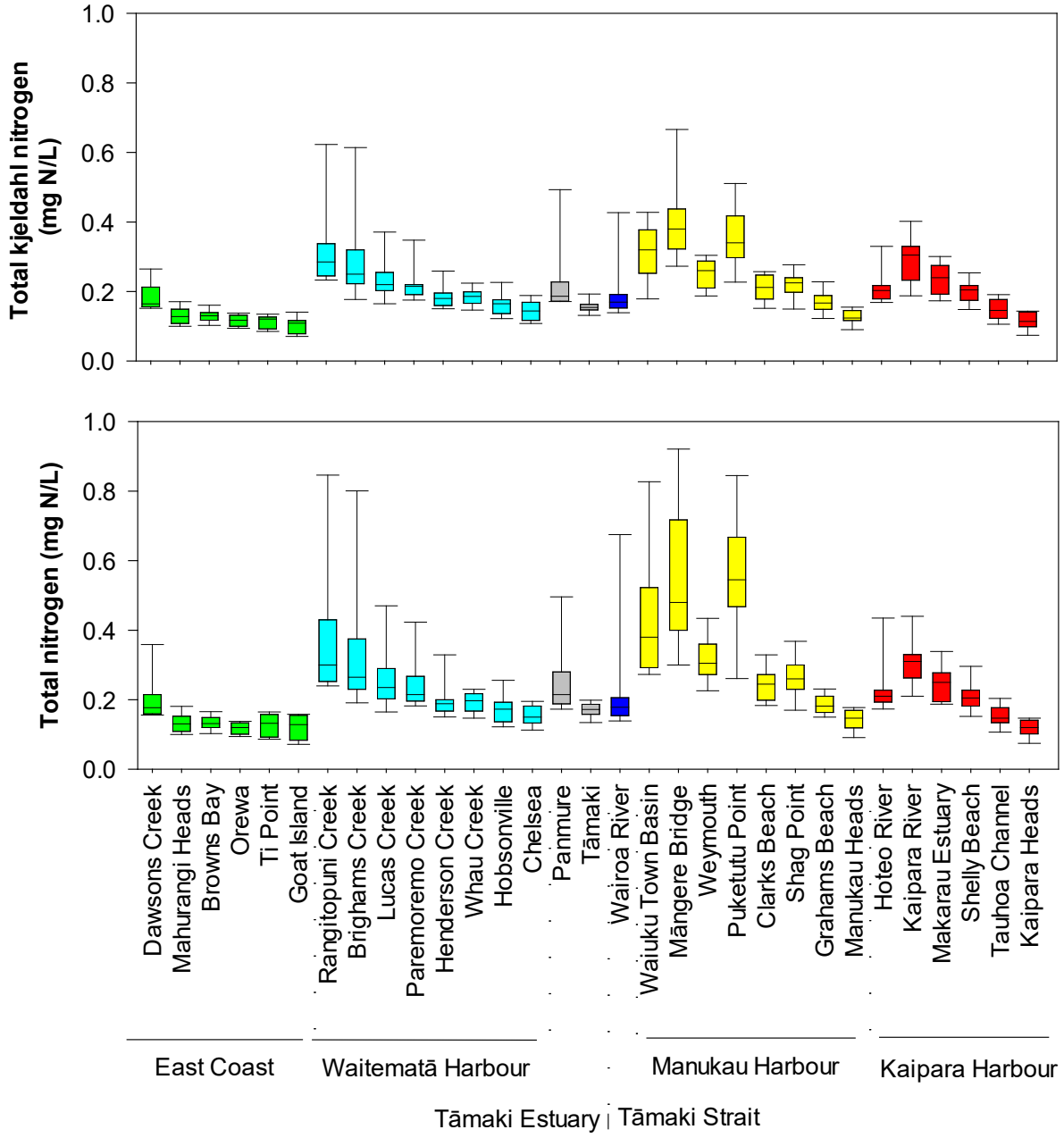

Figure 3-8: Spatial patterns in total kjedahl nitrogen and total nitrogen.

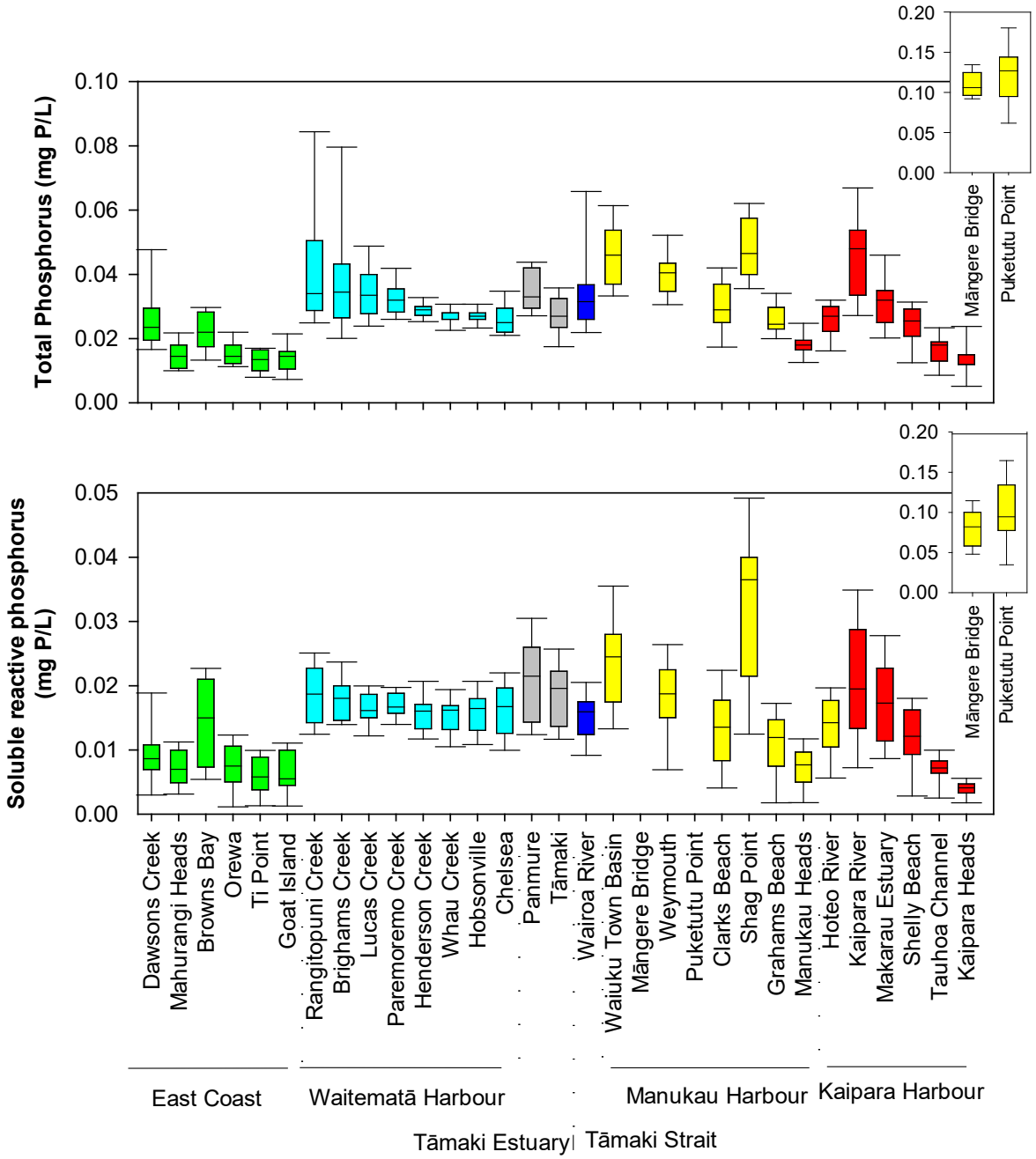

Figure 3-9: Spatial patterns in total phosphorus and soluble reactive phosphorus.

3.3 Water Quality Index

A water quality index (WQI) represents the deviation from reference coastal or estuarine conditions in the Auckland region, rather than indicating whether the water quality is suitable for a particular purpose or activity.

Median monthly values from 2017-2019 are summarised in the water quality index. This includes an overview of water quality status across the region, key differences between areas within the region, and changes in state over time.

3.3.1 Regional water quality class summary

Changes in water quality index scores over time provide an indication of large scale changes in water quality integrated across several key parameters. But it is important to note that the water quality index has a lower sensitivity to detect changes in water quality class where concentrations of contaminants are typically higher than the guideline values and sites are consistently classed as ‘poor’. Long-term trend analysis for each underlying parameter provides a more definitive picture of how water quality has historically changed within and between sites across the region. The most recent regional trend analysis (2007-2016) of individual water quality parameters showed that coastal and estuarine water quality was generally improving at monitored sites across the region (Foley, *et al*., 2018).

The water quality index shows that water quality at monitored sites across the region has been consistent over the past four assessment periods with 74 per cent of sites remaining in the same water quality class between the 2014 to 2016 and 2016 to 2019 periods (Figure 3-10;Table 6-1 in Appendix A).

The 2017-2019 period reflects the first set of values where the majority of samples were analysed by Hill Laboratories (from July 2017 onwards) whilst the 2014-2016 period reflects values where all samples were analysed by Watercare Services. The rolling periods between provide an indication of the influence of this change in analysis in relation to guideline values particularly for ammoniacal nitrogen and chlorophyll α (see section 2.6.1 and Figure 3-11).

There were six sites (19 per cent of all sites) that declined in water quality class over this period. However, these appear to be primarily related to an increase in exceedances of ammoniacal nitrogen coinciding with the change in laboratory service provider. For two of these sites, Mahurangi Heads and Chelsea, ammoniacal nitrogen was the only parameter that exceeded guideline values and the declining score is considered to be an artefact of changing laboratory analysis.

For the other four sites, declining water quality scores were also associated with occasional exceedances of guidelines for a range of other parameters including chlorophyll α at Wairoa River, soluble reactive phosphorus at the Kaipara River mouth, and total oxidised nitrogen at the Kaipara Heads and Tauhoa channel. No sites declined by more than one water quality class.

Two sites, Panmure (Tāmaki Estuary), and Hobsonville (upper Waitematā Harbour), were found to have improved water quality class over this time period. At Panmure, this was primarily associated with fewer exceedances of the dissolved oxygen guideline. At Hobsonville, this was due to a reduction in the number of different parameters that exceeded guidelines with no exceedances of soluble phosphorus or total oxidised nitrogen in the 2017-2019 period.

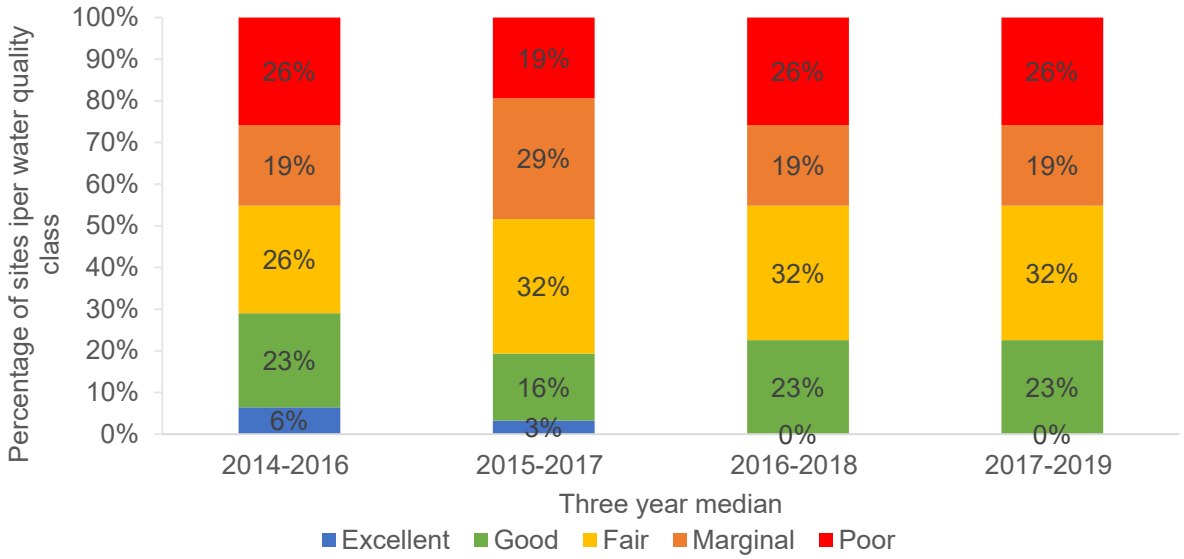

Figure 3-10: Percentage of sites per water quality class from 2014-2019 (*n*=372).

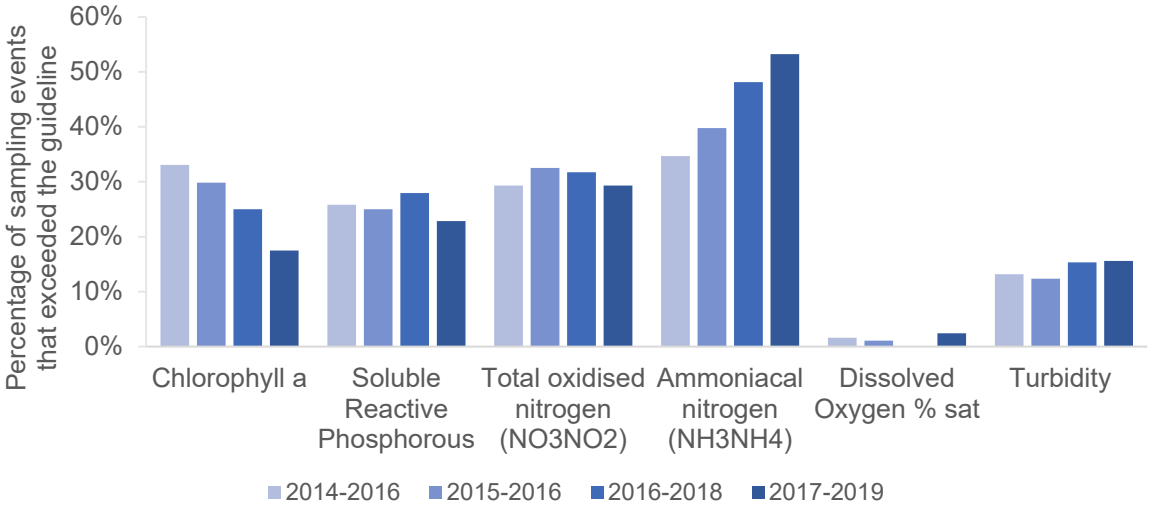

Figure 3-11: Percentage of sampling events that exceeded the relevant water quality guideline by <10 times (*n*=372) **Note possible lab induced changes in exceedances for chlorophyll α and ammoniacal nitrogen.*

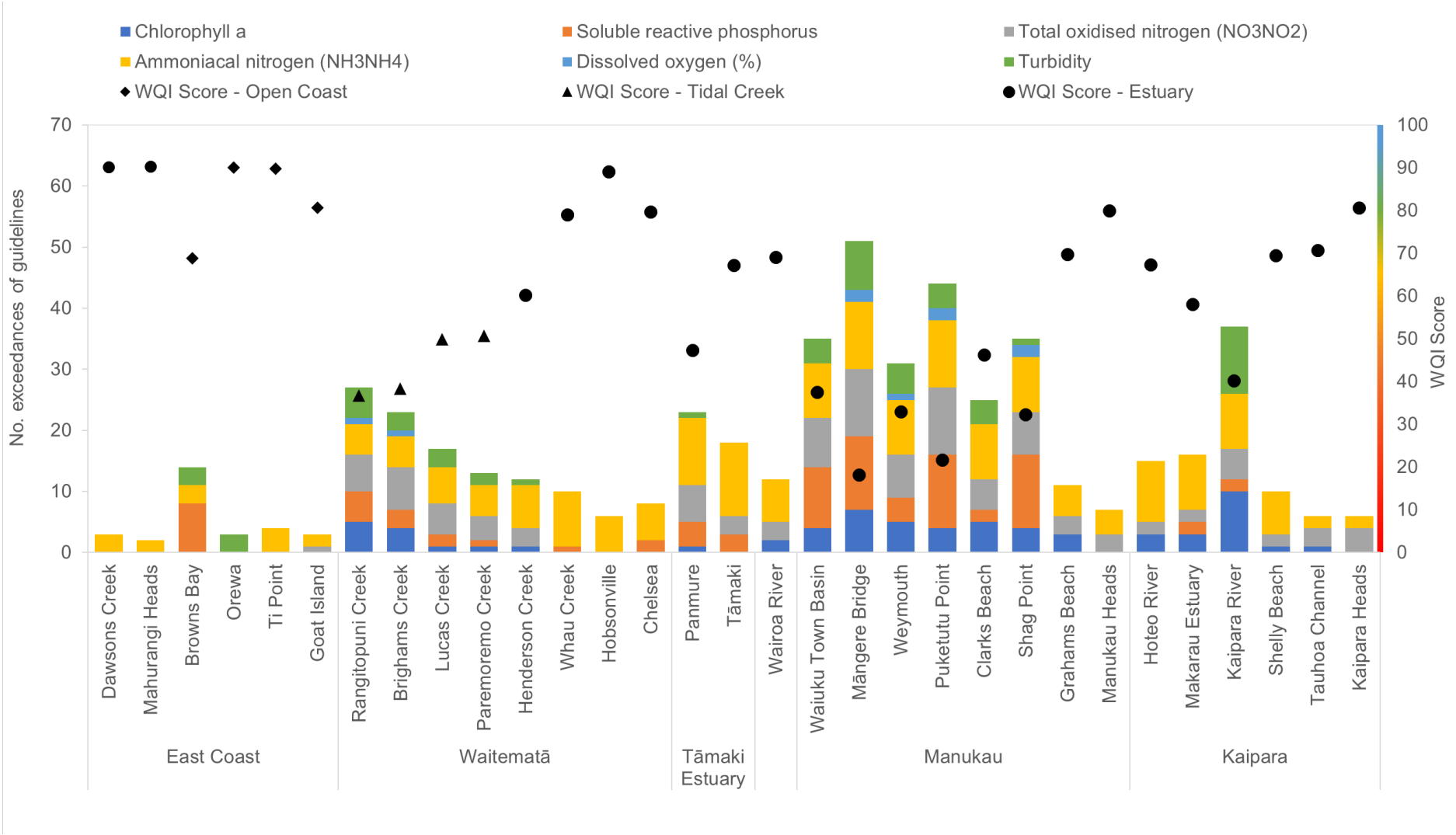

Figure 3-12: Water Quality Index score and summary of number of exceedances <10x the relevant guideline value per site (2017-2019 median values).

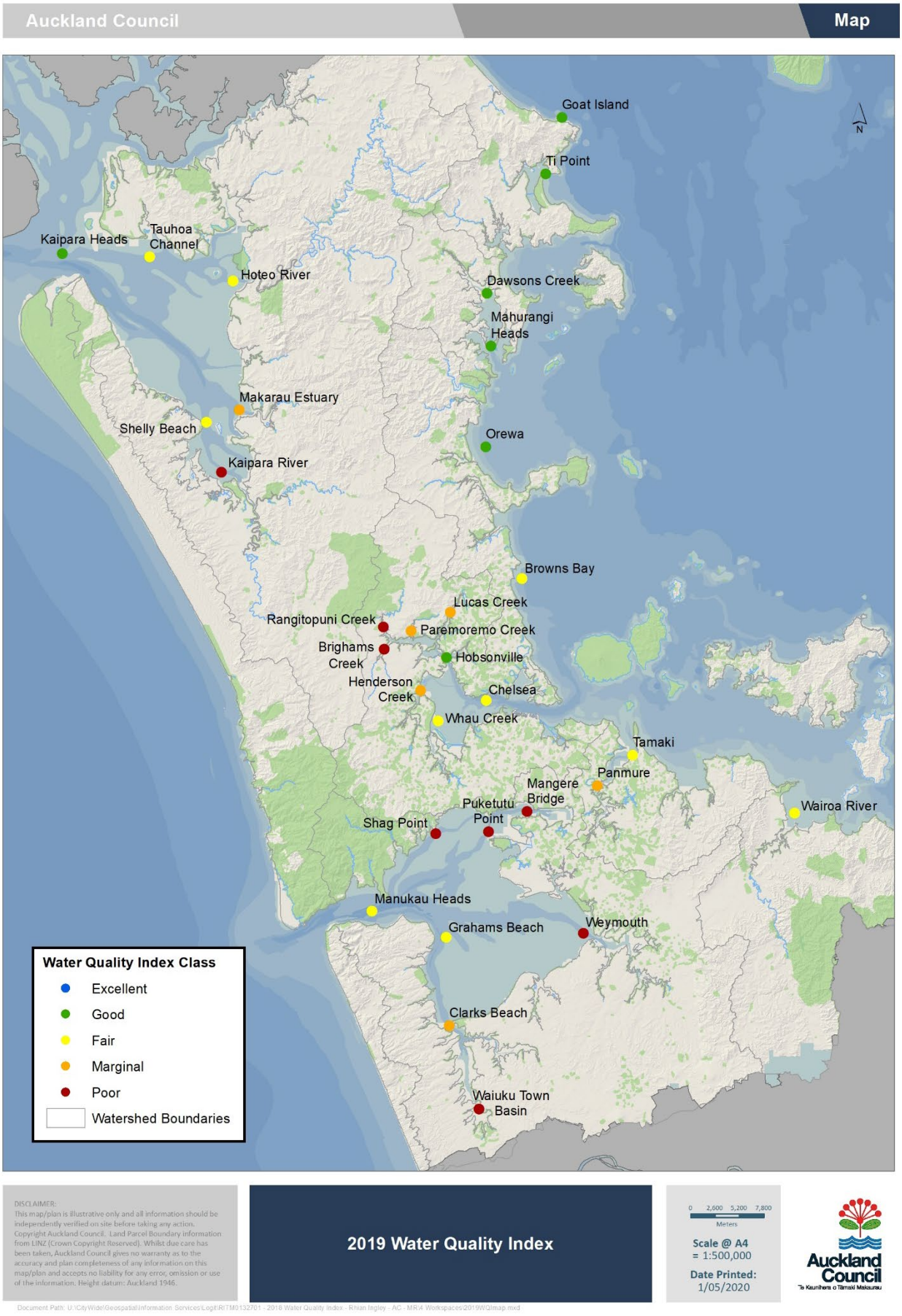

Figure 3-13: Water quality index class at coastal and estuarine water quality monitoring sites

3.3.1.1 Spatial patterns

Recent national-scale analysis of coastal and estuarine water quality found that salinity was strongly correlated with estuarine water quality and that salinity was a more powerful explanatory variable than differences in urban or agricultural land cover in the contributing watershed (Dudley, *et al.,* 2020). Salinity provides a proxy for the degree of freshwater input at a site. Greater freshwater influence resulted in higher concentrations of all forms of nitrogen and phosphorus (total and soluble), and turbidity; chlorophyll α was not significantly associated with salinity (Dudley, *et al.,* 2020).

A similar relationship has been demonstrated in previous regional state and trend analysis where salinity was compared to an average water quality ranking across Auckland state of the environment monitoring sites (Scarsbrook, 2008).

A simple linear regression analysis was undertaken to define the relationship between the 2017-2019 water quality index scores and median salinity at each site for the same period across Auckland. Three sites were excluded from this analysis as elevated concentrations of nitrite were detected at all three of these sites (see Figure 3-7), indicative of point source discharges of nutrients. Therefore, it is considered reasonable to exclude these sites where the relationship would not be expected to follow the hypothesised diffuse freshwater input to contaminant runoff pattern.

Salinity was found to be a statistically significant predictor of overall water quality index scores explaining 49 per cent of the variation between sites ($t = 5.03$, $p < 0.0001$, $R^2 = 0.49$). Open coast and harbour mouth sites generally had ‘good’ water quality, whilst upper tidal creeks all had consistently ‘poor’ water quality (Figure 3-12; Figure 3-13).

A key difference between the results presented in the 2018 annual report (Ingley, 2019) and this analysis is the use of tidal creek water quality guidelines in addition to the separate estuary and open coast guidelines. A comparison was undertaken for the 2017-2019 data following the same regression analysis method outlined above and water quality index scores calculated using the former two sets of guidelines only. Using two sets of guidelines only, salinity explained 58% of the variation between sites ($t = 6.02$, $p < 0.0001$, $R^2 = 0.58$).

Comparing the tidal creek sites to separate tidal creek guidelines has therefore resulted in a weaker relationship between overall salinity and water quality index scores. This was expected as it was anticipated that using the tidal creek guidelines would result in a more even distribution of scores for these sites, not all in the ‘poor’ category. These findings emphasise the importance of controlling for physical

variability between sites in the mixing of freshwater flows with oceanic water to detect the effects of terrestrial derived contaminants on water quality.

The 95th percentile confidence intervals essentially demonstrate the potential error of the regression line of the water quality index to salinity relationship. Sites that lie outside of the 95 per cent confidence interval, or deviate from the predicted relationship, can be considered to have better (above) or worse (below) water quality than expected using salinity as the only predictive variable for each site (Figure 3-14).

Five sites were observed to fall well outside the 95 per cent confidence interval; three sites in the Manukau Harbour (Waiuku Town Basin, Clarks Beach, and Weymouth), one site in the Kaipara Harbour (Kaipara River mouth), and one site in the Tāmaki Estuary (Panmure). Three other sites also had slightly poorer water quality than expected, Makarau Estuary in the Kaipara, Tāmaki Estuary, and Browns Bay.

Six sites were observed to have better water quality than expected: both sites in the Mahurangi Harbour and the open coast reference sites (Goat Island and Ti Point), and the Whau and Henderson Creeks in the Waitematā Harbour.

See section 3.3.2 for further discussion on the water quality parameters potentially driving these results.

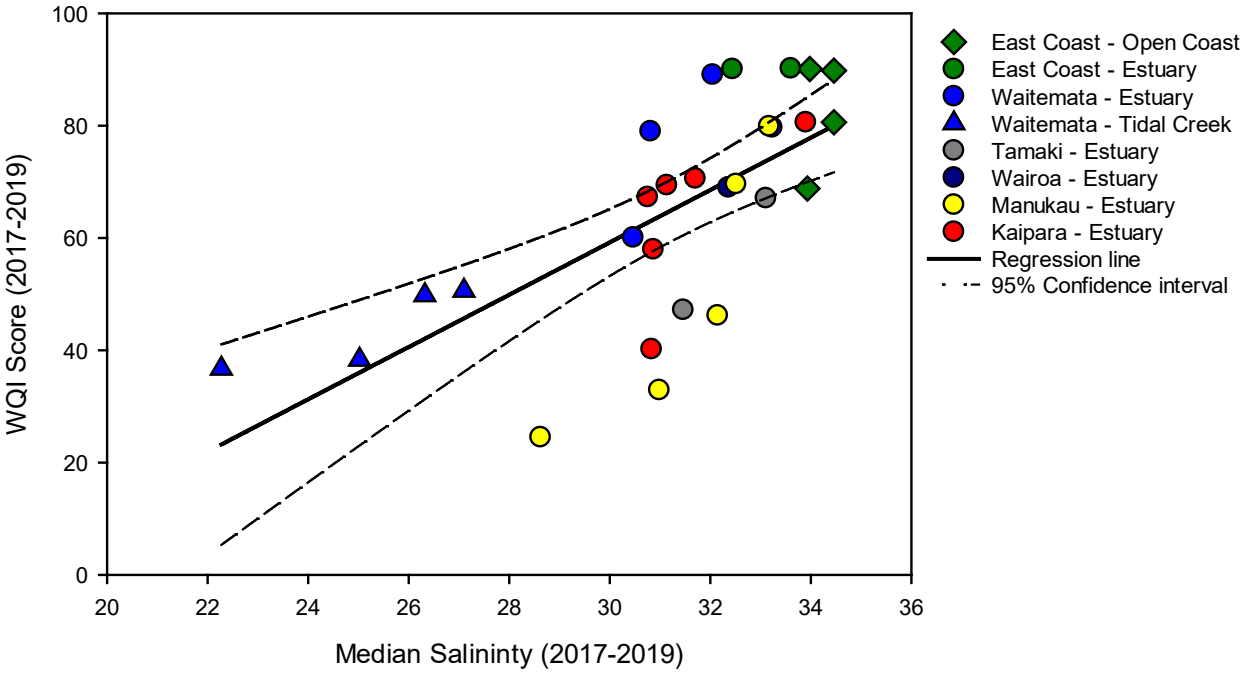

Figure 3-14: Relationship between salinity and water quality index (WQI) score (r^2=0.49). Excluding Māngere Bridge, Puketutu Point, Shag Point

3.3.2 Water quality index class summary by area

The water quality index is based on a combination of the number of times a guideline is exceeded, how many guidelines are exceeded, and the magnitude of those exceedances (see Appendix C for methodology details). Magnitudes are arbitrarily based on three groups: >10 times the guideline value and >25 times the guideline value. Most exceedances fall within the smallest magnitude of <10 times the guideline value and the discussion and figures below focus on these exceedances unless otherwise stated.

3.3.2.1 East Coast

All sites were within the 'good' water quality class except for Browns Bay which was 'fair' (Appendix A, Figure 3-16). However, the underlying parameters driving these scores were quite different between sites.

In the Mahurangi Harbour, Dawsons Creek had a low frequency of exceedances of chlorophyll α, ammoniacal nitrogen, and total oxidised nitrogen however water quality was generally better than expected for the salinity of these sites. Water quality also improved over the expected gradient from Dawsons Creek to the Mahurangi Heads. An abrupt increase in exceedances of ammoniacal nitrogen at Mahurangi Heads over time is likely an artefact of the change in laboratory analysis for this parameter.

Orewa and Browns Bay sites had low to moderate frequency of exceedances of turbidity and soluble reactive phosphorus respectively. It is noted that the open coast guideline for turbidity used here (<1 NTU based on ANZ default guidelines) is very low. Maximum turbidity at these sites was <3 NTU which is well below the lower quartile for open coast sites across New Zealand (Dudley, *et al*., 2018; Dudley, *et al*., 2020). The lower water quality class at Browns Bay is therefore primarily associated with elevated soluble reactive phosphorus.

The reference sites, Goat Island and Ti Point, had a low frequency of exceedances for total oxidised nitrogen and ammoniacal nitrogen. The abrupt increase in exceedances of ammoniacal nitrogen at these sites are likely an artefact of the change in laboratory service (see section 2.6.1 and Figure 3-15). These two sites are located at the outer boundary of the Hauraki Gulf near the edge of the continental shelf. The exceedances of nitrogen observed here are seasonal, occurring in spring, coinciding with upwelling driven by dominant westerly wind resulting in increased nitrate nitrogen concentrations, and in winter, where nitrate is generally present from deep mixing in the water column but not taken up by phytoplankton due to low light levels (Zeldis, *et al.,* 2013).

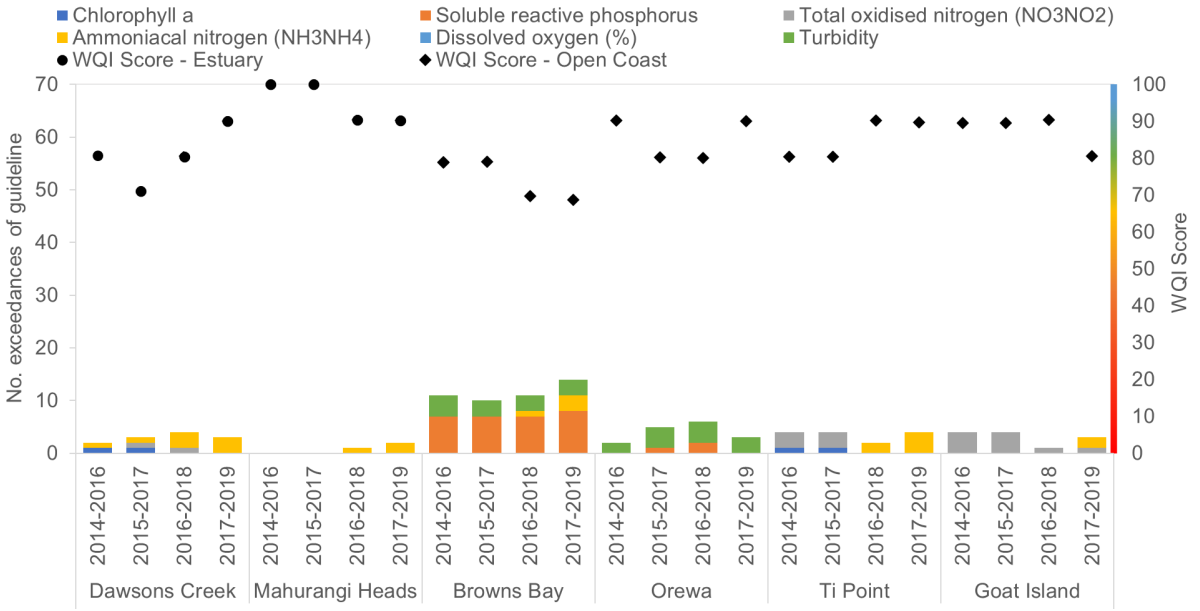

Figure 3-15: Variation in number of exceedances (<10x guideline value) over time for East Coast sites based on rolling three year median values.

3.3.2.2 Waitematā Harbour

Concentrations of nutrients, chlorophyll α, and turbidity were typically elevated in the upper Waitematā Harbour tidal creek sites resulting in a moderate to high frequency of exceedances of these guidelines, whilst the sites in the central harbour were typically within all guidelines except for ammoniacal nitrogen and soluble reactive phosphorus (Figure 3-17). There was no sudden change in the number of exceedances of the ammoniacal nitrogen guideline which suggests that this nutrient is elevated in the Waitematā[3].

The revised guideline values for tidal creeks did not change the overall water quality class for Rangitopuni Creek or Brighams Creek which are both ‘poor’ however the revised guidelines resulted in Lucas Creek and Paremoremo Creek being classified as ‘marginal’ instead of ‘poor’ which is consistent with the higher median salinity (less freshwater influence) at these sites. The differences in water quality class due to the application of the tidal creek guidelines were, no exceedances of the revised dissolved oxygen guideline, and fewer exceedances of the ammoniacal nitrogen and chlorophyll α guidelines. Water quality at Lucas Creek and Paremoremo Creek has been consistent over the four assessment periods whilst Rangitopuni Creek and Brighams Creek have been more variable. This variability is primarily associated with single

[3] It is noted that all concentrations of ammoniacal nitrogen were well below the ANZECC trigger value for total ammoniacal nitrogen (pH adjusted) in relation to chronic marine ammonia (NH_3) toxicity (ANZECC 2000).

instances in the 2014-2016 and 2017-2019 periods where median dissolved oxygen was lower than 80 per cent. Low dissolved oxygen typically occurs at these sites in February and March.

Water quality within the central harbour has also been relatively consistent over the past four assessment periods except at Hobsonville, where water quality improved from ‘fair’ to ‘good’ in 2017-2019. Water quality was within all guidelines except for ammoniacal nitrogen.

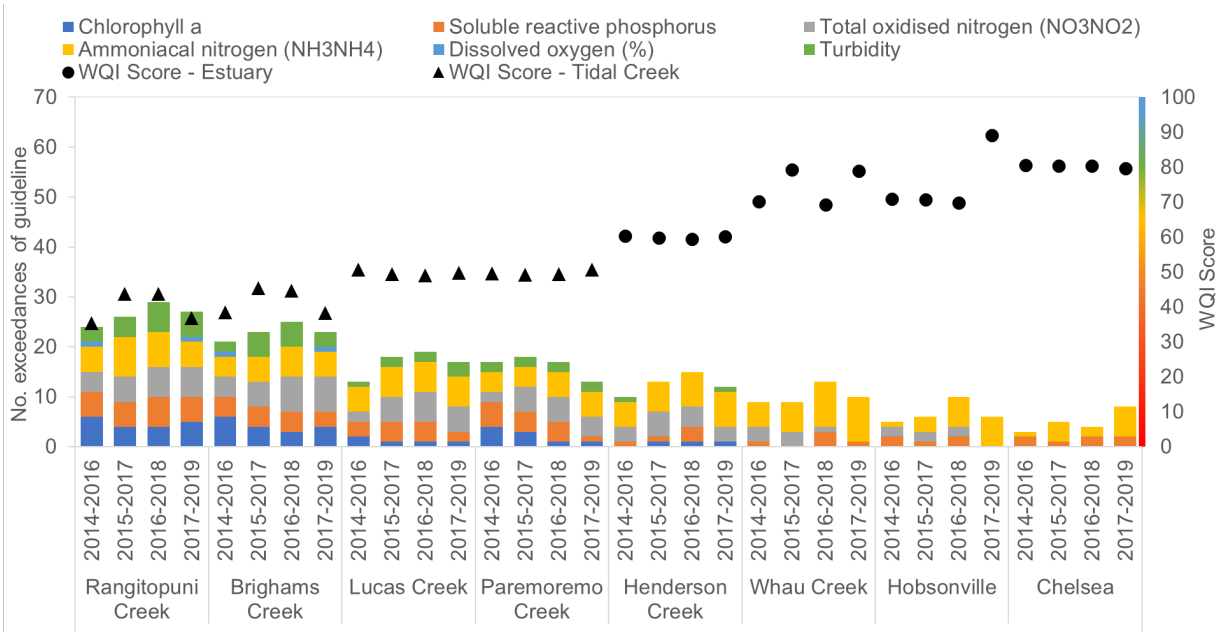

Figure 3-16: Variation in number of exceedances (<10x guideline value) over time within Waitematā Harbour sites based on rolling three year median values.

3.3.2.3 Tāmaki Estuary and Tāmaki Strait

Water quality improves over the expected gradient from at the upper reaches of Tāmaki Estuary at Panmure to the Tāmaki (Half Moon Bay) site. This is primarily associated with higher concentrations of nutrients and chlorophyll α at Panmure.

Water quality at Panmure was lower than expected relative to salinity. However, water quality appears to have improved at Panmure as reflected in the class improving from poor to marginal over the short term. This appears to be primarily associated with turbidity and dissolved oxygen, with no exceedances for these parameters in the two most recent assessment periods.

While concentrations of ammoniacal nitrogen also decrease over the spatial gradient from Panmure to Tāmaki, they remain typically above the water quality index guideline value, with both sites exhibiting a moderate frequency of exceedances (Figure 3-17).

The surrounding catchments draining to the Panmure and Tāmaki sites have a high proportion of urban land cover (>25 per cent of the entire Tāmaki watershed). In urban

environments, most contaminants enter water bodies through stormwater and wastewater networks such as through sewage overflows, illegal connections, and leaky pipes and connections (MfE and Stats NZ, 2017). Nationally, the percentage of urban land cover has been found to be related to higher concentrations of nutrients and chlorophyll α in receiving estuaries (Dudley, *et al.,* 2020).

Water quality at Wairoa River has been variable over time ranging from 'good' to 'marginal' to 'fair'. The apparent decline in water quality since 2014-2016 is primarily associated with an abrupt increase in the frequency of exceedances of ammoniacal nitrogen associated with the change in laboratory, as well as increasing chlorophyll a and total oxidised nitrogen exceedances (Figure 3-17).

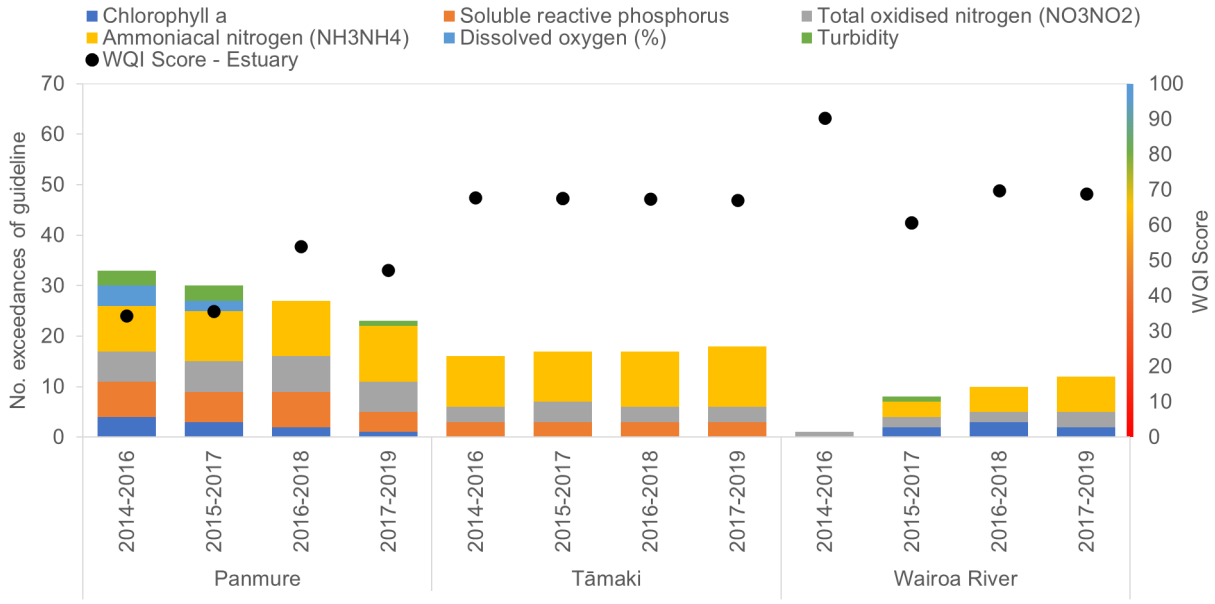

Figure 3-17: Variation in number of exceedances (<10x guideline value) over time for sites within Tāmaki Estuary and at Wairoa River based on rolling three year median values.

3.3.2.4 Manukau Harbour

Three sites in the northern part of the harbour (Māngere Bridge, Puketutu Point, Shag Point) were classed as having 'poor' water quality due to a high frequency of exceedances (<10 times the guideline values) of all nutrient parameters and chlorophyll α (Figure 3-19). Māngere Bridge and Puketutu Point also had instances of high magnitude exceedances (*greater* than 10 times the guideline values, not pictured). In the 2017-2019 period, there was one high magnitude exceedance for ammoniacal nitrogen[4] and three high magnitude exceedances for total oxidised nitrogen at Māngere Bridge. In the 2017-2019 period, there was one high magnitude exceedance for total oxidised nitrogen at Puketutu Point.

Land-use around the northern part of the harbour is urban, with a mix of residential, commercial, and industrial activities. This part of the harbour also has the largest of Auckland's wastewater treatment plants. Māngere Wastewater Treatment Plant services 76 per cent of Auckland's population (Watercare Services Ltd, 2018) and has consent to discharge treated wastewater to the northern part of the harbour until 2032. A large volume of treated water (approx. 350,000 m^3/day) is discharged on the outgoing tide. Puketutu Point is located adjacent to the expected zone of influence of the discharge, with Shag Point located further west (down the Wairopa channel), and Māngere Bridge is located to the north east (up the Wairopa channel).

Two sites in the southern part of the harbour (Weymouth, at the mouth of the Pahurehure Inlet, and Waiuku Town Basin, in the upper reaches of the Waiuku Inlet) also had 'poor' water quality due to a high frequency of exceedances (<10x guideline) of all nutrient parameters and chlorophyll α (Figure 3-19). Clarks Beach (at the mouth of the Waiuku Inlet) was classed as 'marginal' however all three sites had water quality that was poorer than expected given the salinity (and anticipated degree of mixing) at each site.

The Pahurehure and Waiuku inlets are the receiving environments for the Franklin area which has a long history of cultivation and livestock farming (Meijer, *et al*., 2006). There is a long-standing issue of elevated nitrate concentrations in surface and groundwater bodies in the Franklin area, associated with intensive horticultural production (Meijer, *et al.,* 2016). These inlets also receive inputs from highly urban areas on the northern side of the Pahurehure Inlet, and the small urban area of Waiuku town (including the Waiuku Wastewater Treatment Plant).

[4] It is noted that all concentrations of ammoniacal nitrogen were well below the ANZECC trigger value for total ammoniacal nitrogen (pH adjusted) in relation to chronic marine ammonia (NH_3) toxicity (ANZECC, 2000).

Water quality was classed as ‘fair’ at the more central harbour site (Grahams Beach), and at the Manukau Heads. These sites had a low to moderate frequency of exceedances for ammoniacal nitrogen, oxidised nitrogen and chlorophyll α (Figure 3-18).

Watercare and NIWA are developing a hydrodynamic nutrient model for the Manukau Harbour, and Auckland Council are working on sub-catchment scale water-quality model of the entire Auckland region. These two models will improve our understanding of the sources, loads, and transport of nutrients within the harbour. Further research is ongoing through the use of continuous nitrate sensors in ground and surface water in the Franklin area.

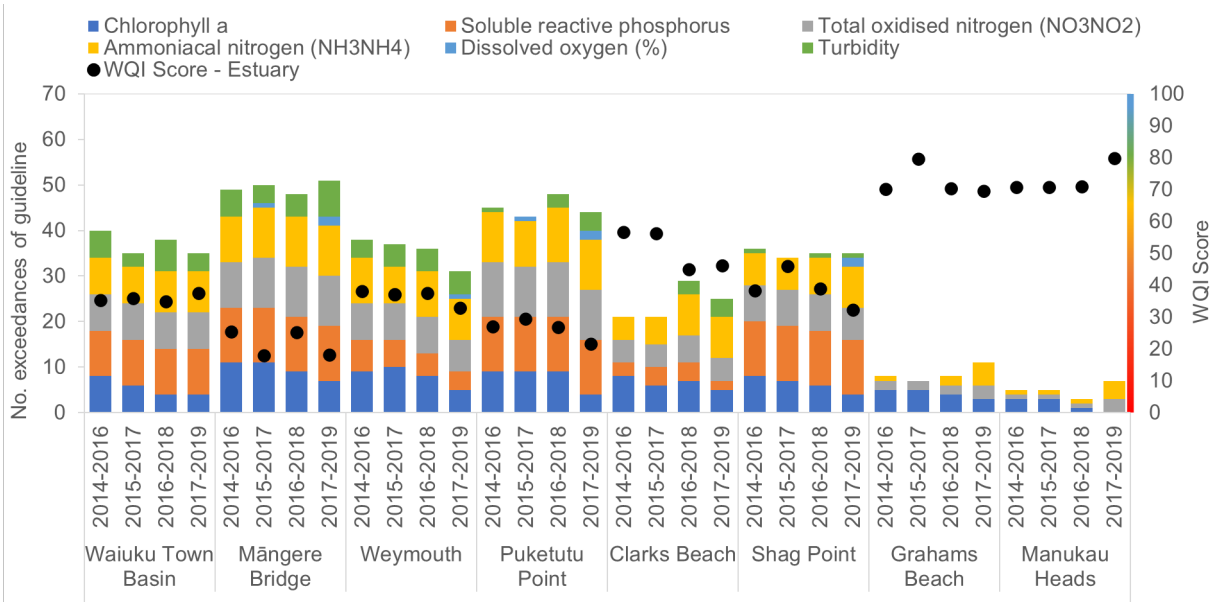

Figure 3-18:Variation in number of exceedances (<10x guideline value) over time for sites within the Manukau Harbour based on rolling three year median values.

3.3.2.5 Kaipara Harbour

In contrast to the Waitematā and Manukau Harbours, the Kaipara Harbour sites had no to minimal exceedances of soluble reactive phosphorus. The Kaipara Harbour sites had fewer exceedances of total oxidised nitrogen than the central Waitematā but a higher frequency of chlorophyll α exceedances. A high frequency of exceedances for ammoniacal nitrogen were consistent across the rolling time period suggesting that concentrations are chronically higher than the guideline within the Kaipara Harbour (Figure 3-19).

Kaipara River mouth had poorer water quality than expected given the median salinity at this site. This appears to be primarily driven by frequent exceedances of the turbidity guideline. The Kaipara and Kaukapakapa rivers are the main local source of sediment to the southern Kaipara Harbour. Dispersion patterns indicate this is generally deposited close to the source, and nitrogen and carbon signatures suggest the sediment input is predominantly from land based sources (Gibbs, *et al*., 2012; Green and Daigneault 2018).

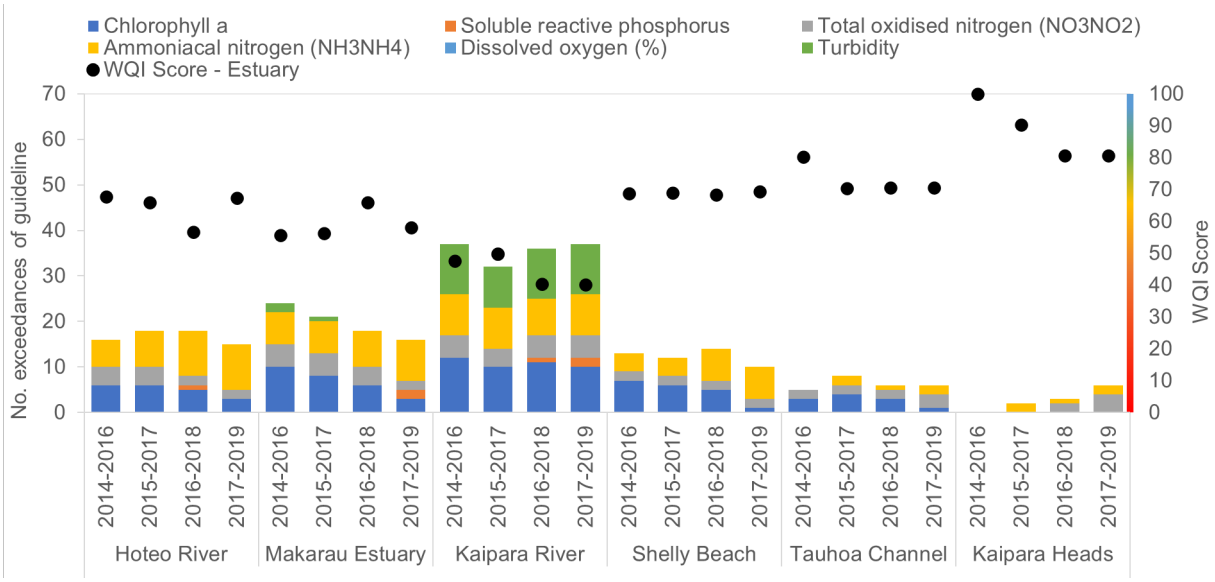

Figure 3-19: Variation in number of exceedances (<10x guideline value) over time for sites within the Kaipara Harbour based on rolling three year median values

4.0 Summary

Coastal water quality is influenced by numerous sources of contaminants including surface and groundwater that runs from the land to the coast, direct discharges from point sources, and activities in the coastal environment. Natural seasonal, and long-term climatic variability in nutrient cycling, sediment dispersal and primary productivity also alter the backdrop that the addition of these contaminants is viewed against.

These influences are moderated by complex estuarine processes including flushing – or how long freshwater stays in an estuary; and mixing – or how ocean water dilutes freshwater. The salinity of a site gives an indication of the extent of mixing between fresh, and ocean waters; where salinity is lower, the proportion of freshwater is higher. There is a spatial gradient in freshwater influence from tidal creeks, to estuaries, to the coast. Nationally, lower salinity has been demonstrated to coincide with higher concentrations of nutrients, and turbidity (Dudley, *et al*., 2020).

In 2019, the period of January to June had below normal rainfall (NIWA, 2019), and the regional annual water quality results are generally representative of median, to lower flow conditions (and associated freshwater contaminant discharge). Elevated concentrations of nutrients, turbidity, and suspended sediment were observed at several estuary and tidal creek sites when monitoring coincided with high river flows in the upstream catchments. Maximum surface water temperatures were also higher in 2019 which is consistent with the marine heatwave conditions reported in early 2019.

The water quality index provides an indication of the state of each site based on several key parameters, moderated across a three-year period. These guidelines are not regulatory triggers or thresholds and are only used to enable comparison between sites, and to identify potential directions for further investigation through identifying which water quality parameters are driving the water quality index results.

Large scale differences between tidal creek, estuarine, and open coastal environments are provided for by using separate water quality index guidelines. Approximately 50 per cent of the variation in water quality index scores between sites can still be explained by variation in salinity. This relationship can be used to identify sites that have better, or poorer, water quality than would be expected using salinity as the only predictive variable. Variation that is not explained by salinity may be driven by differences in total contaminant loads (volume of input and concentrations of contaminants from different land uses or direct discharges), and other physical variability between estuary types.

Three sites within the northern part of the Manukau Harbour were found to be an exception to this pattern, likely due to both direct, point source discharges, and diffuse

inputs. Water quality at these sites was ‘poor’ due to elevated nutrients, chlorophyll α (algae) and turbidity (clarity) compared to reference values. Sites located in the southern part of the Manukau Harbour also had ‘poor’ or poorer than expected water quality also due to elevated nutrients, chlorophyll α (algae) and turbidity (clarity). This is likely influenced by known nutrient issues in river and ground water in the contributing catchments.

Two other sites were found to have poorer water quality than expected: Panmure in the Tāmaki Estuary, and the Kaipara River mouth in the Kaipara Harbour. Panmure has improved water quality class from ‘poor’ to ‘marginal’ over the rolling time periods assessed, primarily due to improvements in dissolved oxygen saturation. However, Kaipara River has declined water quality class from ‘marginal’ to ‘poor’, primarily due to higher concentrations of soluble reactive phosphorus.

The water quality index can also be used to identify large scale changes in key parameters relative to reference values. Based on this index, only minor variation in water quality has been observed recently across the region (2014-2016 to 2017-2019); but it is important to note that the water quality index is most sensitive to changes where water quality is ‘good’, and has a lower sensitivity to detect changes in water quality class where water quality is ‘poor’. Long-term trend analysis is critical to identify where improvements to water quality are being made, and where water quality is degrading. Regional, long-term trend analysis is anticipated to be completed later in 2020.

5.0 References

ANZECC (2000). Australia and New Zealand guidelines for fresh and marine water quality, Volume 1, The guidelines. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Australian and New Zealand Governments (ANZ) (2018). Deriving guideline values for water quality. Australian and New Zealand guidelines for fresh and marine water quality. Canberra (ACT): ANZG and Australian state and territory governments https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive

APHA (2012). Standard methods for the examination of water and wastewater 22nd edition. American Public Health Association, American Waterworks Association, Water Environment Federation.

Auckland Council (2015). The Health of Auckland's Natural Environment in 2015: Te Oranga o te Taiao o Tāmaki Makaurau. Auckland Council, Auckland. 215 pages.

Ballantine, D. (2012). Developing a composite index to describe river condition in New Zealand. A composite river condition index for New Zealand: Prepared for the Ministry for the Environment by the National Institute of Water and Atmospheric Research, Hamilton. HAM2012-131.

Buckthought, L. E. (2019). State of the environment monitoring: river water quality annual report 2017. Auckland Council technical report, TR2019/010.

Canadian Council of Ministers of the Environment (2001). Canadian water quality guidelines for the protection of aquatic life: CCME water quality index 1.0, Technical Report. In *Canadian Environmental Quality Guidelines,* 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Dudley, B., Zeldis, J., Burge, O. (2017). New Zealand Coastal Water Quality Assessment. Prepared for the Ministry for the Environment by the National Institute of Water and Atmospheric Research, Christchurch.

Dudley, B., Jones-Todd, C. (2018). New Zealand Coastal Water Quality Assessment Update. Prepared for the Ministry for the Environment by the National Institute of Water and Atmospheric Research, Christchurch.

Dudley, B.D., Burge, O.R., Plew, D., Zeldis, J. (2020). Effects of agricultural and urban land cover on New Zealand's estuarine water quality. *New Zealand Journal of Marine and Freshwater Research.* DOI:10.1080/00288330.2020.1729819

Foley, M. (2018). Updating how the water quality index is calculated at marine water quality sites in the Auckland region. Auckland Council technical report, TR2018/027.

Foley, M.M., Walker, J., Vaughan, M., Stanley, C.L. and Hussain, E. (2018). Marine water quality state and trends in the Auckland region from 2007-2016. Auckland Council technical report, TR2018/015.

Gibbs, M., Olsen, G., Swales, A., He, S. (2012). Kaipara Harbour Sediment Tracing: Sediment dispersion across the harbour. Prepared for the Integrated Kaipara Harbour Management Group by the National Institute of Water and Atmospheric Research, Hamilton

Green, M., Daigneault, A. (2018). Kaipara Harbour Sediment Mitigation Study: Summary. Prepared for Northland Regional Council and Auckland Council by Streamlined Environmental, Report NRC170-1 (minor revision), Hamilton

Griffiths, R. (2016). Recommended Coastal Water Quality Standards for Northland. Northland Regional Council.

Hewitt, J E., Lohrer, A M and Townsend, M (2012). Health of estuarine soft-sediment habitats: continued testing and refinement of state of the environment indicators. Prepared by NIWA for Auckland Council. Auckland Council technical report, TR2012/012

Ingley, R. (2019). Coastal and estuarine water quality: 2018 annual data report. Auckland Council technical report, TR2019/027

Larned, S., Whitehead, A., Fraser, C., Snelder, T., Yang, J. (2018). Water quality state and trends in New Zealand rivers: Analyses of national data ending in 2017. Prepared for the Ministry for the Environment by the National Institute of Water and Atmospheric Research, Christchurch.

Law, CS, Bell, JJ, Bostock, HC, Cornwall, CE, Cummings, VJ, Currie, KI, Tracey, DM (2018). Ocean acidification in New Zealand waters: trends and impacts. New Zealand Journal of Marine and Freshwater Research, 52(2), 155-195. https://doi.org/10.1080/00288330.2017.1374983.

Lucci, G.M., Shephard, M., Vogeler, I (2013). An assessment of the implications of timing and soil nitrogen dynamics during and after summer drought on Waikato Allophanic soils. Proceedings of the New Zealand Grassland Association (75): 191-196

Meijer, K., Buckthought, L., Curran-Cournane, F., Martindale, M., Prebble, N and Long, L (2016). Elevated nitrate concentrations in Franklin surface and groundwater: a review. Auckland Council technical report, TR2016/015

Mills, G N (2016). Auckland marine sediment contaminant monitoring: data report for November 2015 sampling. Prepared by Diffuse Sources Ltd for Auckland Council. Auckland Council technical report, TR2016/020.

MfE and Stats NZ (2017). New Zealand's Environmental Reporting Series: *Our Freshwater 2017* Ministry for the Environment and Stats NZ ME 1305.

MfE and Stats NZ (2019). New Zealand's Environmental Reporting Series: *Our Marine Environment 2019* Ministry for the Environment and Stats NZ ME 1468.

NIWA (2019) Annual Climate Summary 2019 https://niwa.co.nz/climate/summaries/annual-climate-summary-2019 Accessed 07/04/2020.

NIWA (n.d.) *El Niño and La Niña*. National Institute of Water and Atmospheric Research

https://niwa.co.nz/climate/information-and-resources/elnino. Accessed 20/04/2020.

Perrie A. (2007). The state of water quality in selected rivers and streams in the Wellington region, 2003-2006. Greater Wellington Regional Council, Publication No. GW/EMI-T-07/218, Wellington.

Scarsbrook, Mike R., Chris G. McBride, Graham B. McBride, and Graham G. Bryers (2003). Effects of Climate Variability on Rivers: Consequences for Long Term Water Quality Analysis. Journal of the American Water Resources Association (JAWRA) 39(6):1435-1447

Scarsbrook, M. (2008). Saline Water Quality State and Trends in the Auckland region. Prepared for the Auckland Regional Council by the National Institute of Water and Atmospheric Research, Hamilton. ARC technical report, TR2008/005.

Zeldis, J., Bind, J., Roulston, H., Sykes, J., Walkington, M. (2013). Visualising nutrients and phytoplankton in the Hauraki Gulf Marine Park using GIS. Prepared for Waikato Regional Council by the National Institute of Water and Atmospheric Research, Hamilton. Waikato Regional Council technical report, 2013/50.

6.0 Acknowledgements

The Auckland Council coastal water quality monitoring programme has benefitted from the efforts of numerous people since its inception in 1987. During the 2019 sampling season, special thanks to Dimitri Colella, Luke Stanley, Hamish Allen, Martin Meyer, Sheldon Benito, and Nick Holwerda for organising and undertaking the sampling, to Vanitha Pradeep and Jade Khin for data management and quality assurance processes, to Holly Fleming and Natalie Gilligan for supporting data analysis, and to Kolt Johnson for hydrology support.

We acknowledge the efforts from other members of the environmental teams within RIMU for their help with undertaking the sampling.

Thanks to R J Hill Laboratories for their services in laboratory analysis of these samples.

Thank you to Melanie Tupe, Coral Grant (Auckland Council), and Janine Kamke (Waikato Regional Council) for discussion and providing comments that improved this report.

Appendix A Data tables

Table 6-1: Water Quality Index calculations based on rolling three year median values.
Blue = Excellent, Green = Good, Yellow = Fair, Orange = Marginal, Red = Poor.

Area	Site	WQI Score (2014-2016)*	WQI Score (2015-2017)	WQI Score (2016-2018)	WQI Score (2017-2019)
East Coast	Goat Island[1]	89.5	89.5	90.3	80.6
	Ti Point[1]	80.4	80.4	90.2	89.8
	Dawsons Creek	80.7	71	80.5	90.1
	Mahurangi Heads	100	100	90.3	90.2
	Orewa[1]	90.2	80.3	80.1	90.1
	Browns Bay[1]	78.8	79	69.7	68.8
Waitematā	Chelsea	80.6	80.3	80.5	79.7
	Whau Creek	70.2	79.4	69.2	79.0
	Henderson Creek	60.4	59.8	59.4	60.1
	Hobsonville	70.8	70.7	69.9	89.1
	Lucas Creek[2]	50.6	49.4	49	49.8
	Paremoremo Creek[2]	49.6	49.3	49.5	50.6
	Brighams Creek[2]	38.4	45.3	44.7	38.3
	Rangitopuni Creek[2]	35.2	43.7	43.6	36.7
Tāmaki Estuary	Tāmaki	67.9	67.5	67.4	67.1
	Panmure	34.5	35.7	53.9	47.2
Tāmaki Strait	Wairoa River	90.3	60.7	69.9	69.0
Manukau	Māngere Bridge	25.4	18	25.2	18.2
	Puketutu Point	27	29.5	26.8	21.6
	Weymouth	38.2	37	37.5	32.9
	Waiuku Town Basin	31.6	23.2	23.2	25.4
	Clarks Beach	56.6	56.3	45	46.2
	Grahams Beach	70.2	79.7	70.3	69.6
	Shag Point	38.4	46	38.9	32.2
	Manukau Heads	70.8	70.8	71	79.9
Kaipara	Kaipara Heads	100	90.3	80.6	80.6
	Tauhoa Channel	80.3	70.4	70.6	70.6
	Hoteo River	67.7	66	56.7	67.3
	Makarau Estuary	55.6	56.3	65.8	58.0
	Shelly Beach	68.8	68.9	68.4	69.4
	Kaipara River	47.5	49.8	40.3	40.2

** Revised from Ingley, 2018*

1 Open Coast guidelines

2 Tidal Creek guidelines

Table 6-2: Electrical conductivity (mS.cm-1) for data collected January 2019 to December 2019.

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	11	43.52	53.33	46.79	49.60	52.94
	Mahurangi Heads	11	47.13	53.45	49.38	51.19	52.69
	Browns Bay	11	49.43	53.48	50.61	51.13	52.30
	Orewa	11	48.72	53.46	51.10	51.42	52.74
	Ti Point	11	51.27	53.38	51.63	52.11	52.55
	Goat Island	11	51.74	53.33	51.84	52.25	53.24
Waitematā	**Rangitopuni Creek**	12	1.73	52.85	31.84	43.01	48.83
	Brighams Creek	12	10.90	53.13	34.99	43.39	49.12
	Lucas Creek	12	27.22	53.16	39.32	47.23	49.88
	Paremoremo Creek	12	28.38	53.14	40.87	47.53	50.37
	Henderson Creek	12	36.77	53.19	46.09	50.29	52.00
	Whau Creek	12	43.09	53.16	45.93	50.53	51.69
	Hobsonville	12	39.57	53.08	47.07	51.07	51.99
	Chelsea	12	49.14	53.33	49.56	51.31	52.34
Tāmaki	**Panmure**	10	41.82	53.18	45.56	51.27	52.25
	Tāmaki	10	46.15	53.73	47.58	51.40	52.55
	Wairoa River	11	43.15	53.15	47.21	49.50	51.55
Manukau	**Waiuku Town Basin**	12	34.13	51.60	42.69	47.93	49.00
	Māngere Bridge	12	41.37	51.97	45.23	47.96	49.73
	Weymouth	12	43.44	52.49	45.13	48.91	51.13
	Puketutu Point	12	43.00	51.15	46.20	48.27	50.05
	Shag Point	12	40.07	52.68	46.82	49.40	51.13
	Clarks Beach	12	45.79	52.69	48.33	50.22	51.21
	Manukau Heads	12	46.45	52.81	47.88	49.84	51.55
	Grahams Beach	12	47.58	52.71	50.00	50.55	52.08
Kaipara	**Hoteo River**	12	40.53	52.67	46.83	49.78	51.19
	Kaipara River	12	39.55	52.53	46.35	49.10	50.97
	Makarau Estuary	12	40.68	52.55	46.31	49.81	50.86
	Shelly Beach	12	42.80	52.44	47.16	49.07	51.23
	Tauhoa Channel	11	45.83	52.40	48.67	50.04	51.55
	Kaipara Heads	11	48.21	52.90	49.92	51.51	52.26

Table 6-3: Salinity (ppt) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	11	28.07	35.24	30.39	32.49	34.96
	Mahurangi Heads	11	30.66	35.34	32.27	33.66	34.78
	Browns Bay	11	32.39	35.35	33.25	33.55	34.47
	Orewa	11	31.87	35.34	33.55	33.76	34.83
	Ti Point	11	33.74	35.30	33.98	34.31	34.66
	Goat Island	11	34.01	35.26	34.12	34.43	35.20
Waitematā	**Rangitopuni Creek**	12	0.88	34.86	19.89	27.69	31.92
	Brighams Creek	12	6.22	35.06	22.04	27.91	32.12
	Lucas Creek	12	16.75	35.09	25.10	30.69	32.68
	Paremoremo Creek	12	17.54	35.07	26.15	30.95	33.05
	Henderson Creek	12	23.19	35.11	29.91	32.97	34.26
	Whau Creek	12	27.78	35.10	29.79	33.17	34.04
	Hobsonville	12	25.28	35.06	30.62	33.59	34.27
	Chelsea	12	32.15	35.25	32.42	33.74	34.54
Tāmaki	**Panmure**	10	26.83	35.13	29.56	33.74	34.45
	Tāmaki	10	29.92	35.54	31.03	33.82	34.67
	Wairoa River	11	27.76	35.11	30.77	32.36	33.93
Manukau	**Waiuku Town Basin**	12	21.46	33.97	27.47	31.26	31.99
	Māngere Bridge	12	26.53	34.24	29.27	31.27	32.59
	Weymouth	12	28.01	34.63	29.20	31.91	33.61
	Puketutu Point	12	27.69	33.65	30.01	31.49	32.80
	Clarks Beach	12	25.59	34.78	30.39	32.37	33.62
	Shag Point	12	29.69	34.78	31.54	32.94	33.69
	Grahams Beach	12	30.14	34.88	31.16	32.70	33.94
	Manukau Heads	12	30.95	34.81	32.77	33.20	34.34
Kaipara	**Hoteo River**	12	25.93	34.76	30.42	32.63	33.66
	Makarau Estuary	12	25.24	34.66	30.08	32.05	33.50
	Kaipara River	12	26.03	34.68	30.04	32.60	33.43
	Shelly Beach	12	27.55	34.59	30.63	32.10	33.71
	Tauhoa Channel	11	29.72	34.56	31.70	32.84	33.94
	Kaipara Heads	11	31.37	34.95	32.69	33.90	34.47

Table 6-4: pH (pH units) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	7.93	8.23	8.00	8.05	8.13
	Mahurangi Heads	12	8.04	8.24	8.07	8.13	8.20
	Browns Bay	12	7.99	8.29	8.05	8.15	8.21
	Orewa	12	8.02	8.30	8.11	8.16	8.23
	Ti Point	12	8.05	8.30	8.10	8.18	8.25
	Goat Island	12	7.98	8.38	8.04	8.18	8.29
Waitematā	**Rangitopuni Creek**	12	7.46	8.15	7.79	7.85	7.90
	Brighams Creek	12	7.32	8.14	7.83	7.89	7.96
	Lucas Creek	12	7.75	8.06	7.90	7.97	8.00
	Paremoremo Creek	12	7.78	8.08	7.92	7.97	8.02
	Henderson Creek	12	7.97	8.10	8.00	8.05	8.07
	Whau Creek	12	7.95	8.10	8.01	8.03	8.09
	Hobsonville	12	7.99	8.11	8.03	8.06	8.11
	Chelsea	12	7.94	8.15	8.00	8.08	8.10
Tāmaki	**Panmure**	10	7.73	8.10	7.91	7.97	8.02
	Tāmaki	10	7.92	8.17	8.00	8.08	8.10
	Wairoa River	12	7.96	8.31	8.06	8.12	8.22
Manukau	**Waiuku Town Basin**	12	7.90	8.14	8.00	8.02	8.09
	Māngere Bridge	12	7.97	8.35	8.11	8.16	8.20
	Weymouth	11	7.96	8.33	8.06	8.10	8.14
	Puketutu Point	12	8.03	8.37	8.07	8.15	8.20
	Clarks Beach	12	7.99	8.15	8.08	8.09	8.10
	Shag Point	12	8.04	8.25	8.11	8.18	8.21
	Grahams Beach	12	8.09	8.20	8.11	8.18	8.20
	Manukau Heads	12	8.11	8.22	8.15	8.18	8.20
Kaipara	**Hoteo River**	12	7.82	8.22	8.02	8.06	8.15
	Makarau Estuary	12	7.78	8.14	7.91	8.02	8.10
	Kaipara River	12	7.92	8.16	8.00	8.04	8.10
	Shelly Beach	12	8.00	8.20	8.00	8.08	8.15
	Tauhoa Channel	11	8.04	8.28	8.09	8.12	8.20
	Kaipara Heads	11	8.03	8.32	8.12	8.17	8.20

Table 6-5: Dissolved oxygen (% saturation) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	11	92.7	100.1	94.0	95.8	97.2
	Mahurangi Heads	11	93.9	101.0	96.4	98.2	99.8
	Browns Bay	11	92.9	106.0	95.8	96.7	101.8
	Orewa	11	96.4	103.8	99.4	100.0	101.1
	Ti Point	11	96.9	109.4	98.9	100.8	101.5
	Goat Island	11	93.8	105.2	98.9	100.2	103.3
Waitematā	Rangitopuni Creek	12	76.8	96.3	85.1	88.4	90.6
	Brighams Creek	12	79.5	95.4	87.3	90.3	92.0
	Lucas Creek	12	82.3	97.6	87.9	89.8	95.2
	Paremoremo Creek	12	82.7	96.1	89.5	91.4	93.0
	Henderson Creek	12	90.2	98.9	93.3	94.6	96.3
	Whau Creek	12	92.5	100.4	94.5	95.3	97.0
	Hobsonville	12	92.6	99.7	95.4	97.2	98.0
	Chelsea	12	93.2	99.8	94.3	96.4	99.2
Tāmaki	Panmure	10	93.7	99.6	95.1	96.2	97.9
	Tāmaki	10	93.8	102.5	96.1	97.7	99.6
	Wairoa River	11	92.1	101.5	96.1	97.4	98.6
Manukau	Waiuku Town Basin	12	88.6	106.2	91.2	96.0	100.5
	Māngere Bridge	11	90.8	120.5	95.4	98.7	105.6
	Weymouth	12	93.6	112.5	95.7	97.4	102.9
	Puketutu Point	11	95.5	123.3	97.6	101.1	105.8
	Clarks Beach	12	91.5	103.1	95.8	97.8	99.9
	Shag Point	12	96.1	113.2	98.3	102.4	110.0
	Grahams Beach	12	97.3	108.6	99.3	100.7	105.7
	Manukau Heads	12	98.2	108.2	100.2	102.7	104.7
Kaipara	Hoteo River	12	94.8	103.5	95.8	99.5	102.2
	Makarau Estuary	12	88.1	104.2	92.3	95.2	98.3
	Kaipara River	12	89.9	102.9	92.1	96.7	101.1
	Shelly Beach	12	94.3	103.3	95.8	100.2	101.3
	Tauhoa Channel	11	96.1	105.8	99.0	101.9	102.7
	Kaipara Heads	11	97.6	109.0	101.7	103.6	104.9

Table 6-6: Dissolved oxygen (ppm) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	11	6.7	8.4	6.9	7.4	8.2
	Mahurangi Heads	11	6.8	8.4	7.0	7.9	8.3
	Browns Bay	11	6.7	8.6	6.9	8.2	8.3
	Orewa	11	7.0	8.5	7.3	8.1	8.4
	Ti Point	11	7.1	8.4	7.4	8.1	8.2
	Goat Island	11	6.9	8.8	7.2	8.0	8.3
Waitematā	**Rangitopuni Creek**	12	5.3	9.1	6.2	7.2	8.5
	Brighams Creek	12	6.0	8.7	6.4	7.2	8.3
	Lucas Creek	12	5.8	8.4	6.5	7.4	8.0
	Paremoremo Creek	12	6.0	8.4	6.4	7.2	8.1
	Henderson Creek	12	6.5	9.1	6.7	7.4	8.1
	Whau Creek	12	6.4	8.7	6.9	7.5	8.2
	Hobsonville	12	6.7	8.7	7.0	7.5	8.2
	Chelsea	12	6.7	8.6	6.9	7.5	8.1
Tāmaki	**Panmure**	10	6.7	8.5	6.9	7.4	8.1
	Tāmaki	10	6.8	8.5	7.0	7.5	8.3
	Wairoa River	11	6.9	8.7	7.1	7.6	8.4
Manukau	**Waiuku Town Basin**	12	6.3	8.7	6.7	7.7	8.4
	Māngere Bridge	11	6.7	9.3	7.6	8.0	8.5
	Weymouth	12	6.8	8.6	7.3	7.7	8.4
	Puketutu Point	11	7.0	9.0	7.7	8.3	8.6
	Clarks Beach	12	6.7	8.6	7.0	7.5	8.5
	Shag Point	12	7.0	8.8	7.5	8.1	8.5
	Grahams Beach	12	7.0	8.9	7.5	7.9	8.5
	Manukau Heads	12	7.2	9.1	7.5	8.0	8.4
Kaipara	**Hoteo River**	12	6.8	8.9	7.0	7.6	8.5
	Makarau Estuary	12	6.5	8.6	6.6	7.6	8.3
	Kaipara River	12	6.3	8.8	6.7	7.5	8.4
	Shelly Beach	12	6.8	8.8	7.1	7.7	8.4
	Tauhoa Channel	11	7.1	8.5	7.3	7.7	8.4
	Kaipara Heads	11	7.5	8.6	7.8	8.1	8.5

Table 6-7: Summary table of temperature (°C) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	11	13.0	22.7	14.1	16.9	21.9
	Mahurangi Heads	11	13.6	22.4	14.1	17.7	21.2
	Browns Bay	11	13.4	23.0	13.9	17.6	20.6
	Orewa	11	13.7	22.9	14.3	17.2	20.9
	Ti Point	11	14.2	22.2	15.0	16.2	20.0
	Goat Island	11	14.2	21.6	15.5	15.8	20.1
Waitematā	Rangitopuni Creek	12	11.5	25.4	13.1	17.3	23.2
	Brighams Creek	12	11.9	26.7	13.2	17.3	23.4
	Lucas Creek	12	11.9	24.9	13.3	17.7	23.2
	Paremoremo Creek	12	12.5	25.5	13.4	17.7	22.9
	Henderson Creek	12	10.5	24.2	13.3	18.1	22.3
	Whau Creek	12	11.4	24.6	13.5	17.6	22.3
	Hobsonville	12	12.5	24.0	13.7	18.2	22.1
	Chelsea	12	13.1	23.8	14.2	18.1	21.7
Tāmaki	Panmure	10	13.3	22.4	15.0	18.0	21.9
	Tāmaki	10	13.3	22.4	14.9	18.4	21.7
	Wairoa River	11	12.9	23.0	13.8	17.2	21.6
Manukau	Waiuku Town Basin	12	12.5	25.1	13.9	20.0	22.1
	Māngere Bridge	12	10.9	25.3	13.4	18.9	22.3
	Weymouth	12	12.1	24.4	13.6	19.5	22.4
	Puketutu Point	12	12.2	24.6	13.8	19.2	22.3
	Clarks Beach	12	12.3	24.2	13.8	19.9	22.0
	Shag Point	12	12.1	24.9	14.0	19.5	22.4
	Grahams Beach	12	12.7	23.4	13.5	19.0	22.0
	Manukau Heads	12	13.3	21.9	14.1	17.6	20.9
Kaipara	Hoteo River	12	12.9	24.2	13.9	19.8	22.1
	Makarau Estuary	12	12.3	24.4	13.7	19.5	21.8
	Kaipara River	12	12.6	24.0	13.7	20.1	21.7
	Shelly Beach	12	12.7	23.8	13.8	19.2	22.3
	Tauhoa Channel	11	12.1	23.1	14.4	19.8	21.6
	Kaipara Heads	11	12.2	20.3	14.7	19.7	20.3

Table 6-8: Turbidity (NTU) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	1.5	13.7	2.6	3.7	6.3
	Mahurangi Heads	12	0.8	4.0	1.0	1.6	2.2
	Browns Bay	12	0.4	3.0	0.6	0.8	1.5
	Orewa	12	0.3	2.9	0.4	1.0	1.3
	Ti Point	12	0.2	2.4	0.3	0.5	0.6
	Goat Island	12	0.2	1.5	0.2	0.3	0.4
Waitematā	**Rangitopuni Creek**	12	2.2	32.0	4.0	8.4	12.0
	Brighams Creek	12	2.4	49.0	4.1	7.2	9.1
	Lucas Creek	12	1.8	17.6	3.7	7.1	14.0
	Paremoremo Creek	12	2.1	15.4	3.4	6.2	7.6
	Henderson Creek	12	1.9	10.9	3.3	5.0	7.4
	Whau Creek	12	1.7	7.9	3.6	4.1	6.4
	Hobsonville	12	1.8	7.9	2.4	3.8	6.0
	Chelsea	12	0.5	8.8	1.6	2.3	3.2
Tāmaki	**Panmure**	10	1.7	10.3	3.4	6.3	7.1
	Tāmaki	10	0.7	3.4	1.4	1.9	3.1
	Wairoa River	12	2.8	56.0	3.2	4.5	7.0
Manukau	**Waiuku Town Basin**	12	2.3	22.0	4.2	6.4	10.2
	Māngere Bridge	12	2.0	23.0	4.0	8.0	18.0
	Weymouth	12	2.7	19.1	3.4	5.8	7.0
	Puketutu Point	12	1.4	13.6	2.6	4.1	6.1
	Clarks Beach	12	3.0	17.4	3.5	4.7	7.6
	Shag Point	12	1.0	23.0	1.5	2.9	4.8
	Grahams Beach	12	1.0	9.6	1.6	2.4	3.7
	Manukau Heads	12	0.6	3.9	0.9	1.3	1.6
Kaipara	**Hoteo River**	12	2.2	7.5	3.4	3.7	6.4
	Makarau Estuary	12	8.0	30.0	9.8	13.4	20.5
	Kaipara River	12	2.0	18.2	3.6	5.7	8.0
	Shelly Beach	12	1.6	7.0	2.9	4.4	6.3
	Tauhoa Channel	11	0.8	3.9	1.1	1.8	2.4
	Kaipara Heads	11	0.6	1.9	0.8	1.2	1.5

Table 6-9: Suspended sediment (mg/L) for data collected from January 2019 to December 2019
** More than 50% of data were below the detection limit of 3 mg/L (1.5 mg/L used in analysis)*

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	5.0	65.0	6.5	9.0	30.8
	Mahurangi Heads	12	1.5	35.0	4.5	7.0	13.0
	Browns Bay	12	1.5	32.0	1.5	4.5	9.0
	Orewa	12	1.5	43.0	1.5	6.0	7.5
	Ti Point*	12	1.5	27.0	*NA*	*NA*	*NA*
	Goat Island*	12	1.5	26.0	*NA*	*NA*	*NA*
Waitematā	**Rangitopuni Creek**	12	4.0	29.0	6.8	13.5	22.5
	Brighams Creek	12	6.0	52.0	8.3	12.5	19.8
	Lucas Creek	12	7.0	27.0	9.3	16.0	19.8
	Paremoremo Creek	12	6.0	27.0	8.3	13.0	16.0
	Henderson Creek	12	5.0	21.0	7.0	11.5	17.0
	Whau Creek	12	5.0	17.0	8.3	10.0	14.5
	Hobsonville	12	4.0	15.0	6.5	10.5	12.8
	Chelsea	12	4.0	23.0	4.3	6.0	7.8
Tāmaki	**Panmure**	10	6.0	31.0	11.8	15.0	22.0
	Tāmaki	10	3.0	36.0	5.5	8.5	13.3
	Wairoa River	12	6.0	50.0	7.3	11.0	27.3
Manukau	**Waiuku Town Basin**	12	5.0	53.0	9.5	18.0	37.8
	Māngere Bridge	12	6.0	57.0	17.3	26.0	45.5
	Weymouth	12	7.0	48.0	11.3	16.0	37.8
	Puketutu Point	12	7.0	35.0	8.0	10.0	26.5
	Clarks Beach	12	9.0	60.0	12.0	17.5	34.3
	Shag Point	12	4.0	60.0	5.3	9.0	16.3
	Grahams Beach	12	6.0	42.0	6.3	10.0	26.3
	Manukau Heads	12	4.0	36.0	5.0	6.5	10.0
Kaipara	**Hoteo River**	12	4.0	46.0	7.3	12.0	20.8
	Makarau Estuary	12	11.0	86.0	19.0	32.5	55.3
	Kaipara River	12	5.0	47.0	8.3	14.5	25.0
	Shelly Beach	12	1.5	45.0	7.3	10.5	17.0
	Tauhoa Channel	11	1.5	40.0	5.0	6.0	13.0
	Kaipara Heads	11	1.5	34.0	3.0	5.0	7.0

Table 6-10: Chlorophyll α (mg/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	0.0005	0.0032	0.0009	0.0015	0.0027
	Mahurangi Heads	12	0.0004	0.0015	0.0005	0.0006	0.0010
	Browns Bay	12	0.0003	0.0012	0.0004	0.0007	0.0011
	Orewa	12	0.0001	0.0025	0.0002	0.0005	0.0012
	Ti Point	12	0.0001	0.0018	0.0003	0.0006	0.0012
	Goat Island	12	0.0001	0.0024	0.0004	0.0007	0.0010
Waitematā	**Rangitopuni Creek**	12	0.0005	0.0087	0.0008	0.0025	0.0075
	Brighams Creek	12	0.0005	0.0060	0.0009	0.0030	0.0050
	Lucas Creek	12	0.0004	0.0068	0.0012	0.0022	0.0035
	Paremoremo Creek	12	0.0003	0.0053	0.0012	0.0020	0.0045
	Henderson Creek	12	0.0004	0.0051	0.0009	0.0012	0.0023
	Whau Creek	12	0.0007	0.0029	0.0010	0.0014	0.0026
	Hobsonville	12	0.0007	0.0043	0.0009	0.0013	0.0027
	Chelsea	12	0.0006	0.0036	0.0008	0.0010	0.0018
Tāmaki	**Panmure**	10	0.0009	0.0077	0.0009	0.0017	0.0028
	Tāmaki	10	0.0002	0.0038	0.0007	0.0010	0.0014
	Wairoa River	12	0.0005	0.0071	0.0006	0.0019	0.0027
Manukau	**Waiuku Town Basin**	12	0.0005	0.0142	0.0009	0.0032	0.0100
	Māngere Bridge	12	0.0005	0.0126	0.0012	0.0047	0.0096
	Weymouth	12	0.0004	0.0089	0.0011	0.0018	0.0073
	Puketutu Point	12	0.0001	0.0094	0.0010	0.0014	0.0036
	Clarks Beach	12	0.0001	0.0054	0.0006	0.0018	0.0043
	Shag Point	12	0.0003	0.0075	0.0010	0.0017	0.0049
	Grahams Beach	12	0.0001	0.0044	0.0008	0.0018	0.0024
	Manukau Heads	12	0.0001	0.0025	0.0006	0.0012	0.0022
Kaipara	**Hoteo River**	12	0.0006	0.0046	0.0009	0.0020	0.0025
	Makarau Estuary	12	0.0009	0.0103	0.0030	0.0049	0.0085
	Kaipara River	12	0.0006	0.0044	0.0014	0.0023	0.0025
	Shelly Beach	12	0.0005	0.0040	0.0017	0.0021	0.0026
	Tauhoa Channel	11	0.0004	0.0032	0.0008	0.0008	0.0013
	Kaipara Heads	11	0.0002	0.0025	0.0005	0.0009	0.0013

Table 6-11: Nitrite (mg N/L) for data collected from January 2019 to December 2019

** More than 50% of data were below the detection limit of 0.001 mg/L (0.0005 mg/L used in analysis)*

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek***	12	0.0005	0.0022	*NA*	*NA*	*NA*
	Mahurangi Heads*	12	0.0005	0.0012	*NA*	*NA*	*NA*
	Browns Bay*	12	0.0005	0.0014	*NA*	*NA*	*NA*
	Orewa*	12	0.0005	0.0005	*NA*	*NA*	*NA*
	Ti Point*	12	0.0005	0.0066	*NA*	*NA*	*NA*
	Goat Island	12	0.0005	0.0060	0.0005	0.0009	0.0028
Waitematā	**Rangitopuni Creek**	12	0.0005	0.0040	0.0005	0.0014	0.0026
	Brighams Creek	12	0.0005	0.0040	0.0005	0.0014	0.0021
	Lucas Creek	12	0.0005	0.0026	0.0005	0.0010	0.0023
	Paremoremo Creek*	12	0.0005	0.0024	*NA*	*NA*	*NA*
	Henderson Creek*	12	0.0005	0.0021	*NA*	*NA*	*NA*
	Whau Creek*	12	0.0005	0.0018	*NA*	*NA*	*NA*
	Hobsonville*	12	0.0005	0.0018	*NA*	*NA*	*NA*
	Chelsea	12	0.0005	0.0025	0.0005	0.0008	0.0015
Tāmaki	**Panmure**	10	0.0005	0.0023	0.0005	0.0016	0.0020
	Tāmaki	10	0.0005	0.0020	0.0005	0.0011	0.0018
	Wairoa River*	12	0.0005	0.0025	*NA*	*NA*	*NA*
Manukau	**Waiuku Town Basin**	12	0.0005	0.0093	0.0008	0.0048	0.0085
	Māngere Bridge	12	0.0005	0.0350	0.0007	0.0110	0.0242
	Weymouth	12	0.0005	0.0132	0.0005	0.0029	0.0062
	Puketutu Point	12	0.0005	0.0480	0.0092	0.0149	0.0335
	Clarks Beach	12	0.0005	0.0090	0.0005	0.0031	0.0051
	Shag Point	12	0.0005	0.0200	0.0005	0.0022	0.0100
	Grahams Beach*	12	0.0005	0.0124	*NA*	*NA*	*NA*
	Manukau Heads	12	0.0005	0.0136	0.0005	0.0010	0.0047
Kaipara	**Hoteo River**	12	0.0005	0.0055	0.0005	0.0005	0.0023
	Makarau Estuary	12	0.0005	0.0077	0.0005	0.0023	0.0045
	Kaipara River	12	0.0005	0.0043	0.0005	0.0014	0.0037
	Shelly Beach	12	0.0005	0.0042	0.0005	0.0010	0.0024
	Tauhoa Channel*	11	0.0005	0.0040	*NA*	*NA*	*NA*
	Kaipara Heads*	11	0.0005	0.0046	*NA*	*NA*	*NA*

Table 6-12: Nitrate (mg N/L) for data collected from January 2019 to December 2019

** More than 50% of data were below the detection limit of 0.001 mg/L (0.0005 mg/L used in analysis)*

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	0.0005	0.1330	0.0005	0.0022	0.0180
	Mahurangi Heads*	12	0.0005	0.0340	*NA*	*NA*	*NA*
	Browns Bay	12	0.0005	0.0124	0.0005	0.0013	0.0036
	Orewa*	12	0.0005	0.0147	*NA*	*NA*	*NA*
	Ti Point	12	0.0005	0.0390	0.0005	0.0019	0.0308
	Goat Island	12	0.0005	0.0470	0.0005	0.0055	0.0405
Waitematā	**Rangitopuni Creek**	12	0.0005	0.2500	0.0032	0.0073	0.1030
	Brighams Creek	12	0.0005	0.2100	0.0007	0.0068	0.0633
	Lucas Creek	12	0.0005	0.1240	0.0005	0.0049	0.0527
	Paremoremo Creek	12	0.0005	0.0910	0.0005	0.0033	0.0398
	Henderson Creek	12	0.0005	0.0720	0.0005	0.0024	0.0287
	Whau Creek*	12	0.0005	0.0290	*NA*	*NA*	*NA*
	Hobsonville	12	0.0005	0.0420	0.0005	0.0030	0.0154
	Chelsea	12	0.0005	0.0350	0.0005	0.0053	0.0093
Tāmaki	**Panmure**	10	0.0005	0.0710	0.0013	0.0108	0.0470
	Tāmaki	10	0.0005	0.0300	0.0022	0.0128	0.0212
	Wairoa River*	12	0.0005	0.3200	*NA*	*NA*	*NA*
Manukau	**Waiuku Town Basin**	12	0.0005	0.4800	0.0011	0.0400	0.2330
	Māngere Bridge	12	0.0005	0.3600	0.0023	0.0845	0.2220
	Weymouth	12	0.0005	0.1770	0.0014	0.0150	0.1540
	Puketutu Point	12	0.0102	0.4900	0.0897	0.1730	0.2270
	Clarks Beach	12	0.0005	0.1050	0.0009	0.0115	0.0575
	Shag Point	12	0.0005	0.1090	0.0005	0.0168	0.0920
	Grahams Beach	12	0.0005	0.0480	0.0005	0.0009	0.0333
	Manukau Heads	12	0.0005	0.0400	0.0005	0.0027	0.0226
Kaipara	**Hoteo River**	12	0.0005	0.1390	0.0005	0.0016	0.0150
	Makarau Estuary	12	0.0005	0.0790	0.0005	0.0081	0.0295
	Kaipara River	12	0.0005	0.0480	0.0005	0.0055	0.0170
	Shelly Beach	12	0.0005	0.0510	0.0005	0.0017	0.0147
	Tauhoa Channel*	11	0.0005	0.0185	*NA*	*NA*	*NA*
	Kaipara Heads*	11	0.0005	0.0108	*NA*	*NA*	*NA*

Table 6-13: Ammoniacal N (mg N/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	**Dawsons Creek**	12	0.0090	0.0310	0.0100	0.0120	0.0140
	Mahurangi Heads	12	0.0070	0.0220	0.0113	0.0130	0.0160
	Browns Bay	12	0.0070	0.0220	0.0110	0.0125	0.0172
	Orewa	12	0.0080	0.0260	0.0102	0.0120	0.0138
	Ti Point	12	0.0080	0.0240	0.0133	0.0145	0.0170
	Goat Island	12	0.0080	0.0190	0.0102	0.0140	0.0170
Waitematā	**Rangitopuni Creek**	12	0.0060	0.0440	0.0150	0.0175	0.0238
	Brighams Creek	12	0.0070	0.0500	0.0102	0.0155	0.0225
	Lucas Creek	12	0.0090	0.0300	0.0140	0.0150	0.0220
	Paremoremo Creek	12	0.0100	0.0270	0.0123	0.0145	0.0205
	Henderson Creek	12	0.0090	0.0380	0.0120	0.0150	0.0232
	Whau Creek	12	0.0110	0.0260	0.0130	0.0165	0.0207
	Hobsonville	12	0.0100	0.0240	0.0123	0.0145	0.0187
	Chelsea	12	0.0090	0.0200	0.0125	0.0155	0.0175
Tāmaki	**Panmure**	10	0.0060	0.0280	0.0113	0.0215	0.0270
	Tāmaki	10	0.0070	0.0330	0.0147	0.0215	0.0255
	Wairoa River	12	0.0100	0.0470	0.0115	0.0140	0.0227
Manukau	**Waiuku Town Basin**	12	0.0080	0.0890	0.0123	0.0375	0.0760
	Māngere Bridge	12	0.0090	0.1370	0.0163	0.0585	0.1160
	Weymouth	12	0.0090	0.0490	0.0148	0.0365	0.0440
	Puketutu Point	12	0.0120	0.1990	0.0435	0.0705	0.1070
	Clarks Beach	12	0.0090	0.0500	0.0133	0.0200	0.0352
	Shag Point	12	0.0090	0.0490	0.0140	0.0315	0.0420
	Grahams Beach	12	0.0080	0.0390	0.0118	0.0145	0.0215
	Manukau Heads	12	0.0070	0.0300	0.0100	0.0145	0.0160
Kaipara	**Hoteo River**	12	0.0100	0.0600	0.0118	0.0155	0.0238
	Makarau Estuary	12	0.0080	0.1290	0.0115	0.0175	0.0475
	Kaipara River	12	0.0100	0.0870	0.0130	0.0250	0.0425
	Shelly Beach	12	0.0090	0.0420	0.0123	0.0150	0.0257
	Tauhoa Channel	11	0.0100	0.0190	0.0100	0.0130	0.0160
	Kaipara Heads	11	0.0090	0.0180	0.0110	0.0130	0.0150

Table 6-14: Total kjedahl nitrogen (mg N/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	12	0.151	0.280	0.156	0.165	0.213
	Mahurangi Heads	12	0.100	0.179	0.108	0.128	0.149
	Browns Bay	12	0.100	0.165	0.118	0.130	0.140
	Orewa	12	0.093	0.139	0.100	0.117	0.132
	Ti Point	12	0.083	0.135	0.093	0.121	0.127
	Goat Island	12	0.071	0.148	0.079	0.109	0.116
Waitematā	Rangitopuni Creek	12	0.230	0.710	0.245	0.285	0.338
	Brighams Creek	12	0.170	0.740	0.223	0.250	0.320
	Lucas Creek	12	0.156	0.410	0.203	0.220	0.255
	Paremoremo Creek	12	0.170	0.390	0.191	0.215	0.220
	Henderson Creek	12	0.147	0.280	0.160	0.180	0.196
	Whau Creek	12	0.145	0.230	0.166	0.186	0.199
	Hobsonville	12	0.121	0.240	0.137	0.165	0.176
	Chelsea	12	0.106	0.192	0.117	0.144	0.169
Tāmaki	Panmure	10	0.171	0.520	0.172	0.187	0.227
	Tāmaki	10	0.130	0.195	0.147	0.155	0.163
	Wairoa River	12	0.138	0.520	0.153	0.169	0.192
Manukau	Waiuku Town Basin	12	0.170	0.440	0.253	0.320	0.377
	Māngere Bridge	12	0.270	0.720	0.323	0.380	0.438
	Weymouth	12	0.182	0.310	0.210	0.260	0.287
	Puketutu Point	12	0.200	0.520	0.297	0.340	0.417
	Clarks Beach	12	0.151	0.260	0.178	0.212	0.248
	Shag Point	12	0.142	0.280	0.198	0.225	0.240
	Grahams Beach	12	0.120	0.240	0.149	0.167	0.189
	Manukau Heads	12	0.082	0.155	0.117	0.124	0.145
Kaipara	Hoteo River	12	0.166	0.360	0.179	0.203	0.218
	Makarau Estuary	12	0.178	0.420	0.233	0.305	0.330
	Kaipara River	12	0.170	0.310	0.192	0.240	0.275
	Shelly Beach	12	0.139	0.260	0.174	0.205	0.218
	Tauhoa Channel	11	0.103	0.194	0.123	0.146	0.177
	Kaipara Heads	11	0.069	0.144	0.099	0.114	0.141

Table 6-15: Total nitrogen (mg N/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	12	0.155	0.410	0.160	0.177	0.215
	Mahurangi Heads	12	0.100	0.182	0.109	0.131	0.153
	Browns Bay	12	0.100	0.171	0.120	0.132	0.149
	Orewa	12	0.093	0.139	0.101	0.120	0.134
	Ti Point	12	0.084	0.167	0.093	0.133	0.158
	Goat Island	12	0.071	0.159	0.084	0.129	0.155
Waitematā	Rangitopuni Creek	12	0.240	0.960	0.253	0.300	0.430
	Brighams Creek	12	0.190	0.960	0.230	0.265	0.375
	Lucas Creek	12	0.156	0.530	0.203	0.235	0.290
	Paremoremo Creek	12	0.180	0.480	0.196	0.215	0.268
	Henderson Creek	12	0.147	0.350	0.167	0.189	0.200
	Whau Creek	12	0.145	0.230	0.168	0.197	0.218
	Hobsonville	12	0.121	0.280	0.137	0.173	0.193
	Chelsea	12	0.113	0.200	0.133	0.150	0.182
Tāmaki	Panmure	10	0.173	0.520	0.188	0.215	0.280
	Tāmaki	10	0.133	0.199	0.158	0.172	0.187
	Wairoa River	12	0.138	0.840	0.155	0.178	0.206
Manukau	Waiuku Town Basin	12	0.270	0.920	0.292	0.380	0.522
	Māngere Bridge	12	0.270	0.960	0.400	0.480	0.717
	Weymouth	12	0.220	0.440	0.273	0.305	0.360
	Puketutu Point	12	0.210	0.890	0.468	0.545	0.667
	Clarks Beach	12	0.182	0.350	0.199	0.245	0.272
	Shag Point	12	0.153	0.380	0.230	0.260	0.300
	Grahams Beach	12	0.147	0.240	0.164	0.182	0.210
	Manukau Heads	12	0.083	0.178	0.119	0.147	0.169
Kaipara	Hoteo River	12	0.169	0.510	0.193	0.210	0.227
	Makarau Estuary	12	0.210	0.440	0.263	0.310	0.330
	Kaipara River	12	0.185	0.360	0.195	0.250	0.278
	Shelly Beach	12	0.143	0.320	0.182	0.205	0.227
	Tauhoa Channel	11	0.103	0.210	0.134	0.147	0.177
	Kaipara Heads	11	0.069	0.148	0.102	0.120	0.141

Table 6-16: Total phosphorus (mg P/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	12	0.016	0.048	0.020	0.024	0.030
	Mahurangi Heads	12	0.010	0.023	0.011	0.015	0.018
	Browns Bay	12	0.013	0.030	0.018	0.022	0.028
	Orewa	12	0.011	0.022	0.012	0.015	0.018
	Ti Point	12	0.008	0.017	0.010	0.014	0.017
	Goat Island	12	0.007	0.023	0.011	0.015	0.016
Waitematā	Rangitopuni Creek	12	0.024	0.097	0.029	0.034	0.051
	Brighams Creek	12	0.018	0.094	0.027	0.035	0.043
	Lucas Creek	12	0.023	0.050	0.028	0.034	0.040
	Paremoremo Creek	12	0.026	0.044	0.028	0.032	0.036
	Henderson Creek	12	0.025	0.034	0.027	0.029	0.030
	Whau Creek	12	0.022	0.031	0.026	0.028	0.028
	Hobsonville	12	0.023	0.031	0.026	0.027	0.028
	Chelsea	12	0.021	0.036	0.022	0.025	0.030
Tāmaki	Panmure	10	0.027	0.044	0.030	0.033	0.042
	Tāmaki	10	0.017	0.036	0.024	0.027	0.033
	Wairoa River	12	0.021	0.076	0.026	0.032	0.037
Manukau	Waiuku Town Basin	12	0.033	0.062	0.037	0.046	0.054
	Māngere Bridge	12	0.092	0.136	0.096	0.106	0.125
	Weymouth	24	0.030	0.136	0.040	0.073	0.108
	Puketutu Point	24	0.054	0.185	0.095	0.127	0.144
	Clarks Beach	12	0.015	0.042	0.025	0.029	0.037
	Shag Point	12	0.035	0.063	0.040	0.047	0.058
	Grahams Beach	12	0.020	0.035	0.023	0.025	0.030
	Manukau Heads	12	0.012	0.026	0.017	0.018	0.020
Kaipara	Hoteo River	12	0.015	0.032	0.022	0.027	0.030
	Makarau Estuary	12	0.026	0.072	0.034	0.048	0.054
	Kaipara River	12	0.019	0.046	0.025	0.032	0.035
	Shelly Beach	12	0.011	0.032	0.021	0.026	0.029
	Tauhoa Channel	11	0.008	0.024	0.013	0.018	0.019
	Kaipara Heads	11	0.004	0.025	0.012	0.012	0.015

Table 6-17: Soluble reactive phosphorus (mg P/L) for data collected from January 2019 to December 2019

Area	Site	Count	Min	Max	25th %ile	Median	75th %ile
East Coast	Dawsons Creek	12	0.003	0.022	0.007	0.009	0.011
	Mahurangi Heads	12	0.003	0.012	0.005	0.007	0.010
	Browns Bay	12	0.005	0.023	0.007	0.015	0.021
	Orewa	12	0.001	0.012	0.005	0.008	0.011
	Ti Point	12	0.001	0.010	0.004	0.006	0.009
	Goat Island	12	0.001	0.011	0.004	0.006	0.010
Waitematā	Rangitopuni Creek	12	0.012	0.026	0.014	0.019	0.023
	Brighams Creek	12	0.014	0.024	0.015	0.018	0.020
	Lucas Creek	12	0.012	0.020	0.015	0.016	0.019
	Paremoremo Creek	12	0.014	0.020	0.016	0.017	0.019
	Henderson Creek	12	0.011	0.021	0.013	0.016	0.017
	Whau Creek	12	0.010	0.020	0.013	0.016	0.017
	Hobsonville	12	0.010	0.021	0.013	0.016	0.018
	Chelsea	12	0.010	0.022	0.013	0.017	0.020
Tāmaki	Panmure	10	0.012	0.031	0.014	0.022	0.026
	Tāmaki	10	0.012	0.026	0.014	0.020	0.022
	Wairoa River	12	0.008	0.021	0.012	0.016	0.018
Manukau	Waiuku Town Basin	12	0.013	0.037	0.018	0.025	0.028
	Māngere Bridge	12	0.045	0.117	0.058	0.082	0.100
	Weymouth	12	0.005	0.027	0.015	0.019	0.023
	Puketutu Point	12	0.027	0.166	0.078	0.095	0.134
	Clarks Beach	12	0.003	0.023	0.008	0.014	0.018
	Shag Point	12	0.010	0.051	0.022	0.037	0.040
	Grahams Beach	12	0.001	0.018	0.007	0.012	0.015
	Manukau Heads	12	0.001	0.012	0.005	0.008	0.010
Kaipara	Hoteo River	12	0.005	0.020	0.011	0.014	0.018
	Makarau Estuary	12	0.005	0.037	0.013	0.020	0.029
	Kaipara River	12	0.008	0.029	0.011	0.017	0.023
	Shelly Beach	12	0.002	0.018	0.009	0.012	0.016
	Tauhoa Channel	11	0.002	0.010	0.006	0.007	0.008
	Kaipara Heads	11	0.002	0.006	0.003	0.004	0.005

Appendix B Physical-chemical parameters

Table 6-18: Summary of marine water quality parameters, detection limits, analytical methods and two sources of data collection

Parameter	Unit	Detection Limit	Method	Source
Dissolved oxygen	ppm	0.1	EXO2 Sonde (Xylem Analytics)	Field
Dissolved oxygen saturation	% sat	0.01	EXO2 Sonde (Xylem Analytics)	Field
Temperature	°C	0.01	EXO2 Sonde (Xylem Analytics)	Field
Conductivity	mS cm	0.01	EXO2 Sonde (Xylem Analytics)	Field
Salinity	ppt	0.2	EXO2 Sonde (Xylem Analytics)	Field
pH	pH units	0.01	EXO2 Sonde (Xylem Analytics)	Field
Total suspended solids	mg/L	3	APHA (2012) 2540 D	Lab
Turbidity	NTU	0.05	APHA (2012) 2130 B (modified)	Lab
Chlorophyll α	mg/L	0.0002	APHA (2012) 10200 H (modified)	Lab
Nitrate nitrogen (NO_3N)	mg/L	0.001	Calculation ((NO3N+NO2N) – NO2)	Lab
Nitrite nitrogen (NO_2 N)	mg/L	0.001	APHA (2012) 4500-NO2 I (modified)	Lab
Total oxidised nitrogen (NO2N + NO3N)	mg/L	0.001	APHA (2012) 4500-NO3 I (modified)	
Ammoniacal nitrogen (NH_4-N)	mg/L	0.005	APHA (2012) 4500-NH3 H (modified)	Lab
Total Kjedahl nitrogen (TKN)	mg N/L	0.01	Calculation: TN – (NO3N + NO2N)	Lab
Total nitrogen (TN)*	mg N/L	0.01	APHA (2012) 4500-N C & 4500 NO3 I (modified)	Lab
Soluble reactive phosphorus	mg/L	0.001	APHA (2012) 4500-P G	Lab
Total phosphorus*	mg/L	0.004	APHA (2012) 4500-P B & E (modified)	Lab

** Note: analysis methods have changed from July 2017*

Table 6-19: Summary of parameters assessed

Parameter	Description
Salinity and Chloride	Salinity and chloride levels decrease as the influence of freshwater increases. Consequently, levels tend to be lower and more variable in estuaries. Salinity levels affect the toxicity of some contaminants.
Temperature	Sea surface temperature is driven by seasonal changes in solar radiation and climatic conditions (e.g. El Niño or La Niña weather patterns). The level of deep-water upwelling, which is driven by offshore winds, has a large influence on interannual variations in sea surface temperature. Shallower tidal creek sites are typically more variable associated with the extent of freshwater inputs and warming of water from exposed intertidal sediments on the incoming tide. Temperature affects biological processes and moderates the toxicity of contaminants.
pH	pH is a measure of acidity/alkalinity. Seawater is highly buffered and tends to have relatively stable pH levels between pH 7.8 and 8.3. pH is more variable in upper tidal creek areas because of greater freshwater inputs. pH affects biological processes and moderates the toxicity of contaminants. The accuracy of pH measurement methods used here are not expected to detect recent changes in ocean acidification in NZ (annual change of 0.0013 +- 0.0003 (Law, *et al.,* 2018)).
Dissolved Oxygen (DO)	Oxygen is released by plants during photosynthesis and taken up by plants, animals and bacteria for respiration. Oxygen-scavenging compounds associated with organic matter also affect DO levels. High DO values can reflect high primary production while low DO values can reflect high rates of decomposition of organic matter. In extreme cases low DO levels due to respiration and/or chemical uptake can stress or kill aquatic organisms i.e. reduce the life-supporting capacity of the water. DO levels are diurnally and seasonally variable. DO is typically higher during the day and decreases at night. Colder waters also typically hold more oxygen than warmer water.
Turbidity Suspended solids	Turbidity is a measure of the degree to which light is scattered in water by particles, such as sediment and algae. Total suspended solids are a measure of the amount of suspended material in the water column such as plankton, non-living organic material, silica, clay and silt. Coastal turbidity and suspended solids are influenced by the runoff of terrestrial sediments and resuspension of marine sediments. High turbidity and suspended solids levels reduce the aesthetic quality of seawater and inhibit photosynthesis by algae and seaweeds. Terrestrial sediments may also cause estuary infilling, contribute to mangrove expansion, smother biota and habitats, clog gills and impede the feeding of aquatic organisms. These variables are usually closely correlated but can vary where tannins or other coloured compounds can increase turbidity but are not associated with solid particles. Estuarine waters are generally more turbid than marine or riverine waters due to flocculation, phytoplankton production and the resuspension of sediments. Land-derived sediment loads are dominated by stormflows, which are only occasionally intercepted by our routine monthly monitoring.

Parameter	Description
Nitrite (NO_2), Nitrate (NO_3) Total Oxidised Nitrogen (TON, NO_2 +NO_3-N) Ammoniacal Nitrogen (NH_3 + NH_4-N) Total Kjedahl Nitrogen (TKN) Total Nitrogen (TN)	Nitrite is the intermediate step in the conversion of ammonia to nitrate. It is usually short lived in the aquatic environment in the presence of oxygen and is typically an indication of a source of nitrogenous waste in the immediate vicinity of the sampling site. Ammonium-N and nitrate-nitrite-N are dissolved forms of nitrogen that are immediately available for phytoplankton and macroalgae uptake and growth, and are used as key indicators for that nutrient. Ammonia is reported as a combination of un-ionised ammonia (NH_3) and the ammonium ion (NH_4), at normal pH values ammonium (NH_4) dominates. Un-ionised ammonia is the more toxic form to aquatic life and is highly dependent on water temperature, salinity and pH. Total Kjedahl Nitrogen is the sum of ammoniacal nitrogen and organic nitrogen (amino acids and proteins). Total Nitrogen includes all forms of dissolved and particulate nitrogen (TKN + TON). Particulate nitrogen consists of plants and animals, and their remains, as well as ammonia adsorbed onto mineral particles. Particulate nitrogen can be found in suspension or in the sediment. Total Nitrogen is usually higher in upper estuarine sites where particulate matter is higher. Low dissolved forms of nitrogen compared to total nitrogen suggest that most of the nitrogen present is particulate matter such as plants, animals, and adsorbed to sediment particles. Organic nitrogen is usually removed in wastewater treatment as settled sludge and ammoniacal nitrogen is nitrified to nitrate. Nitrate is then removed through denitrification processes. High nutrient levels cause algal blooms, nuisance plant growth and eutrophication. High concentrations of some nutrients are also toxic to aquatic organisms (e.g. ammonia).
Soluble Reactive Phosphorus (SRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Soluble Reactive Phosphorus is immediately available for uptake and growth by phytoplankton and macroalgae. Particulate phosphorus consists of plants and animals and their remains, as well as phosphorus in minerals and adsorbed onto mineral surfaces. Total Phosphorus is a measure of both dissolved and particulate forms in a water sample. The adsorption and desorption of phosphate from mineral surfaces forms a buffering mechanism that regulates dissolved phosphate concentrations in rivers and estuaries. Sources of phosphorus include sewage and animal effluent, cleaning products, fertilisers, and industrial discharges. Earthworks and forestry can also release phosphorus through soil erosion. Wetland drainage can expose buried phosphorus.
Chlorophyll α	Chlorophyll α is used as an indicator of phytoplankton concentration which can indicate trophic status. Chlorophyll α levels vary naturally according to seasonal cycles and climatic conditions. However, excess nutrients caused by human activity can increase chlorophyll α levels to the point where water quality is affected. Effects include altered water colour and clarity, unpleasant odours, altered pH levels and lowered oxygen concentrations.

Appendix C Water Quality Index. Background and methodology

The communication of water quality data is often hampered by the volume of results and the complexity of the information. In this report, a water quality index developed by the Canadian Council of Ministers for the Environment (CCME) (2001) was applied to the marine water quality data collected by Auckland Council to enable improved understanding and communication of the work.

The CCME approach uses water quality results to produce four water quality indices, and these indices can be used to assign a water quality class to each monitoring site. The four indices are;

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

$$WQI = 100 - \left[\left\{\sqrt{(Scope^2 + Frequency^2 + Magnitude^2)}\right\} \div 1.732\right]$$

The divisor 1.732 normalises the resultant values to a range between 0 and 100, where 0 represents the “worst” water quality and 100 represents the “best” water quality.

The WQI is used by Auckland Council to assign a water quality class to each site using the following ranges;

- Between 95 and 100 = excellent water quality
- Between 80 and 94 = good water quality
- Between 65 and 79 = fair water quality
- Between 45 and 64 = marginal water quality
- Lower than 44 = poor water quality

Significant modifications were made to the application of the WQI methodology in 2018 including: alteration of parameters included, separate coastal and estuarine guidelines, setting a static period for reference site guidelines, and using a rolling three-year average value to calculate scores (Foley, 2018). Ingley (2019) applied an additional modification to use rolling *median*, not average values. This was adopted to resolve the effects of skew on average values caused by anomalous events within a single year and is consistent with ANZ recommendations and other regional councils' application of the method (ANZ 2018; Perrie, 2007; Griffiths, 2016). Consequently, previous WQI scores are not directly comparable.

Three year median values moderate major inter-annual variation due to natural environmental changes (e.g. heavy rainfall and storms) or human impacts such as development. Exceedances are consequently indicative of sustained high concentrations (chronic effects) at that site.

Identification of objectives

Before an index can be calculated, appropriate objectives need to be defined.

A set of static objectives were defined using 10 years of data from the least modified open coastal, and estuarine sites within the programme (2007-2016). The estuary reference sites, were selected from harbours with predominantly urban catchments but located in areas that are subject to greater mixing and dilution (i.e. best available) which consequently represent guidelines that are regionally achievable.

Both strong El Niño and La Niña conditions were experienced within between 2007-2016.

These data were also compared to the existing ANZECC default guidelines (ANZECC 2000). We used Auckland Council data when the 80th percentile exceeded ANZECC guidelines; and the ANZECC guidelines when they were more permissive than Auckland Council data. Defining guidelines based on sites in Auckland is reflective of local conditions and represent guidelines that are achievable.

Table 6-20: Reference sites used to calculate objectives

Open coast sites	**Estuary sites**
Goat Island	Chelsea
Ti Point	Hobsonville
	Manukau Heads

Parameters

A summary of all parameters monitored in the coastal and estuarine water quality programme is provided in Table 6-19. A subset of six of these parameters were selected for use within the Water Quality Index, Dissolved Oxygen, Turbidity, Total Oxidised Nitrogen, Soluble Reactive Phosphate, and Chlorophyll α.

These parameters were selected to minimise potential ‘double counting’ of closely related parameters (such as turbidity and total suspended solids) and are reflective of the most bioavailable form of nutrients which combined with chlorophyll α provides an indication of trophic status. Physical parameters such as temperature, pH and salinity are excluded from the water quality index however these provide important context to further interpret water quality state.

Appendix D Programme history

The coastal and estuarine water quality programme (also known as the marine or saline water quality programme) was designed to assess water quality on a regional scale over decadal time scales.

The marine water quality program commenced in 1987 with six sites in the Manukau harbour, following the Waitangi Tribunal decision on the Manukau Claim (Waitangi Tribunal 1985). Additional sites were added to the program in the early 1990s as water quality concerns across the region began to grow. Between 1991 and 1993, the programme was expanded to include sites in the Waitematā Harbour, Hauraki Gulf, and Kaipara Harbour. This network was the status quo until an Auckland Regional Council programme review in 2008 resulted in the addition of one site in the Manukau Harbour (Manukau Heads), two sites in Tāmaki Strait and six sites in the Kaipara. An additional site in Manukau Harbour (Waiuku Town Basin) was added in 2012 based on water quality concerns voiced by the Franklin Local Board.

In June 2014, the monitoring site “Confluence” in the Upper Waitematā Harbour was dropped from the sampling programme. In July 2015 a further four sites were dropped from the sampling programme due to budget constraints, Omokiti Beacon in the Kaipara, Turanga Estuary in the Tāmaki Strait, Rarawaru and Waimarie in the Upper Waitematā Harbour. These sites were selected following an analysis of the relevance of the data that each site was providing.

Parameters

Parameters used to determine the health of the region’s coastal waters were chosen because they are affected by human activities (e.g., land use and climate change) and can affect the growth and survival of marine plants and animals.

Faecal coliforms were removed from the list of laboratory tests in 2009 as enterococci were considered a more appropriate bacteria indicator in coastal marine waters. However, a decision was made to remove enterococci from sampling parameters in 2014 because an analysis of the results showed that the temporal variability requires a much more focused programme. For this information Auckland Council (along with Watercare, Surf Lifesaving Northern Region and Auckland Regional Public Health Service) runs Safeswim, a programme which provides water quality forecasts and up-to-date information on risks to your health and safety at 84 beaches and 8 freshwater locations around Auckland (www.safeswim.org.nz).

Total nitrogen (TN) was added to the list of chemical variables in 2009 as the current nitrogen species analysed allow for it to be calculated.

A review of the programme in 2005 resulted in the removal of the biological oxygen demand (BOD) parameter from the list of analytical laboratory tests. This was due to laboratory analysis consistently returning results at the detection limit (<2ppm) and no improved methodology was forthcoming or available.

The measurement of water clarity using a Secchi disk also ceased in July 2005 due to the difficulty of accurately estimating readings from the helicopter. Turbidity (measured in NTU) was deemed to be useful approximate parameter instead.

Laboratory analysis

The service provider for laboratory analysis changed in July 2017 from Watercare Services Ltd to Hill Laboratories. This change over coincided with some minor changes to analytical methodologies, and detection limits for selected parameters.

Sampling equipment

In November 2008, a hand-held multi-parameter water probe was introduced to the programme. The hand-held probe (YSI 556 MPS) was able to take in situ measures of salinity, conductivity, temperature and two dissolved oxygen readings (% saturation and concentration recorded in mg./L^{-1}). Previously, these parameters were measured in the lab by WLS. In December 2014, the YSI 556 MPS multi-parameter meter was upgraded to the EXO 2 multi-parameter sonde (Xylem Analytics).

Find out more: phone 09 301 0101, email rimu@aucklandcouncil.govt.nz or visit aucklandcouncil.govt.nz **and knowledgeauckland.org.nz**

Auckland Council
Te Kaunihera o Tāmaki Makaurau