Coastal and Estuarine Water Quality in Tāmaki Makaurau / Auckland: 2020 Annual Data Report

R Ingley, J Groom

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Name: Dr Jonathan Benge

Position: Head of Research, Evaluation and Monitoring (RIMU)

Name: Sietse Bouma

Position: Manager, Water Quality (RIMU)

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Auckland Harbour Bridge Waitematā Harbour Photograph by N. Gilligan (RIMU)
Taihiki River facing towards the Waiuku Inlet Manukau Harbour Photograph by N. Gilligan (RIMU)

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). 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, including the Tāmaki Estuary, and Mahurangi Harbour.

This annual report summarises the results for 16 water quality variables collected monthly during 2020. These include measures of nutrient enrichment, sediment and water clarity, and other physical variables. This programme does not include indicators of faecal pollution which is managed through Safeswim. 2020 was the driest year in Auckland on record and these annual water quality results are therefore representative of lower river flow conditions (and associated freshwater discharge to the coast).

This annual report provides an overview of the state of water quality using a regional Water Quality Index. The index compares values recorded over the period of 2018-2020 to regional guidelines for six core parameters. Scores range from zero (worst) to one hundred (best) and are divided into five classes from 'poor' to 'excellent'.

Nearly 60 per cent of sites assessed had 'good' to 'fair' water quality. Water quality class generally follows a spatial gradient in freshwater influence from 'poor' in the upper tidal creeks to 'good' at harbour mouths and along the coast.

- All sites along the East Coast and within the Mahurangi Harbour were within the 'good' water quality class except for Browns Bay which was 'fair'.
- Water quality in the Waitematā Harbour ranged from 'poor' in the upper tidal creeks, to 'fair' along the main channel from Hobsonville towards the Harbour Bridge.
- Water quality improved from the mid reaches of Tāmaki Estuary towards the lower channel near Half Moon Bay marina from 'marginal' to 'fair'.
- Water quality was classed as 'poor' at five of the eight monitored sites within the Manukau Harbour and improved to 'good' at the harbour mouth. Water quality at these five sites was 'poor' due to elevated nutrients, chlorophyll a (algae) and turbidity (suspended particles affecting water clarity) compared to regional reference values.
- Water quality ranged from 'poor' at the southern end of the Kaipara Harbour near the Kaipara River mouth and improved to 'fair' at Shelly Beach up the south Kaipara channel. Water quality also improved from 'fair' to 'good' along the Tauhoa Channel from the Hoteo River towards the mouth of the harbour.

Changes in water quality index scores over time can provide an indication of large-scale changes in water quality. The regional distribution of water quality index class has been largely consistent over the past four assessment periods considered here (2014-2016 to 2018-2020). Most site-specific changes in index class over this time frame were considered likely to be associated with analytical and sampling variability, and climatic variation. Long-term trend analysis was recently completed for the 2010 to 2019 period and this previous report should be referred to for further information on changing water quality over time (Ingley, 2021).

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1 Introduction

The marine environment in the Auckland region/Tāmaki Makarau 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, point source discharges directly to the coast, and activities undertaken in the coastal environment. These processes are influenced by land-use and population growth. Land-use outside of the Auckland region also impacts coastal water quality, particularly in the Hauraki Gulf, and Kaipara Harbour. Coastal water quality also fluctuates naturally due to changes in ocean hydrodynamics, seasonal and climatic variation.

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 passed down from previous generations). The results of the coastal and estuarine water quality monitoring programme can be added to matauranga Māori 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 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.

Auckland Council's coastal and estuarine water quality monitoring programme focuses on nutrient and water clarity parameters that can be altered by changes in land-use, location of point source discharges direct to the coast, land erosion and activities in the coastal environment. Other contaminants associated with urban land-use and stormwater contamination, such as metals, are monitored in Auckland Council's river water quality (Ingley, 2021b) and estuarine sediment and ecology monitoring programmes (Mills and Allen, 2021; Drylie, 2021) and are not assessed here.

The purpose of this report is to communicate the state of our coastal and estuarine water quality based on the council's coastal and estuarine water quality monitoring programme for 2020. 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.

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. Trend analysis is undertaken on a five-yearly basis and was last presented in 2021 for the 10-year period of 2010 to 2019 (Ingley 2021). Trend analysis is not undertaken in this annual report.

1.1 Programme objectives

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.

1.2 Supporting reports

This is the 31st data report since the inception of the coastal water quality monitoring programme in 1987. Prior to 2000, the rivers, streams and lakes, and coastal water quality monitoring results were presented in combined reports.

Previous annual data reports and supplementary data files relating to this report can be obtained from Auckland Council's Knowledge Auckland website https://www.knowledgeauckland.org.nz/natural-environment

For further enquiries and data supply, please email environmentaldata@aucklandcouncil.govt.nz.

For the most recent comprehensive trend analysis, please refer to *Coastal and estuarine water quality state and trends in Tāmaki Makaurau / Auckland 2010-2019*, (Ingley, 2021).

2 Methods

2.1 Programme design

Auckland Council collects coastal and estuarine surface water quality samples monthly 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, and Hauraki Gulf sites and 2.5 to 4 hours after high tide for the Manukau Harbour. Sampling within the Waitematā Harbour is taken at approximately one hour before high tide to two hours after high tide. 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 illustrated in Figure 2-1.

Each monitoring site was selected to provide information on,

- A range of exposure levels including open coast, harbours, large estuaries, and tidal creeks[1].
- The three main harbours and large estuaries.
- A variety of contributing catchment land uses, ranging from urban to rural[2].

Refer to Appendix 1 for a summary of site details.

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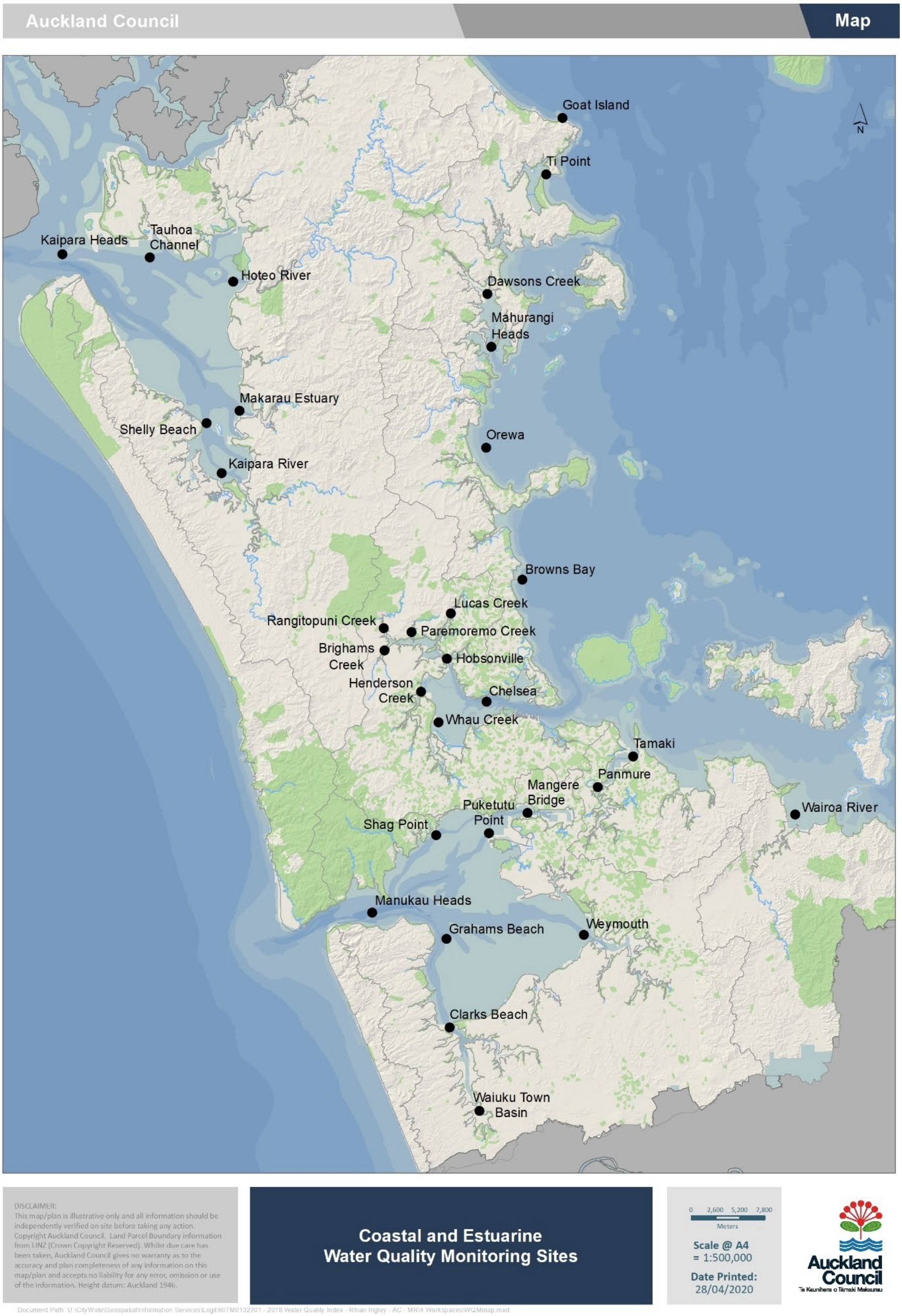
[1] For the purposes of this assessment, 'tidal creek' monitoring sites are those located in narrow channels upstream of the 'mouth' or confluence with the main estuary or harbour body and where median salinity over 2007-2016 was <30 ppt (polyhaline).

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



Coastal and Estuarine Water Quality Monitoring Sites

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

2.2.1 Tāmaki Estuary site changes

Two sites are monitored within the Tāmaki Estuary. One site is located in the upper estuary (Panmure) and one site was located in the lower estuary at Half Moon Bay Marina referred to as 'Tāmaki' in previous reports.

The construction of the new North Pier at Half Moon Bay Marina enclosed the marina monitoring site within new breakwaters (Figure 2-2). Active construction was observed between April to December 2020. The newly enclosed site was not considered to be adequately representative of the main channel of Tāmaki Estuary. Monitoring at an alternate site located at the end of the Half Moon Bay ferry terminal commenced in July 2019 (Figure 2-2) and dual analysis at both sites was undertaken for a period of 18 months. Subsequent analysis presented in this 2020 annual data report are focused on the new ferry terminal site referred to as 'Tāmaki'.

The water quality index assessment requires a minimum of three years of data (see section 2.5.1) and is therefore calculated from information from both the marina and ferry terminal locations.

Figure 2-2: Aerial photograph of Tāmaki Estuary Half Moon Bay (cred: N. Gilligan, RIMU). Original site (yellow asterisk) enclosed by the marina extension, and the alternate ferry terminal site (orange asterisk).

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 including measures of physical parameters (e.g. temperature, salinity), nutrients (dissolved and total nitrogen and phosphorus), suspended solids and turbidity, chlorophyll a, and dissolved oxygen. A summary of all parameters monitored is provided in Table B-2 in Appendix 2.

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 2). At each site, water samples were collected from the surface (approx. top 0.3m) by lowering two 1 litre plastic bottles into the water or lowering a Van dorn sampler into the water and subsequently filling the bottles.

All field measurements collected in 2020 were consistent with equipment accuracy specifications and were operated in accordance with in-house procedures and calibration requirements (see 2). 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). The finalised monitoring standard was released in February 2020 (NEMS, 2020).

Samples were analysed under contract by RJ Hill Laboratories Ltd (Hills), an IANZ accredited laboratory. Analytical methods follow the “Standard Methods for the Examination of Water and Wastewater” 22nd Edition (APHA, 2017). 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 specialised water quality database, KiWQM (Kisters Pty Ltd).

2.3.1 2020 COVID-19 impacts on monitoring

Water quality monitoring was suspended during Covid 19 Alert Level 4 lock down conditions. Water quality monitoring able to be undertaken from land or via boat was resumed during Level 3 conditions. Water quality monitoring undertaken via helicopter was resumed during Level 2 conditions. Consequently no samples were collected within the Waitematā Harbour in March, and no samples were collected for the East Coast, Kaipara Harbour, or Manukau Harbour in April 2020.

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, that have been aligned where possible with the NEMS quality coding framework.

Data collected for each variable were analysed for each site and initially compared to data previously collected over a ten-year period. Historical data were 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 inconsistencies or comment as appropriate. Prior to any analysis, data points that were assigned a ‘poor’ quality assurance code were removed from the dataset.

2.5 Data analysis

Descriptive statistics for the 2020 calendar year are presented as box plots which show variation in the data. Box plots were produced using the R software package, using the default percentile functions. The boxes represent the inter-quartile range (25th and 75th percentiles) and the whiskers extend to the maximum, or minimum value within 1.5 times the inter-quartile range. Values beyond that range are plotted as outliers. The median is shown as a line within each box.

The y-axis of some box plots is limited to enable the presentation of the range in data between sites, and the whiskers and outlier values are not all displayed.

Refer to the summary statistics provided in supplementary data files. Percentiles were calculated using R software standard percentile methods.

2.5.1 Water Quality Index

A Water Quality Index (WQI) is used to simplify how we communicate the state of water quality at each site by incorporating multiple factors into a single score and overall water quality class (Table 2-1).

The WQI 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 three main sources, the 80th percentile of 10 years of data (2007-2016) at reference sites within the Auckland region, Australia and New Zealand default guidelines (ANZECC 2000), or Northland Regional Council tidal creek guidelines (Table 2-2). Separate guidelines are used for open coast, estuarine sites, and tidal creek sites (Foley, 2018; Ingley, 2020). 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.

Monthly median values over a three-year period (2018 to 2020) were used to calculate the 2020 WQI score. See Appendix 4 for further detail on Auckland Council’s application of the CCME WQI methodology.

Table 2-1: 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 2-2: 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 a (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 ANZECC 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

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 programme inception as new technology has become more affordable, instrument sensitivity has improved, and the programme objectives modified. Refer to Appendix 5 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 2020 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 (see Ingley, 2021 for further information).
- Total nitrogen, where a series of step increases has been observed dating to January 2016 and July 2017.
- Chlorophyll a, 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 Results and Discussion

3.1 Annual data summary

Sites within the coastal and estuarine water quality programme are representative 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 3-1). 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. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity.

Box plots in Figure 3-1 to Figure 3-6 describe the distribution of concentrations of each water quality parameter per site within the 2020 calendar year. Refer to the supplementary data files for the numerical summary statistics depicted in these plots.

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.

Some notable events were recorded in 2020 including:

- Puketutu Point – high[3] dissolved reactive phosphorus and total phosphorus concentrations were recorded at this location in January. This occurred during low rainfall, drought conditions (see section 4) and was localised. There was no indication of higher weekly discharge of total or soluble phosphorus from the nearby outfall for the Māngere Wastewater Treatment Plant coinciding with this sample (Watercare, pers. comm.).
- Most sites across the Kaipara, Manukau, Waitematā, and Mahurangi Harbours had higher[3] salinity in February and/or March 2020 which may be associated with low freshwater inputs and severe meteorological drought conditions (see section 4).
- A storm and reported tornados occurred on the 25th-27th of June 2020 coinciding with very high river flows (highest two percent of flows) across the region. This influenced the East Coast, and West Coast sampling runs that occurred on the 25th of June and the 7th of July, respectively.

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[3] G*reater than the 98th percentile recorded over the preceding 10 years.*

  - Browns Bay – high[4] turbidity, and total oxidised nitrogen and total nitrogen concentrations.
  - Wairoa River – high[4] total oxidised nitrogen and total nitrogen concentrations.
  - Kaipara Harbour – moderate flows persisted over several days following the June storm prior to the July west coast sampling. High[4] total oxidised nitrogen levels were observed across the Kaipara Harbour (at Kaipara River, Hoteo River, and the Tauhoa Channel). Total suspended solids were also elevated in the outer harbour in July at Tauhoa Channel and the Kaipara Heads, though turbidity remained low. This was followed by high chlorophyll a levels in August at the Tauhoa Channel.
- Henderson Creek – elevated[4] turbidity was observed in October which was not associated with a recent rain event or high winds.
- East Coast – high[4] total suspended solids were recorded at several sites (Orewa, Browns Bay, and Goat Island) in December though turbidity remained low.

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[4] G*reater than the 98th percentile recorded over the preceding 10 years.*

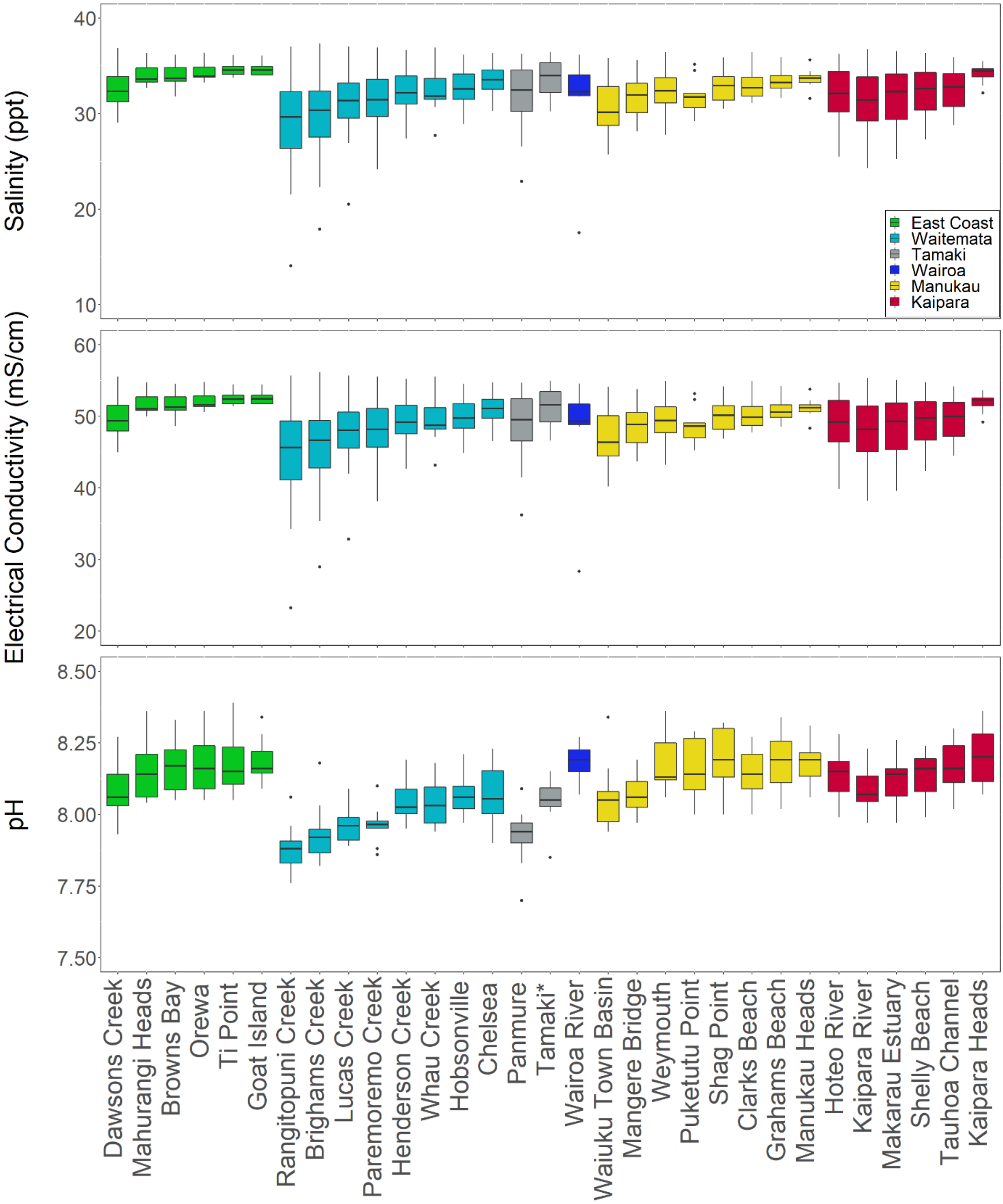

Figure 3-1: Variation in salinity, conductivity, and pH for coastal water quality data collected from January to December 2020. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

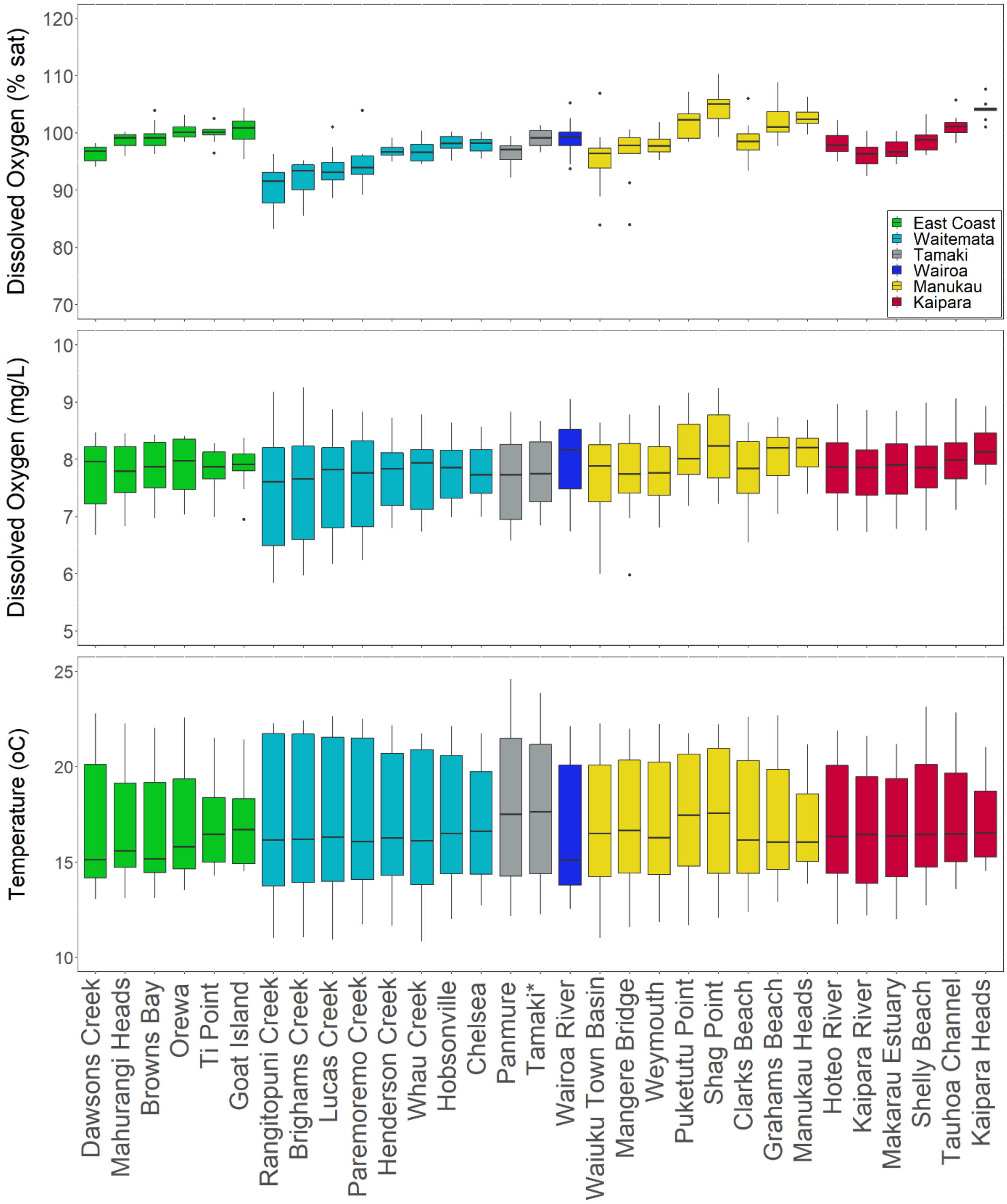

Figure 3-2: Variation in two indices of dissolved oxygen (% saturation and mg/L) and sea surface temperature for coastal water quality data collected from January to December 2020. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

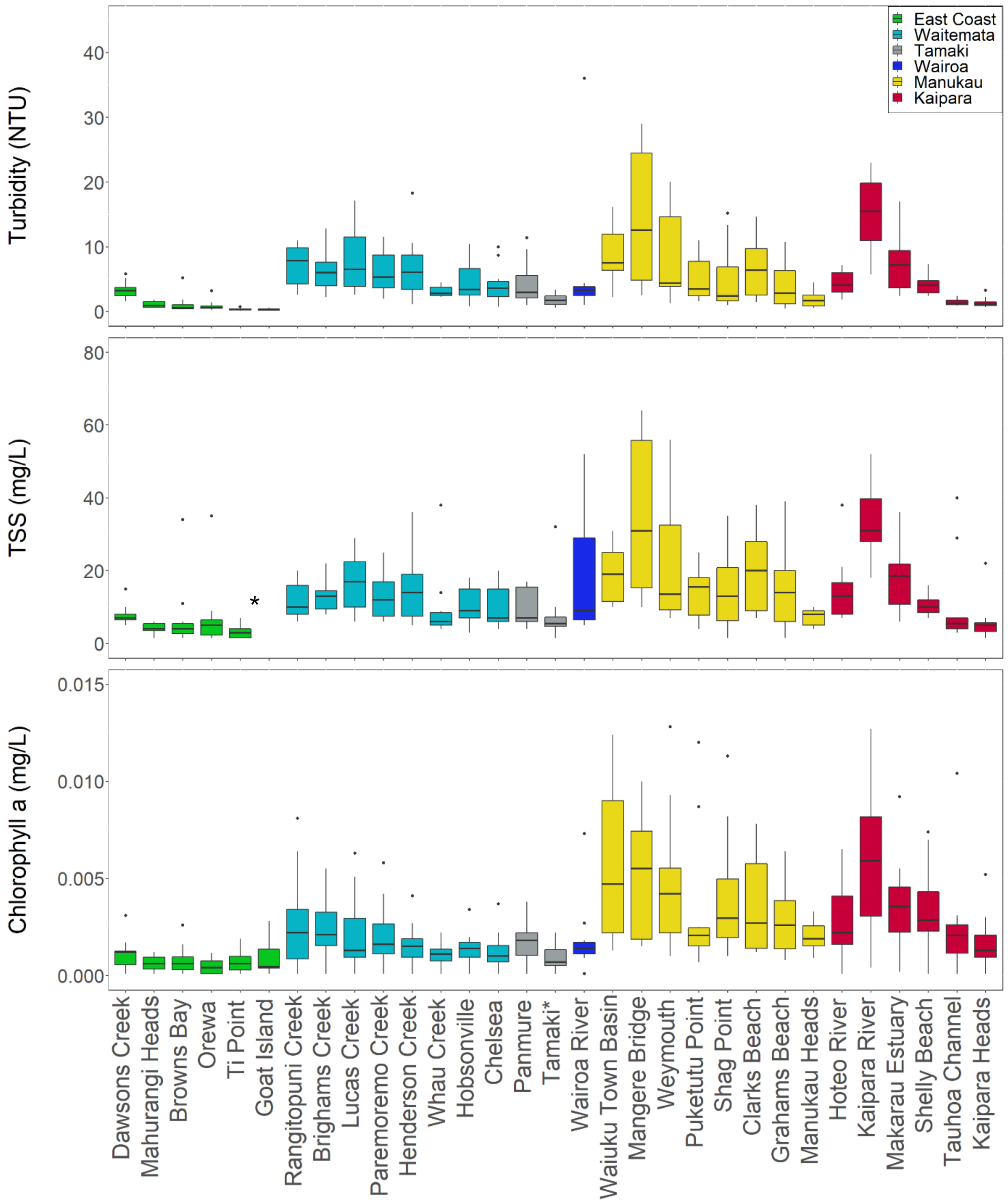

Figure 3-3: Variation in turbidity, total suspended sediment, and chlorophyll a for coastal water quality data collected from January to December 2020. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

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* = >50 per cent of values below laboratory detection limit
One outlier value for chlorophyll a >0.015 mg/L is not displayed (0.02 mg/L at Māngere Bridge).

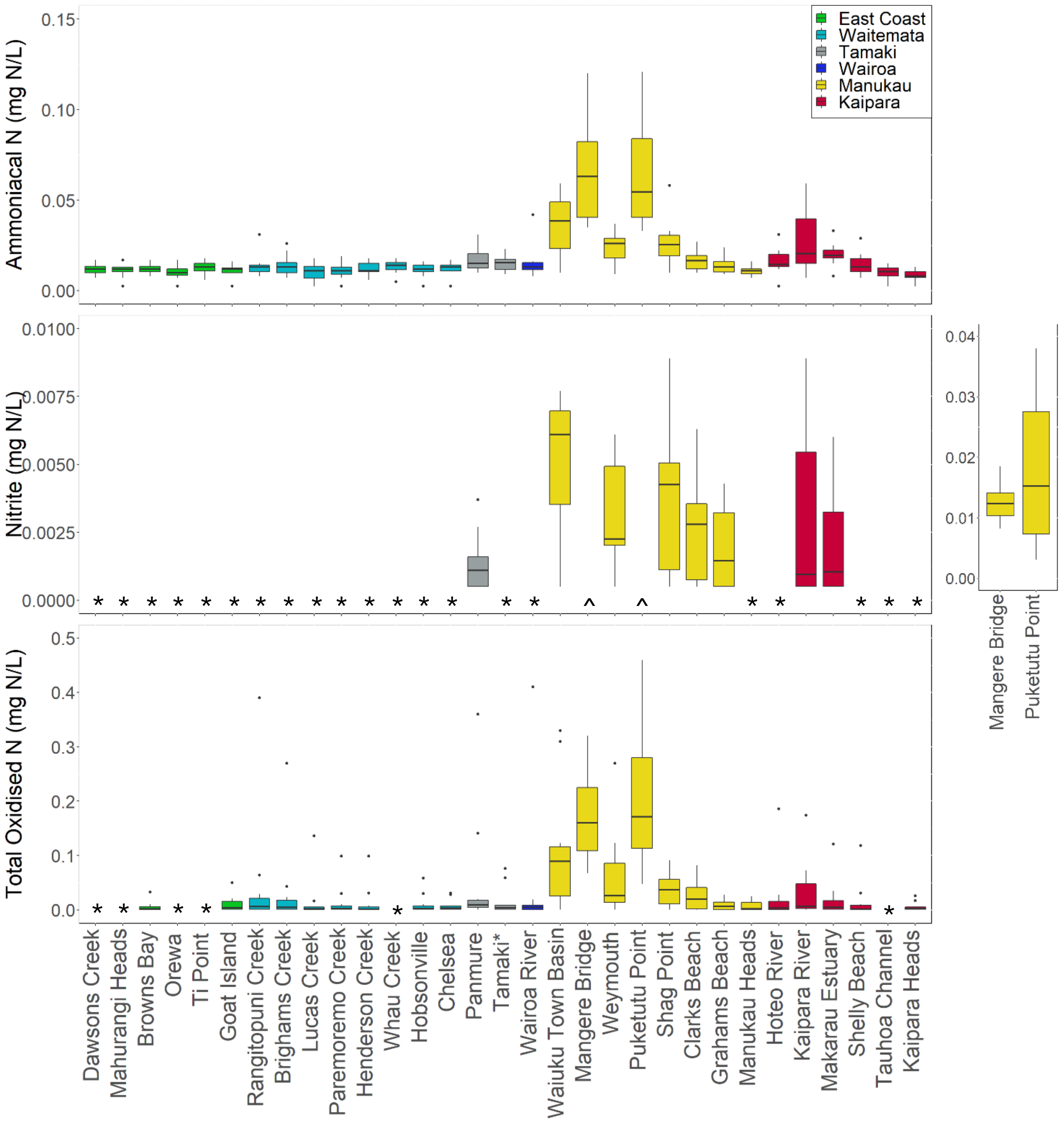

Figure 3-4: Variation in ammoniacal N, nitrite N, and total oxidised N (nitrite+nitrate) for coastal water quality data collected from January to December 2020.Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

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^ = see inset

* = >50 per cent of values below laboratory detection limit.

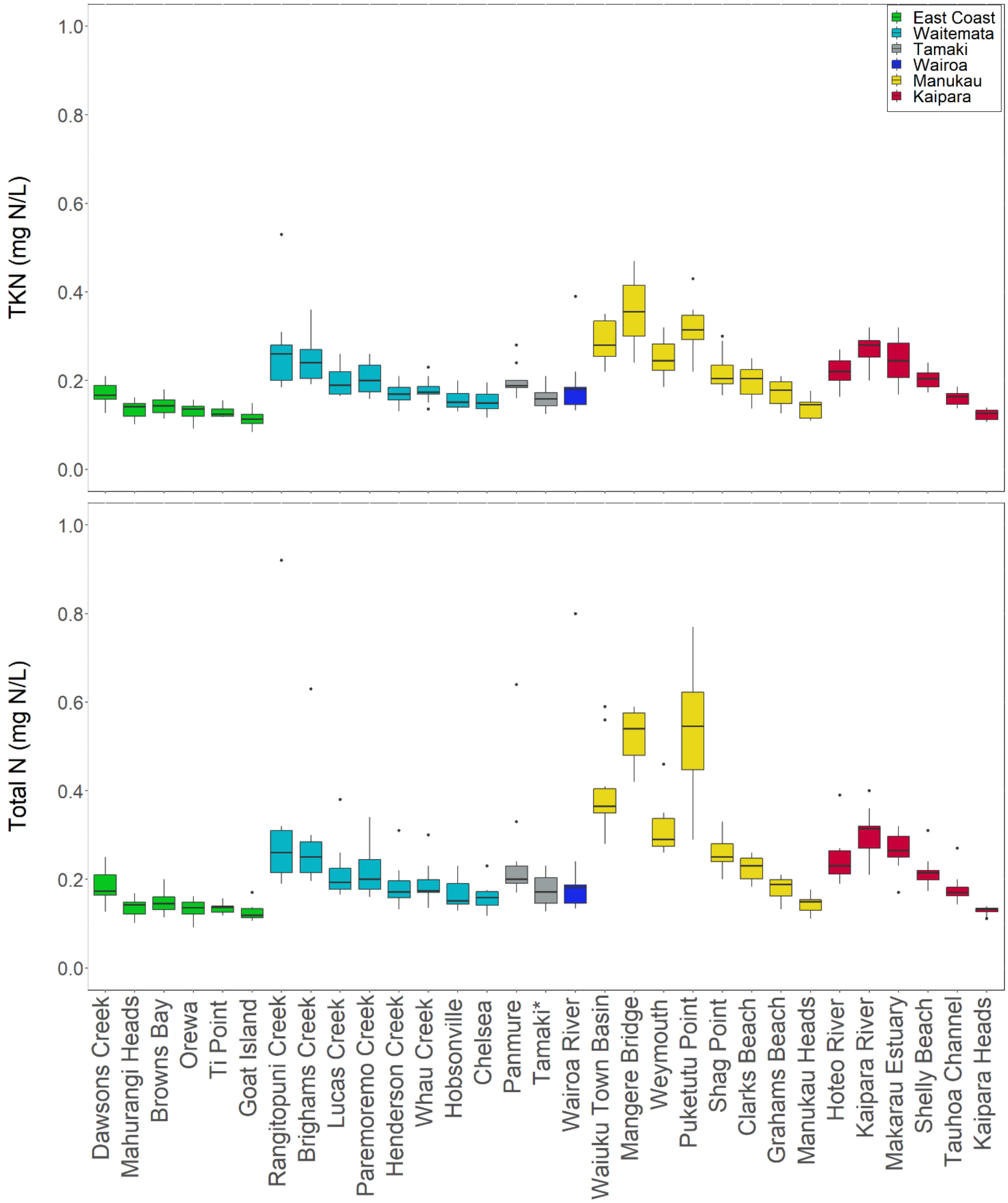

Figure 3-5: Variation in total kjedahl nitrogen and total nitrogen for coastal water quality data collected from January to December 2020. Sites are ordered for each harbour or estuary grouping by increasing long-term (2007-2016) median salinity. Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

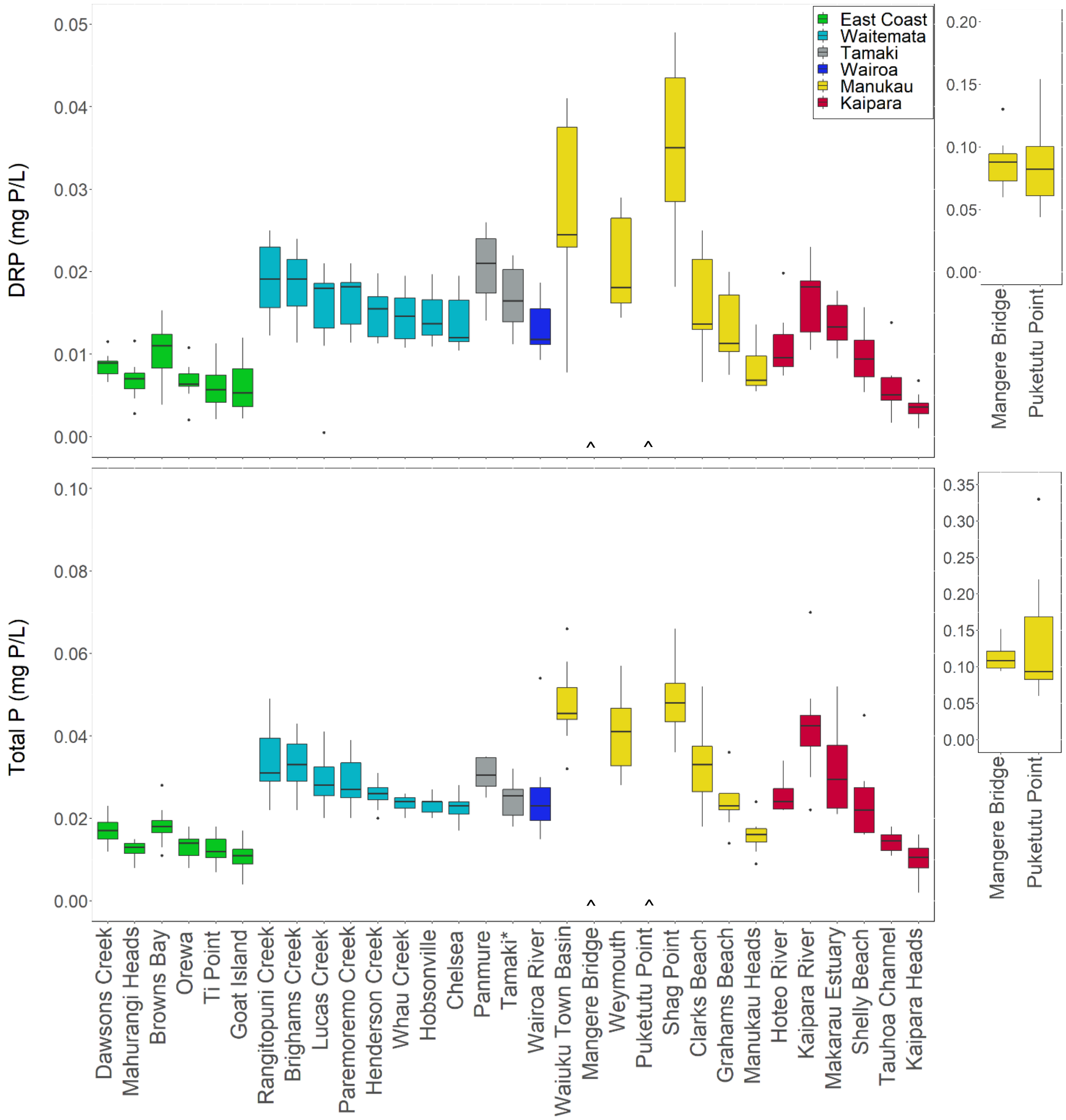

Figure 3-6: Variation in dissolved reactive phosphorus and total phosphorus for coastal water quality data collected from January to December 2020. Box plots show interquartile range (IQR). Whiskers extend to maximum or minimum values within 1.5x the IQR. Outliers are shown for values outside that range.

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^ = see inset

3.2 Water Quality Index

The 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 2018-2020 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.

3.2.1 Regional water quality class summary

In the current assessment period of 2018-2020, 42 per cent of monitored sites had water quality that was ‘marginal’ to ‘poor’ and nearly 30 per cent of monitored sites had ‘good’ water quality (Figure 3-7). There are clear spatial patterns with water quality tending to improve with increasing salinity towards the harbour mouths, and open coastal areas (Figure 3-8 and Figure 3-10).

Changes in water quality index scores over time provide an indication of large-scale changes in water quality integrated across several key parameters. The index has a higher sensitivity to changes where water quality is good and 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 (for trend analysis over 2010 to 2019 see Ingley, 2021).

The WQI results show that the water quality class has been largely consistent over the past four assessment periods (Figure 3-7). The majority of sites (67 per cent) were in the same water quality class between the 2014 to 2016 and 2018 to 2020 periods (Figure 3-7;Table C-1 in Appendix 3).There were five sites that declined in water quality class, and five sites that improved water quality class over this period (Table C-1 in Appendix 3). No sites changed by more than one class.

In several instances, declining water quality class appeared to be associated with higher ammoniacal N concentrations. There has been an observed step increase in ammoniacal N from 2018 (particularly at low concentrations) associated with laboratory changes (see section 2.6.2). These changes in overall WQI class should therefore be interpreted with caution. Further detail on long term trends in ammoniacal N is provided in the 2010-2019 State and Trends Report (Ingley, 2021). While this step change has implications for considering changes over time, the current 2020 state assessment can be read with reasonable confidence. There is no evidence to suggest that the current analytical results for ammoniacal N are inaccurate.

Specifically, the decline in index class at Mahurangi Heads (‘Excellent’ to ‘Good’) was only associated with ammoniacal N. This also appears to have influenced WQI scores at Chelsea and Wairoa River. However declining scores at these two sites were also associated with more exceedances of the chlorophyll a guideline which is indicative of potential nutrient enrichment.

There were no exceedances of any guideline at the Kaipara Heads in the earlier 2014-2016 assessment period (‘Excellent’) however there have been occasional exceedances of total ammoniacal N, total oxidised N, or chlorophyll a in the subsequent assessment periods (‘Good’). The decline in index class at the Kaipara River mouth ('Marginal' to 'Poor') was associated with a low frequency of exceedances of additional parameters (dissolved reactive phosphorus (DRP) and dissolved oxygen (DO%)) in addition to the frequent exceedances of other nutrients, chlorophyll a, and turbidity typically occurring.

Three of the five sites that improved water quality class were in the Waitematā Harbour: Lucas Creek, Paremoremo Creek ('Marginal' to 'Fair'), and Whau Estuary ('Fair' to 'Good'). Improvement was associated with fewer exceedances of the total oxidised nitrogen (TON) guideline, and no exceedances of the DRP guideline in the 2018-2020 period. This differs from previous trend analysis that found degrading trends (increasing concentration) in DRP at these sites over 2010 to 2019 (Ingley, 2021). It is possible this is associated with climatic (and sampling) variability over 2019 and 2020 within the Waitematā Harbour (see sections 3.3.2 and 4 below). Continued monitoring will provide further information on whether these apparent improvements are sustained over time. Improvement in water quality class at Panmure in the Tāmaki Estuary ('Poor' to 'Marginal') was primarily associated with fewer exceedances of the dissolved oxygen guideline. Improvement in water quality class at the Manukau Heads was primarily associated with no exceedances of the chlorophyll a guideline, and fewer exceedances of TON or ammoniacal N guidelines.

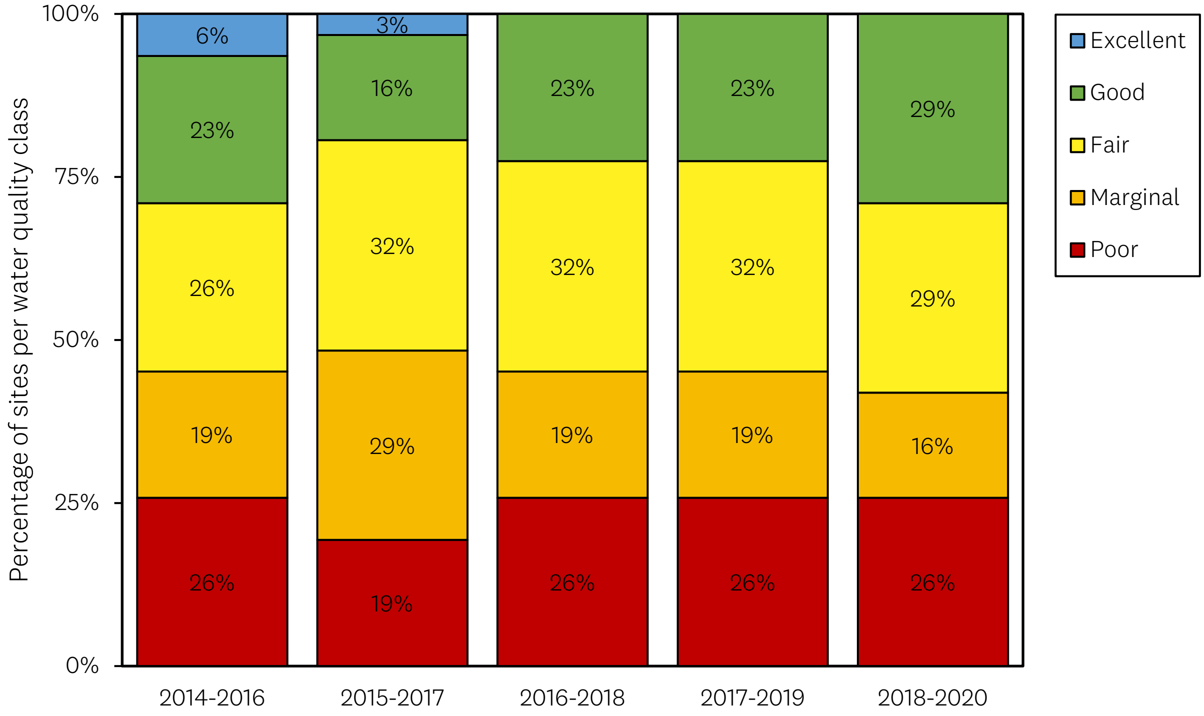

Figure 3-7: Percentage of monitored sites in each water quality index class over rolling time periods (*n* = 31).

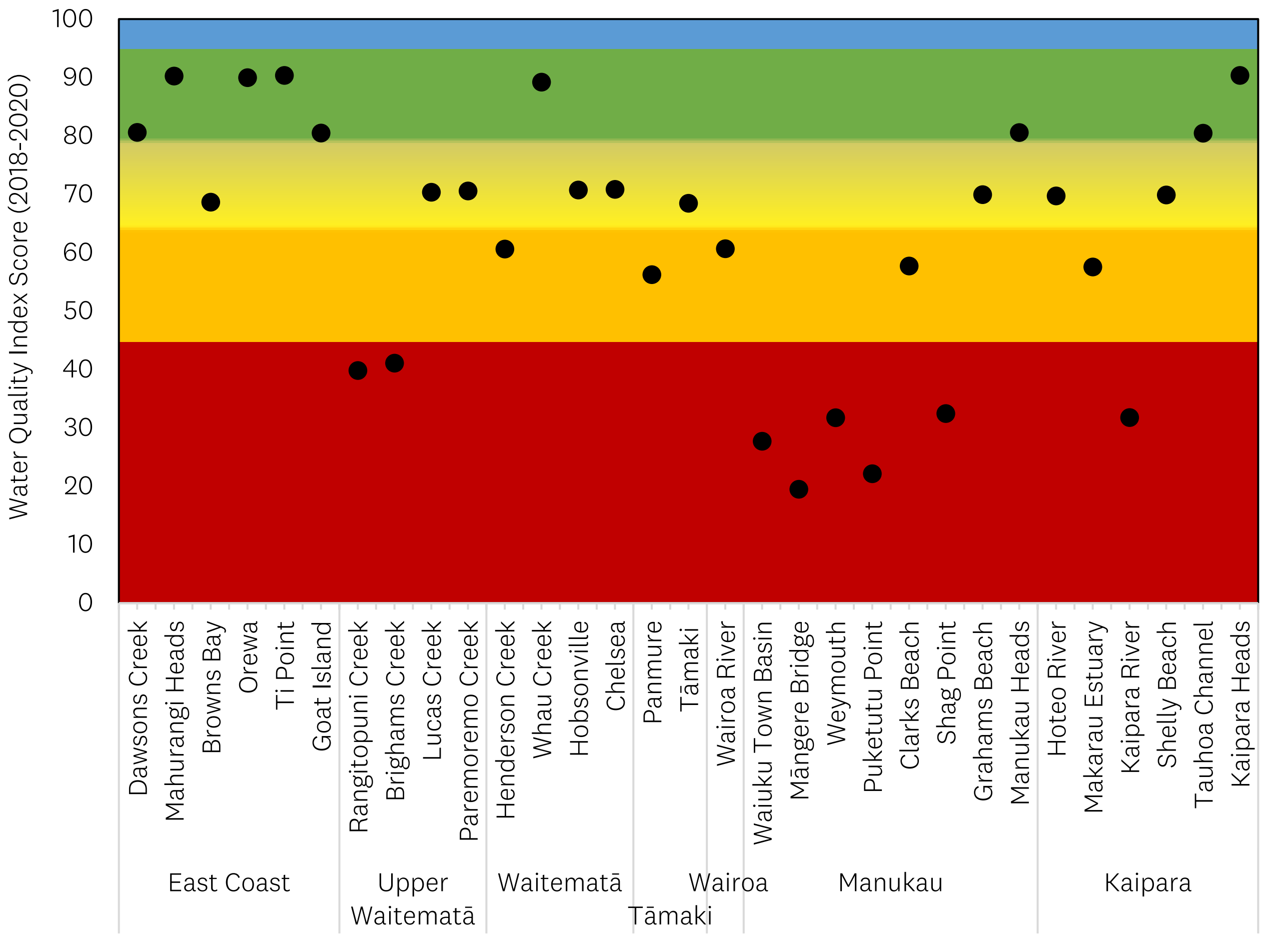

Figure 3-8: Water Quality Index score for 2018-2020. Sites are ordered by long-term median salinity within each reporting area from lower salinity to higher salinity.

The most common water quality issues affecting monitored sites across the region were elevated nutrients (particularly ammoniacal nitrogen) and chlorophyll a which is an indicator of nutrient enrichment (Figure 3-9:).

Over the previous four rolling time periods the frequency of guideline exceedances increased for ammoniacal nitrogen which was largely attributed to an analytical step increase at low concentrations influencing high quality sites (East Coast/Harbour mouths). However, there was a lower frequency of ammoniacal N exceedances in the most recent rolling period which is primarily associated with fewer exceedances in the upper Waitematā Harbour. There were also notably fewer exceedances of total oxidised nitrogen (TON) in the most recent rolling period which can also be attributed to differences in the upper Waitematā.

The frequency of exceedances of the dissolved oxygen guidelines also increased over the past few rolling periods, mostly associated with sites within the Manukau Harbour.

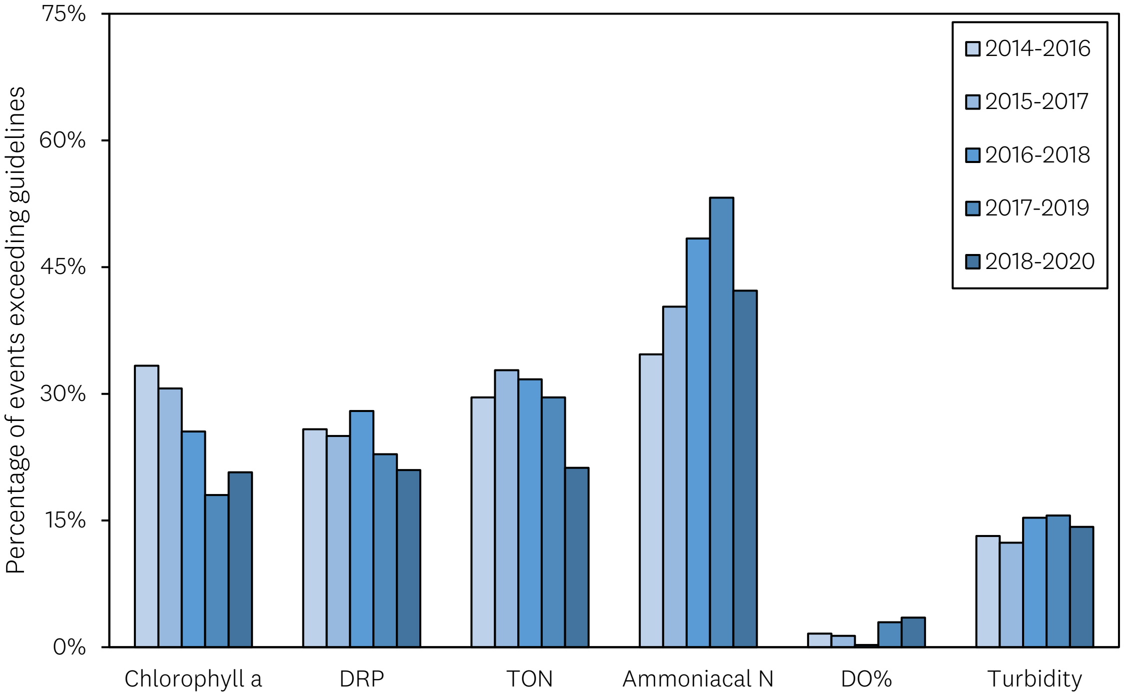

Figure 3-9: Percentage of median monthly samples that exceeded the relevant water quality guideline over rolling time periods (n=372)

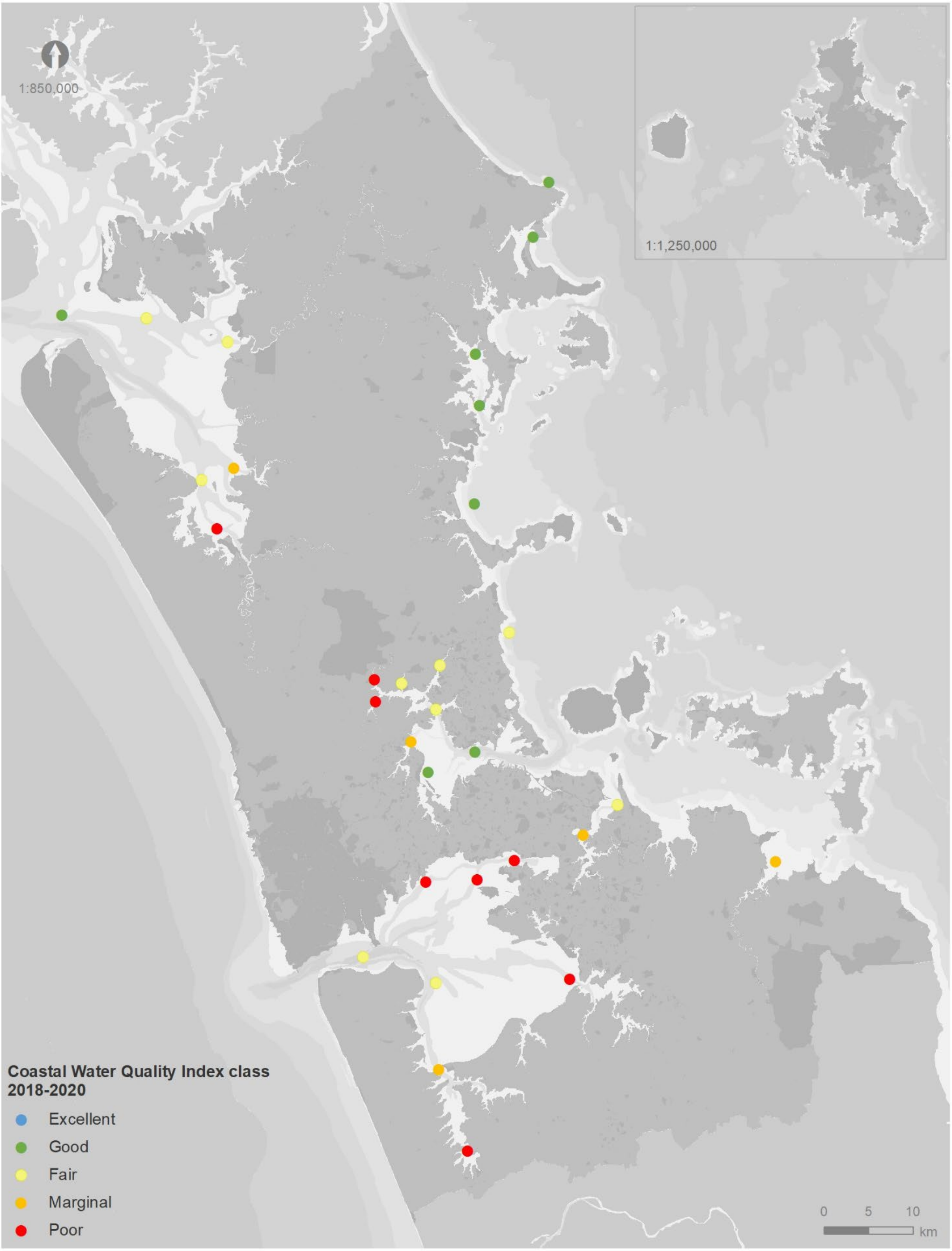

Figure 3-10: Water quality index class at coastal and estuarine water quality monitoring sites over the 2018-2020 period.

3.3 Water quality index by area

The water quality index groups the exceedances for each site into three magnitudes: less than 10 times the guideline value; greater than 10 times the guideline value; and greater than 25 times the guideline value. Exceedances fall within the smallest magnitude of less than 10 times the guideline value unless otherwise stated.

The frequency of exceedances for each site and parameter are summarised for each harbour or area in this section. A low frequency of guideline exceedances (1-3) suggests that the parameter was occasionally found to have monthly median concentrations higher than regional reference values, such as a seasonal peak. A moderate frequency of guideline exceedances (4-6) suggests that parameter was found to have monthly median concentrations higher than regional reference values for more than one season. High (7-9) and very high (10-12) frequencies of exceedances reflect values that are elevated most of the time.

3.3.1 East Coast

All sites along the East Coast and within the Mahurangi Harbour were within the ‘good’ water quality class except for Browns Bay, which was ‘fair’ (Figure 3-16, Appendix 3).

In the Mahurangi Harbour, Dawsons Creek had a low frequency of exceedances of ammoniacal nitrogen, and total oxidised nitrogen (TON). 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.

Both Orewa and Browns Bay were more turbid than further north at Ti Point and Goat Island. It is noted that the open coast guideline for turbidity used here (<1 NTU based on ANZ default guidelines) is very low. Turbidity at these sites was typically <3 NTU which is well below the lower quartile for open coast sites across New Zealand (Dudley, et al., 2017; Dudley, et al. 2020).

The lower water quality class at Browns Bay was primarily associated with elevated dissolved reactive phosphorus. This appears to be seasonal with phosphorus concentrations peaking in winter at this location. This is consistent with the expected spatial and seasonal patterns in nutrient cycling across the Hauraki Gulf based on transect surveys undertaken by NIWA from the inner Firth of Thames to the outer gulf (Zeldis, et al. 2013). Nitrogen becomes increasingly limited and phytoplankton production becomes increasingly isolated inshore in the inner gulf over winter, while phosphorus concentrations increase (Zeldis, et al. 2013). This is indicative of lower consumption of phosphorus by primary producers (e.g. phytoplankton and algae) over this period.

The reference sites, Goat Island and Ti Point, had a low frequency of exceedances for ammoniacal nitrogen. An abrupt increase in exceedances of ammoniacal nitrogen at these sites since 2017 is likely an artefact of the change in laboratory service (see section 2.6.2).

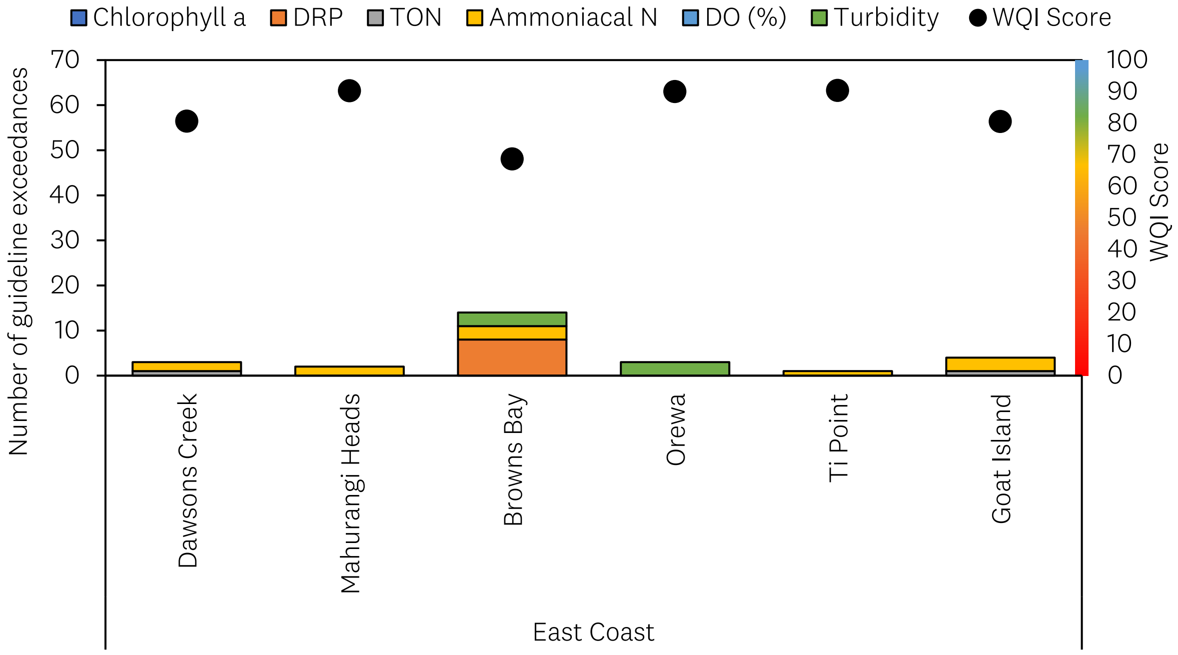

Figure 3-11: Water quality index scores and number of exceedances of the relevant guideline value per East Coast site (2018-2020 median values). Sites are ordered by increasing salinity.

3.3.2 Waitematā Harbour

Water quality in the Waitematā Harbour ranged from ‘poor’ in the upper tidal creeks, to ‘fair’ along the main channel from Hobsonville to Chelsea. Water quality at the mouth of Henderson Creek was ‘marginal’ whilst the best overall site within the harbour in this assessment period was at the mouth of the Whau River where water quality was ‘good’.

Both Paremoremo Creek and Lucas Creek in the upper Waitematā Harbour improved overall water quality class from ‘marginal’ to ‘fair’ in this assessment period. Whau Estuary improved overall class from ‘fair’ to ‘good’. These changes appear to be driven by a considerable decrease in the frequency of exceedances of the total oxidised nitrogen (TON) guideline with no exceedances in the current period compared to a moderate frequency in previous rolling periods (Ingley, 2020). There were also no exceedances of the dissolved reactive phosphorus (DRP) guideline at these two sites in this assessment period (Figure 3-12). No long-term trends were identified in TON concentrations at the two upper harbour sites over the past 10 years (2010-2019), though there was some indication of improving trends at the Whau. Conversely concentrations of DRP were found to be very likely increasing (degrading trends) (Ingley, 2021).

There were also fewer exceedances of the TON guideline at Brighams Creek, Rangitopuni Creek, and Henderson Creek, however this had minimal influence on the overall WQI scores as there was still a low to moderate frequency of exceedances across all water quality parameters (Figure 3-12; Ingley, 2020). The most common water quality issues at Brighams Creek and Rangitopuni Creek were elevated chlorophyll a, and turbid conditions (Figure 3-12). Dissolved oxygen saturation was also occasionally (in autumn) lower than the tidal creek guideline of 80 percent

Elevated ammoniacal N concentrations were the most common water quality issue influencing sites in the central Waitematā Harbour (Figure 3-12). There were no exceedances of the DRP guideline in the central harbour except, near the Chelsea sugar factory (in winter months).

It is unclear why DRP concentrations were lower in the 2018-2020 assessment period within the Waitematā Harbour considering the long-term trends in these parameters to 2019. Although the WQI moderates interannual variability, it is possible that this is associated with lower flow conditions intercepted at these sites over the preceding two years of below normal rainfall in 2019 and 2020 (Johnson 2022; NIWA 2020, NIWA 2021). This is particularly evident in 2020 where sampling within the Waitematā Harbour was reflective of a smaller range of flow conditions than were intercepted on other sampling days across the broader coastal monitoring network (as outlined in section 4.1 below).

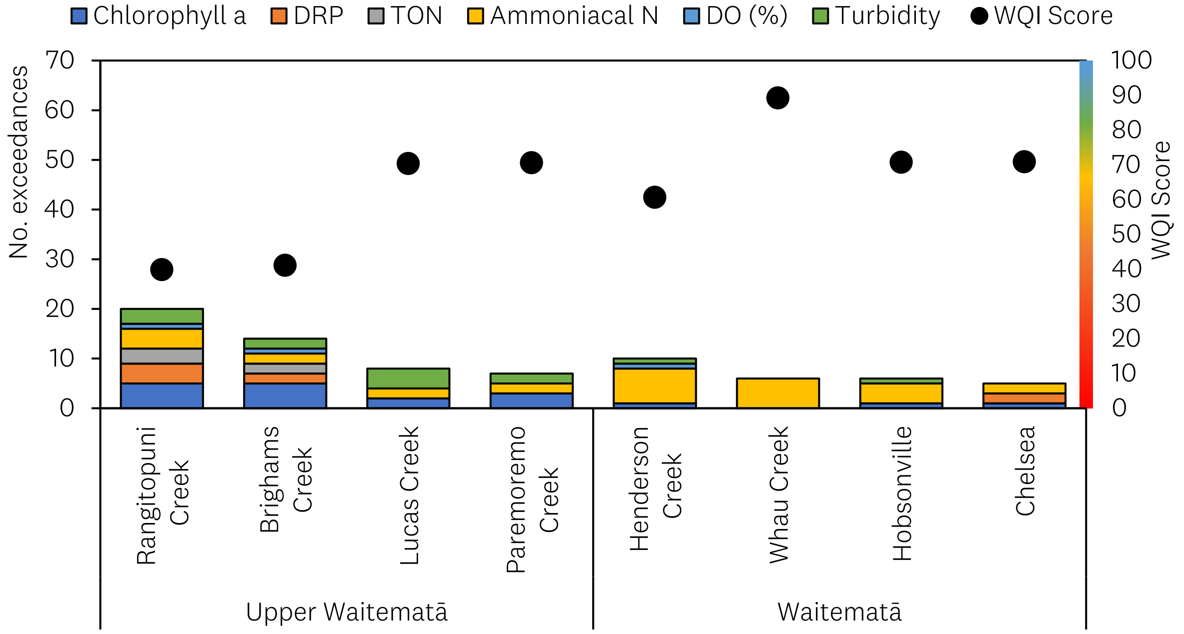

Figure 3-12: Water quality index scores and number of exceedances of the relevant guideline value per Waitematā Harbour site (2018-2020 median values). Sites are ordered by increasing salinity.

3.3.3 Tāmaki Estuary and Wairoa

Two sites are monitored within the Tāmaki Estuary. Water quality improves over the expected gradient from the mid reaches of Tāmaki Estuary at Panmure ('marginal') to the lower Tāmaki ('fair') site. This is primarily associated with higher concentrations of nutrients and chlorophyll a at Panmure (Figure 3-13).

The lower Tāmaki monitoring location was moved from within the Half Moon Bay Marina, to the ferry terminal in 2019 and consequently the WQI score for this site was calculated based on the overlapping period between locations. Good consistency between the two lower Tāmaki locations was observed for all physical parameters (temperature, salinity, and dissolved oxygen). However, some differences were observed for measures of nutrients and sediments. The ferry terminal site was observed to have lower concentrations of ammoniacal N than at the marina. This is reflected as fewer exceedances of this guideline value compared to the preceding period.

The surrounding catchments draining to the Panmure and Tāmaki sites have a high proportion of urban land cover (>25 per cent for the entire Tāmaki Estuary 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 catchment urban land cover has been found to be related to higher concentrations of nutrients and chlorophyll a in receiving estuaries (Dudley et al. 2020).

Water quality at the Wairoa River mouth 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 a low frequency of exceedances across several parameters including chlorophyll a, and total oxidised nitrogen, and in some years also turbidity (Figure 3-13).

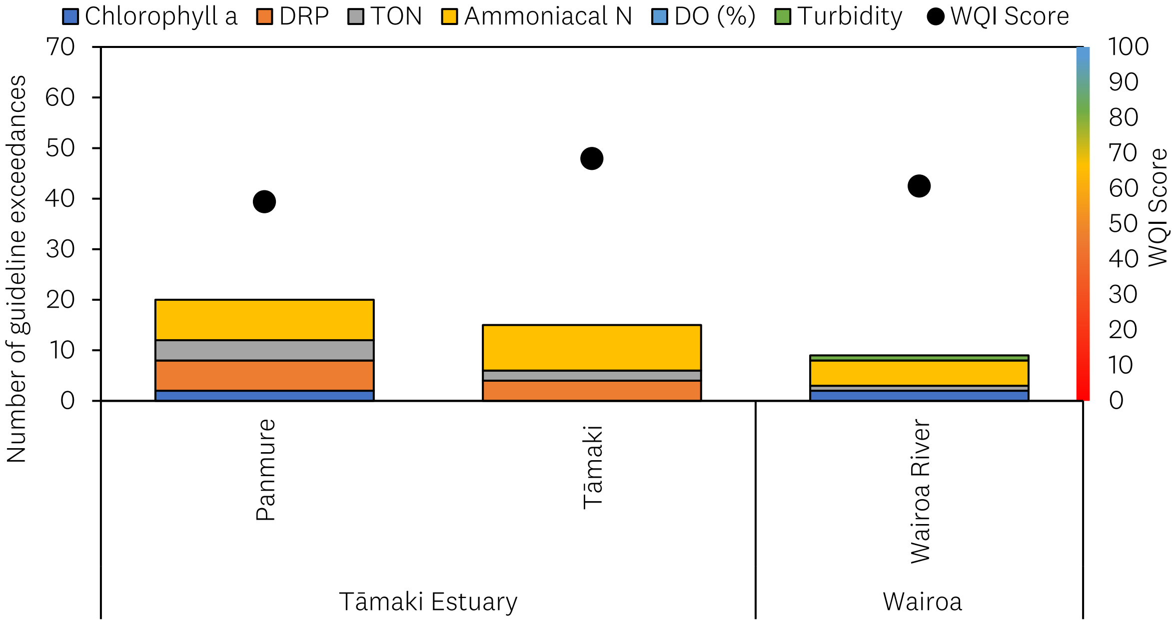

Figure 3-13: Water quality index scores and number of exceedances of the relevant guideline value per Tāmaki Estuary site (2018-2020 median values). Sites are ordered by increasing salinity.

3.3.4 Manukau Harbour

Water quality was classed as ‘poor’ at five of the eight monitored sites within the Manukau Harbour. The harbour mouth was classed as ‘good’ compared to ‘fair’ in the previous assessment period which appears to be associated with fewer exceedances of total oxidised nitrogen and ammonia guideline values, and no exceedances of the chlorophyll a guideline in the 2018-2020 period.

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 a (Figure 3-19). There was at least one exceedance of the upper dissolved oxygen guideline at each of these sites. Turbidity was elevated through September to December, extending over August and January at Māngere Bridge. There was one high magnitude exceedance for total oxidised nitrogen at Māngere Bridge for the month of July. There were no high magnitude exceedances at Puketutu Point in this period.

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 approximately 80 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 is discharged on the outgoing tide (approx. 300,000-320,000 m^3/day in 2020/2021). 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 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 a (Figure 3-19). Turbidity was also elevated through September to December. There was one high magnitude exceedance for total oxidised nitrogen at Waiuku Town Basin for the month of July. Waiuku Town Basin also had the highest frequency of exceedances of the dissolved oxygen guideline. This was due to low dissolved oxygen saturation where median monthly oxygen levels fell below the lower guideline (90 per cent saturation) in contrast to the hyper saturation of dissolved oxygen above guideline values observed in the northern part of the Harbour. The low oxygen levels occurred over the autumn period (March to May). Oxygen saturation remained above 80 per cent at this site however the lowest daily minimum oxygen levels are typically observed in the early hours of the morning which would not be detected by this monthly monitoring.

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. 2016). There is a long-standing issue of elevated nitrate concentrations in surface streams 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).

Water quality improved along the Waiuku channel towards the mouth of the harbour from poor in the upper basin, to ‘marginal’ at Clarks Beach at the mouth of the inlet, to ‘fair’ at Grahams Beach. These sites had a low to moderate frequency of exceedances for ammoniacal nitrogen, oxidised nitrogen and chlorophyll a, and did not exceed DRP or dissolved oxygen guidelines (Figure 3-14).

Watercare and NIWA are developing a hydrodynamic nutrient model for the Manukau Harbour, and Auckland Council is working on a sub-catchment scale water-quality model of the entire Auckland region. These two models will improve our understanding of the sources and loads to, and transport of nutrients within, the harbour. Further research is currently underway to characterise the interaction between surface water in streams and groundwater throughout the Pukekohe/Franklin area.

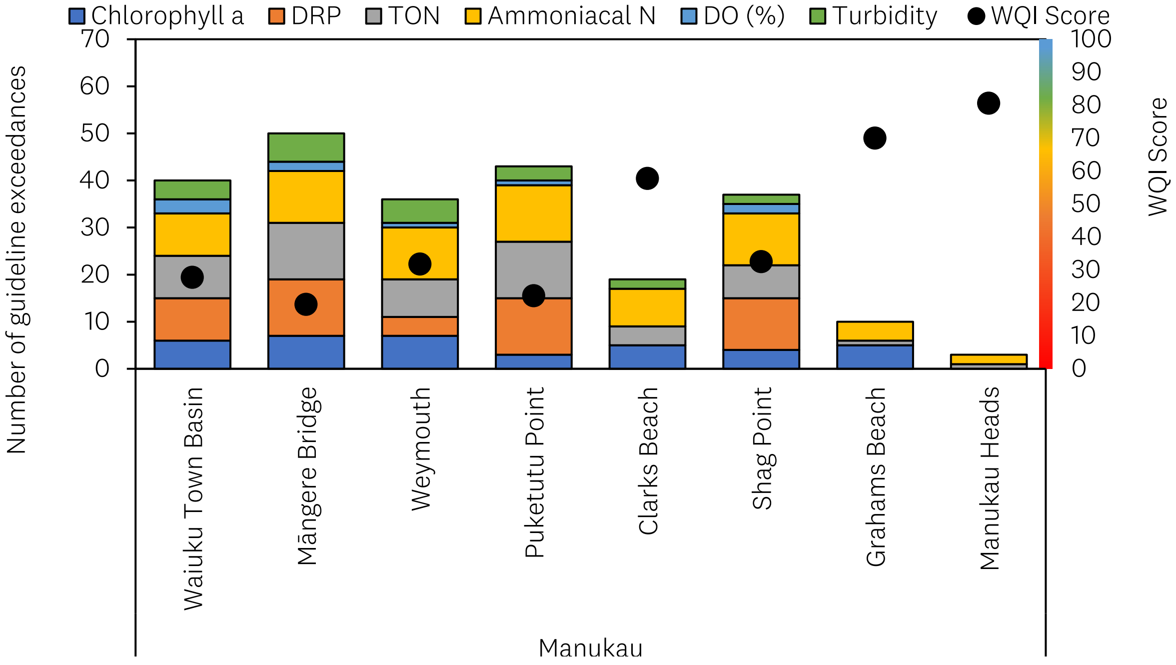

Figure 3-14: Water quality index scores and number of exceedances of the relevant guideline value per Manukau Harbour site (2018-2020 median values). Sites are ordered by increasing salinity.

3.3.5 Kaipara Harbour

Water quality ranged from 'poor' at the southern end of the Kaipara Harbour improving to 'fair' at Shelly Beach up the south Kaipara channel. Water quality also improved from 'fair' to 'good' along the Tauhoa Channel from the Hoteo River towards the mouth of the harbour.

The three river mouth sites, Hoteo River, Makarau Estuary, and Kaipara River had higher ammoniacal N concentrations most of the time (moderate to high frequency exceedances), and also occasionally had elevated DRP and total oxidised N (Figure 3-15). Chlorophyll a was elevated occasionally at Makarau Estuary, and most of the time at Kaipara River, Figure 3-15). The lower dissolved oxygen guideline was also exceeded on one occasion at the Kaipara River mouth.

Kaipara River was the only site that had high turbidity and this site consistently had the highest median turbidity across all sites monitored within the Auckland region. The Kaipara and Kaukapakapa rivers are the main local source of sediment to the Kaipara Harbour south of Shelly Beach (Gibbs et al. 2012). 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). The Kaipara River mouth was the only site in the Kaipara that exceeded the dissolved oxygen saturation guideline on at least one occasion. This was associated with low oxygen saturation <90% in April 2019.

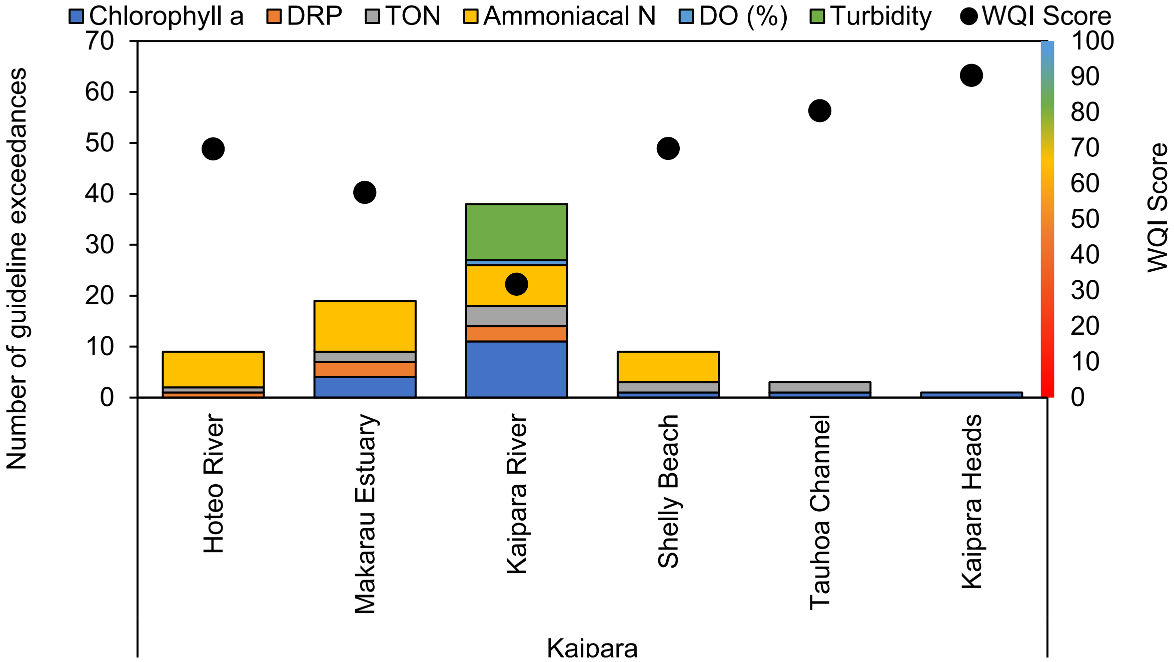

Figure 3-15: Water quality index scores and number of exceedances of the relevant guideline value per Kaipara Harbour site (2018-2020 median values). Sites are ordered by increasing salinity.

4 Annual Climate Summary

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 networks.

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 (both coastal and river and catchment based) and nutrient leaching. 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.).

This section outlines key climate information within 2020 and summarises river flows occurring at hydrology monitoring stations within some upstream catchments on the days coinciding with coastal water quality monitoring[5].

Auckland experienced ‘marine heatwave’ conditions for two summers in a row over 2018 and 2019 (NIWA, 2019). While 2020 did not see a third heatwave, this was the warmest winter on record with above average winter sea surface temperatures (NIWA, 2020).

2020 was the driest year in Auckland on record[6]. Record low rainfall resulted in severe meteorological drought in January and February 2020 with drought conditions easing in April to May (NIWA, 2021). In 2020, the early part of the year was in neutral ENSO conditions (NIWA, 2021). Conditions transitioned towards a La Niña phase from June reaching La Niña conditions from October through to the end of the year (NIWA, 2020).

Scarsbrook (2008) previously found that, temperature, nitrate, and ammoniacal nitrogen all tend to be higher during La Niña phases and lower during El Niño phases within the Manukau Harbour. La Niña phases are usually associated with higher rainfall in Auckland, and we would expect coastal nutrient concentrations to generally be higher where influenced by diffuse freshwater runoff. However this year, the La Niña response was non-traditional due to the extended dry spell, and we would expect lower concentrations of land derived contaminants associated with reduced freshwater inflows to estuarine environments (Scarsbrook et al., 2003; Scarsbrook, 2008; NIWA, 2021).

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[5] The river hydrology stations, and coastal water quality monitoring stations are not explicitly paired, and the hydrology stations vary in their distance upstream. The size or order of the rivers discharging to the coast also varies.

[6] With records dating to 1959 (NIWA, 2021)

4.1 2020 regional river flows and hydrology

Auckland Council operates a network of river hydrology monitoring stations across the region. Several of these stations are located upstream of tidal creek or estuary water quality monitoring sites. Long-term flow records[7] were compared to the flow conditions experienced at each selected river hydrology monitoring station on the days that we undertook the coastal and estuarine water quality monitoring during 2020.

The extent of influence of upstream river flows on coastal water quality monitoring sites is variable depending on proximity and size of inputs, and other coastal dynamics. This information is used to broadly characterise variation in river flows between years, between sites, and to identify notable high flow events that may explain observations of high concentrations of contaminants in the downstream environment (see section 3.1 above).

Figure 4-1 summarises the range of flows that occurred, standardised by the per cent exceedance of flows. High percentile exceedance indicates **low flow** conditions i.e. 90 per cent of flows within that stream over time are higher than the flow recorded on that day. Low percentile exceedance indicates **high flow** conditions i.e. where only 10 per cent of flows are higher than the flow recorded on that day. Figure 4-1 shows that median flow levels on the sampling days (box plots) were near, or above the long-term 50th percentile (blue background) demonstrating that conditions were generally representative of lower river flow conditions.

Notably lower flow conditions within the streams leading to the Waitematā Harbour occurred on the days that the harbour was sampled compared to the other harbour runs (see Figure 4-1). Some samples were obtained in conditions equivalent to the lowest flows recorded over the history of flow monitoring at that site (whiskers extend to 100 per cent exceedance). This is consistent with the drought period and is representative of the lower annual flows in the upstream catchments in 2020. The monitoring programme is not specifically designed to capture high river flow events. In 2020, flows higher than the highest 10 per cent of flow conditions were not intercepted across the Waitematā Harbour (box plot whiskers do not cross the yellow line in Figure 4-1).

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

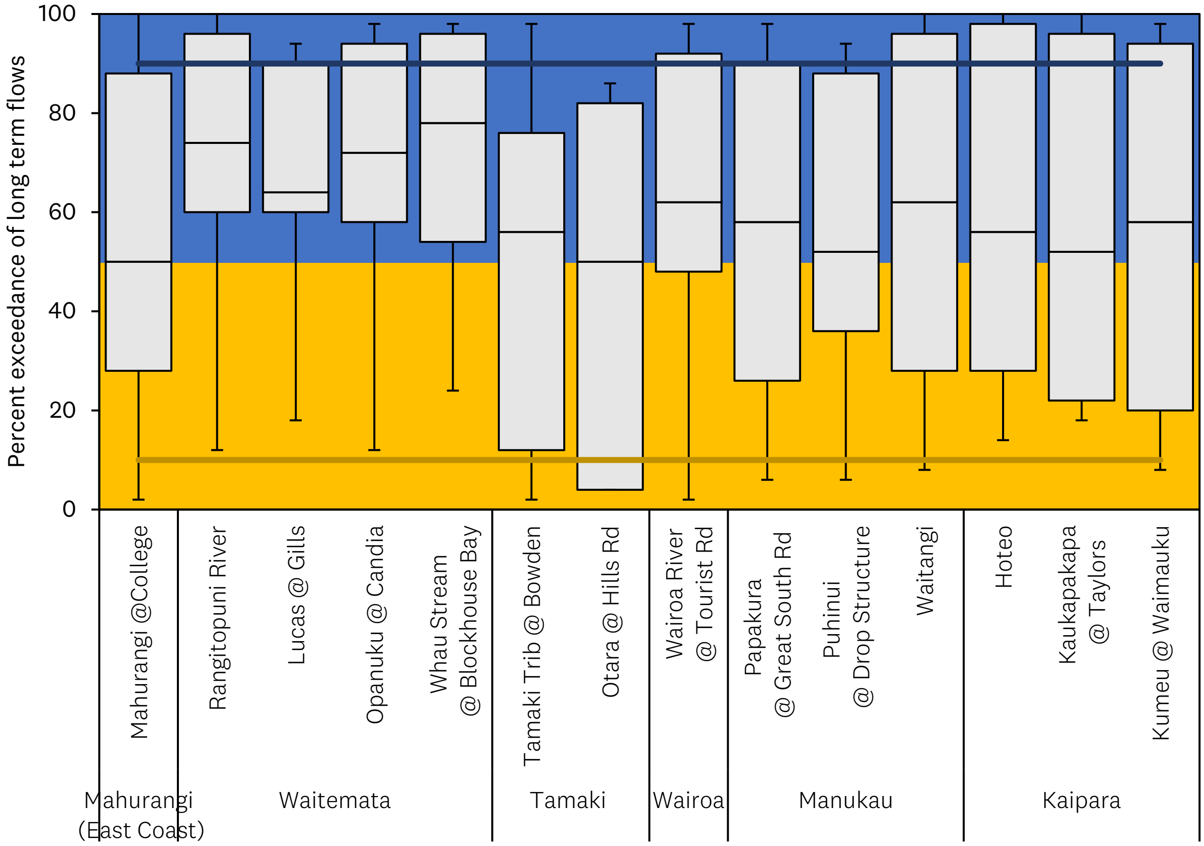

Figure 4-1: Range of river flows in upstream catchments on coastal water quality sampling days. Box plots show the interquartile range, and whiskers show min-max flows.

Blue line shows **low** flow conditions i.e. 90% of long-term flows are higher than this. Yellow line shows **high** flow conditions – 10% of all flows are higher than this.

5 Summary

The purpose of this report is to provide an annual update on the current state of our coastal and estuarine water quality for 2020. Auckland Council's coastal and estuarine water quality monitoring programme focuses on nutrient and suspended sediment and water clarity parameters that can be altered by changes in land-use, location of point source discharges direct to the coast, land erosion and activities in the coastal environment

Coastal water quality is influenced by numerous sources of contaminants including those entrained with surface and groundwater that runs from the land to the coast, direct discharges from coastal 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 decreasing spatial gradient in freshwater influence from tidal creeks, to estuaries, to the coast. Nationally, and regionally, lower salinity (more freshwater input) has been demonstrated to coincide with higher concentrations of nutrients, and turbidity (Dudley, et al. 2020; Ingley, 2020).

2020 was the driest year in Auckland on record (NIWA, 2021). The regional annual water quality results are therefore generally representative of low flow, or low river discharge conditions. The extent of influence of upstream river flows on coastal water quality monitoring is variable depending on proximity and size of inputs, and other coastal dynamics. However, this information provides further context for comparisons among sites in 2020, and relative to long-term conditions. This was particularly notable in the Waitematā Harbour where scheduling of monthly monitoring did not coincide with any notable rain events in 2020 and was representative of lower flow conditions than sampling days in the Kaipara or Manukau Harbours.

The water quality index provides an indication of the state of each site based on guidelines for several key parameters, moderated across a three-year period. These guidelines are not regulatory triggers or thresholds. Large-scale differences between tidal creek, estuarine, and open coastal environments are provided for by using separate water quality index guidelines. The index is 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.

In the current assessment period of 2018-2020, 42 per cent of monitored sites had water quality that was 'marginal' to 'poor' and nearly 30 per cent of monitored sites had 'good' water quality. There are clear spatial patterns with water quality tending to improve with increasing salinity towards the harbour mouths, and open coastal areas. The most common water quality issues affecting monitored sites across the region were elevated nutrients (particularly ammoniacal nitrogen) and chlorophyll a which is an indicator of nutrient enrichment.

Changes in water quality index scores over time provide an indication of large-scale changes in water quality integrated across several key parameters. The water quality index class has been largely consistent over the past four assessment periods. The majority of sites (67 per cent) were in the same water quality class between the 2014 to 2016 and 2018 to 2020 periods. There were five sites that declined in water quality class, and five sites that improved water quality class over this period. No sites changed by more than one class.

In several instances, declining water quality class appeared to be associated with higher ammoniacal N concentrations at higher quality sites (harbour mouths) which are likely influenced by an artefact of changing laboratory analysis. In these instances, changes in water quality index over time should be interpreted with caution. There is no evidence to suggest the current state assessment is inaccurate. The Kaipara River mouth was the only other site where a notable decline in water quality index class was observed (from ‘marginal’ to ‘poor’). This was associated with occasional exceedances of more parameters (dissolved reactive phosphorus (DRP) and dissolved oxygen (DO%)) in addition to the frequent exceedances of chlorophyll a, and turbidity typically occurring at this location.

While the water quality index moderates the influence of annual variability, both 2019 and 2020 were very dry years. It appears that this has contributed to lower nutrient concentrations over the 2018 to 2020 period, particularly within the tidal creeks in the upper Waitematā Harbour. This is also reflected in apparent improvements in water quality class. While general spatial patterns over the salinity gradient are still apparent, variation in water quality index scores for 2018 to 2020 was not well explained by differences in salinity among sites. Previously, salinity has been found to explain nearly 50 per cent of the regional variation in overall water quality (Ingley, 2020). 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.

The influence of climatic variability over these short time scales emphasises the importance of long-term trend analysis to identify where improvements to water quality are being made, and where water quality is degrading. Long-term trend analysis was recently completed for the 2010 to 2019 period and this previous report should be referred to for further information (Ingley, 2021).

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Appendix 1: Current monitoring sites

Table A-1: Current coastal and estuarine water quality monitoring sites.

	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 Creek	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*	1768895	5916761	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 Basin	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

** Updated to ferry terminal location*

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

Appendix 2: Physical-chemical parameters

Table B-1: 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 a	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 B-2: 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.

Parameter	Description
	Land-derived sediment loads are dominated by stormflows, which are only occasionally intercepted by our routine monthly monitoring.
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).
Dissolved Reactive Phosphorus (DRP) Total Phosphorus (TP)	Phosphorus is found in water as dissolved and particulate forms. Dissolved 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 natural input, 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 a	Chlorophyll a is used as an indicator of phytoplankton concentration which can indicate trophic status. Chlorophyll a levels vary naturally according to seasonal cycles and climatic conditions. However, excess nutrients caused by human activity can increase chlorophyll a 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 3: WQI Scores

Table C-1: Water Quality Index calculations based on monthly median values for rolling three-year periods. 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)	WQI Score (2018-2020)
East Coast	Goat Island[1]	🟩 89.5	🟩 89.5	🟩 90.3	🟩 80.6	🟩 80.5
	Ti Point[1]	🟩 80.4	🟩 80.4	🟩 90.2	🟩 89.8	🟩 90.3
	Dawsons Creek	🟩 80.7	🟨 71	🟩 80.5	🟩 90.1	🟩 80.6
	Mahurangi Heads	🟦 100	🟦 100	🟩 90.3	🟩 90.2	🟩 90.2
	Orewa[1]	🟩 90.2	🟩 80.3	🟩 80.1	🟩 90.1	🟩 90.0
	Browns Bay[1]	🟨 78.8	🟨 79	🟨 69.7	🟨 68.8	🟨 68.6
Waitematā	Chelsea	🟩 80.6	🟩 80.3	🟩 80.5	🟨 79.7	🟨 70.9
	Whau Creek	🟨 70.2	🟨 79.4	🟨 69.2	🟨 79.0	🟩 89.2
	Henderson Creek	🟧 60.4	🟧 59.8	🟧 59.4	🟧 60.1	🟧 60.6
	Hobsonville	🟨 70.8	🟨 70.7	🟨 69.9	🟩 89.1	🟨 70.7
	Lucas Creek[2]	🟧 50.6	🟧 49.4	🟧 49	🟧 49.8	🟨 70.4
	Paremoremo Creek[2]	🟧 49.6	🟧 49.3	🟧 49.5	🟧 50.6	🟨 70.6
	Brighams Creek[2]	🟥 38.4	🟧 45.3	🟥 44.7	🟥 38.3	🟥 41.1
	Rangitopuni Creek[2]	🟥 35.2	🟥 43.7	🟥 43.6	🟥 36.7	🟥 39.8
Tāmaki	Tāmaki*	🟨 67.9	🟨 67.5	🟨 67.4	🟨 67.1	🟨 68.4
	Panmure	🟥 34.5	🟥 35.7	🟧 53.9	🟧 47.2	🟧 56.2
	Wairoa River	🟩 90.3	🟧 60.7	🟨 69.9	🟨 69.0	🟧 60.7
Manukau	Māngere Bridge	🟥 25.4	🟥 18	🟥 25.2	🟥 18.2	🟥 19.5
	Puketutu Point	🟥 27	🟥 29.5	🟥 26.8	🟥 21.6	🟥 22.1
	Weymouth	🟥 38.2	🟥 37	🟥 37.5	🟥 32.9	🟥 31.7
	Waiuku Town Basin	🟥 31.6	🟥 23.2	🟥 23.2	🟥 25.4	🟥 27.7
	Clarks Beach	🟧 56.6	🟧 56.3	🟧 45	🟧 46.2	🟧 57.7
	Grahams Beach	🟨 70.2	🟨 79.7	🟨 70.3	🟨 69.6	🟨 69.9
	Shag Point	🟥 38.4	🟧 46	🟥 38.9	🟥 32.2	🟥 32.5
	Manukau Heads	🟨 70.8	🟨 70.8	🟨 71	🟨 79.9	🟨 80.6
Kaipara	Kaipara Heads	🟦 100	🟩 90.3	🟩 80.6	🟩 80.6	🟩 90.3
	Tauhoa Channel	🟩 80.3	🟨 70.4	🟨 70.6	🟨 70.6	🟩 80.4
	Hoteo River	🟨 67.7	🟨 66	🟧 56.7	🟨 67.3	🟨 69.7
	Makarau Estuary	🟧 55.6	🟧 56.3	🟨 65.8	🟧 58.0	🟧 57.5
	Shelly Beach	🟨 68.8	🟨 68.9	🟨 68.4	🟨 69.4	🟨 69.9
	Kaipara River	🟧 47.5	🟧 49.8	🟥 40.3	🟥 40.2	🟥 31.8

* Years 2014-2016 to 2017-2019 are based on the marina site while 2018-2020 is based on a transition between the marina site and new ferry terminal location. 1. Open Coast guidelines 2. Tidal Creek guidelines

Appendix 4: 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.

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). It is important to control for such physical variability between sites in the mixing of freshwater flows with oceanic water to detect the effects of terrestrial derived contaminants on water quality. Consequently, different index objectives were defined for open coastal and estuarine environments, and more recently preliminary objectives were defined for upper tidal creek environments.

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 which consequently represent guidelines that are regionally achievable.

Both strong El Niño and La Niña conditions were experienced 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 D-1: Reference sites used to calculate objectives.

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

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).

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.

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.

Comparing the tidal creek sites to separate tidal creek guidelines resulted in a weaker relationship between overall salinity and water quality index scores (Ingley, 2019). 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.

Parameters

A summary of all parameters monitored in the coastal and estuarine water quality programme is provided in Table B-2. 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 WQI however these provide important context to further interpret water quality state.

Appendix 5: Programme history

The coastal and estuarine water quality programme (also known as the marine or saline water quality programme) was designed to assess regional water quality 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 at each site.

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 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 Watercare Services. In December 2014, the YSI 556 MPS multi-parameter meter was upgraded to the EXO 2 multi-parameter sonde (Xylem Analytics).

Find out more: rimu@aucklandcouncil.govt.nz
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