Review of coastal water quality monitoring in the Northland Region

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Climate, Freshwater & Ocean Science

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Executive summary

Several national developments, in particular the introduction of the National Policy Statement for Freshwater Management 2020 (NPSFM), have created a need for Northland Regional Council (NRC) to review its State of the Environment (SOE) coastal water quality monitoring programme. In order to implement the NPSFM, NRC has identified a suite of freshwater management units (FMUs), all of which drain to the Coastal Marine Area (CMA). A key focus of the review is to identify if there is sufficient spatial coverage across existing monitoring sites in the CMA to assess the impact of freshwater inputs from these FMUs on coastal water quality. NIWA was engaged to provide this assessment and build on an internal review of the programme. Specifically, the scope of the assessment was to: evaluate the representativeness of monitored coastal locations with regard to occurrence of coastal hydrosystem types in Northland and as receiving waters for Northland's recently established FMUs,

- consider how the monitoring programme will help NRC give effect to the NPSFM, in particular Policy 3 and Section 3.11 (integrated — 'source to sea' — management), and
- comment on whether the monitoring sites, variables and methods are fit-for-purpose to assess the effectiveness of the Proposed Regional Plan for Northland (PRPN) for managing coastal water quality and assess compliance against the water quality standards in the PRPN.

We have considered representativeness of monitored coastal locations in two ways. Firstly, we assessed the susceptibility of Northland's estuaries to poor water quality in freshwater inflows as represented by hydrosystem type and calculation of catchment sediment and nutrient loads. Secondly, we considered how closely the composition of catchment land use upstream of monitoring sites represents the composition of wider land use upstream of all coastal water bodies associated with the FMU. We also considered freshwater and coastal monitoring locations needed to support integrated ('source to sea') management under the NPSFM 2020. This included an assessment of terminal river reaches that contribute the greatest sediment and nutrient loads to downstream coastal hydrosystems.

Our analysis indicates that the upstream land use composition across coastal hydrosystems included in NRC's coastal water quality monitoring programme adequately represents the overall composition of FMU land drainage to all downstream coastal hydrosystems. Overall, there is a focus on monitoring more heavily freshwater-dominated hydrosystems which means that the programme is more likely to identify where coastal water quality problems are or may occur. However, more than half of Northland's FMUs lack downstream receiving water quality monitoring at present and there is a lack of terminal river reach sites on some rivers that are estimated to input significant loads of sediment and/or nutrients.

While we concur with focussing monitoring resources primarily on impacted coastal hydrosystems, oceanic monitoring is currently limited to a small cluster of sites in the south-east of the region and spatial coverage could be improved. This, along with improved terminal reach coverage, would provide improved data on the state of fresh and oceanic water entering estuaries across the Northland Region.

The suite of water quality variables currently monitored by NRC closely match those recommended in recent national reports and guidance, and the list of variables in the PRPN with associated water quality standards. However, pH is not currently monitored at any location and the detection limits for

some variables do not meet National Environmental Monitoring Standards (NEMS) (2020) requirements.

The monthly sampling frequency is considered appropriate for SOE monitoring and adopting a variable tidal state is justified, especially with a reasonable time-series now available for most sites. We suggest that for deeper estuaries susceptible to eutrophication, regular surface sampling programmes could be supported by one-off, estuary-by-estuary bathymetry, water quality and depth profile CTD (conductivity-temperature-depth) sampling. This approach would also confirm whether regular sub-surface sampling is required in deeper estuaries.

In this report, we provide rationale for the following recommendations, recognising that NRC will need to consider them within the much larger context of priorities across all environmental monitoring, as well as logistical constraints (e.g., resources, suitable road/site access) and community needs/interests.

1. Extend or rework the current monitoring effort of the ‘Open Coast’ CMU across to the west coast to provide data on oceanic inputs to coastal hydrosystems on this coast.
2. Establish water quality monitoring in a coastal hydrosystem downstream of one or more of the FMUs that currently lack receiving water monitoring, using the outputs of Tables 3-1 to 3-4 to guide selection.
3. Increase water quality in or near terminal river reaches, using the information in Table 4-1 and Table 4-2 to select sites that contribute the most significant contaminant loads.
4. Investigate participation in the NZ Ocean Acidification Observing Network to track trends in pH at one or few coastal waters sites in Northland.
5. Measure dissolved forms of copper and zinc (and associated supporting variables) in place of, or in addition to, measurement of total forms, with detection limits adopted taking into account NEMS (2020) requirements and toxicity guideline values.
6. Identify estuaries in which catchment contaminant modelling may be required and initiate collection of additional physical information to support this modelling, notably:
   - accurate measurement of estuary extent and form, including tidal prism, intertidal area, and volume at high tide,
   - salinity measurements inside and outside the estuary, and
   - water sampling at a range of depths in deeper estuaries, where stratification of waters is suspected, to support dilution modelling.

1 Introduction

Northland Regional Council (NRC) is responsible for managing the near-shore coastal marine area (CMA) of the Northland Region. This area spans 3,200 km of coastline from the Kaipara and Mangawhai harbours in the south, to Cape Rēinga in the north, and extends from mean high water springs to 12 nautical miles offshore. The Northland CMA supports a high diversity of plants and animals, and also provides for a wide range of human activities and values, including recreation, commercial fishing, aquaculture, mahinga kai/food gathering and tourism.

As part of a broader coastal monitoring programme that informs its management of the CMA, NRC monitors physico-chemical and microbiological water quality at a selection of coastal sites on a regular basis. Good water quality is essential for supporting the wide range of activities and values in the CMA. Monitoring in the early years was focussed on microbiological water quality at sites popular for swimming, surfing, shellfish collection and other forms of recreation, with monitoring later expanding to include a broader range of water quality characteristics to support assessments of ecosystem health. This broader monitoring is referred to as NRC's coastal state of the environment (SOE) water quality monitoring programme and is the subject of this report.

NRC regularly reviews its SOE coastal water quality monitoring programme to ensure that it is robust, consistent with recommended best practice, and can suitably inform its management of activities which may impact coastal water quality. Although the last review was only undertaken in 2018, several national developments, in particular the introduction of the National Policy Statement for Freshwater Management 2020 (NPSFM, NZ Govt 2020), have created a need to revisit the programme. In order to implement the NPSFM, NRC has identified a suite of freshwater management units (FMUs), all of which drain to the CMA. A key focus of the review is to identify if there is sufficient spatial coverage across existing monitoring sites in the CMA to assess the impact of freshwater inputs on coastal water quality.

This report, funded through Envirolink Medium Advice Grant NLRC227 (MBIE Contract C01X2105), is intended to complement an internal draft review of NRC's coastal water quality monitoring programme by Griffiths (2021a). The internal review focussed primarily on individual site locations, whereas the focus of this review is broader.

1.1 Scope

In this review we:

- evaluate the representativeness of monitored coastal locations with regard to occurrence of coastal hydrosystem types in Northland and as receiving waters for Northland's recently established FMUs,
- consider how the monitoring programme will help NRC give effect to the NPSFM, in particular Policy 3 and Section 3.11 (relating to integrated management), and
- comment on whether the monitoring sites, variables and methods are fit-for-purpose to assess the effectiveness of the Proposed Regional Plan for Northland (PRPN) for managing coastal water quality and assess compliance against the water quality standards in the PRPN.

The commentary in this report should be considered alongside that of Griffiths (2021a).

1.2 Report outline

We begin in Section 2 with a brief outline of the current regulatory framework for coastal water quality management in Northland to provide the context for our programme review. We focus primarily on summarising relevant provisions of the NPSFM 2020 and PNRP.

In Section 3 we address the representativeness of monitored coastal locations. We consider monitored locations with regards to both:

- the susceptibility of Northland's estuaries to poor water quality in freshwater inflows, as represented by hydrosystem type and an assessment of catchment sediment and nutrient loads, and
- how closely the composition of catchment land use upstream of monitoring sites represents the composition of wider land use upstream of all coastal water bodies associated with the FMU.

Section 4 has a modelling focus, addressing freshwater and coastal monitoring locations needed to support integrated ('source to sea') management under the NPSFM 2020. This includes an assessment of terminal river reaches that contribute the greatest sediment and nutrient loads to downstream coastal hydrosystems.

In Section 5 we comment on the current suite of water quality variables and associated sampling and measurement methods, including the frequency of sampling.

Conclusions and recommendations are presented in Section 6.

2 Legislative context

Under the Resource Management Act 1991 (RMA), NRC is responsible for managing activities that affect coastal water quality in the Northland Region. Figure 2-1 illustrates the hierarchy of national and regional regulations and policy that guides NRC's management of coastal water quality. In this section, to provide context for later sections of this report, we briefly overview provisions in the National Policy Statement for Freshwater Management 2020 (NPSFM) of relevance to the CMA, and coastal water quality standards contained in NRC's Proposed Northland Regional Plan (PNRP).

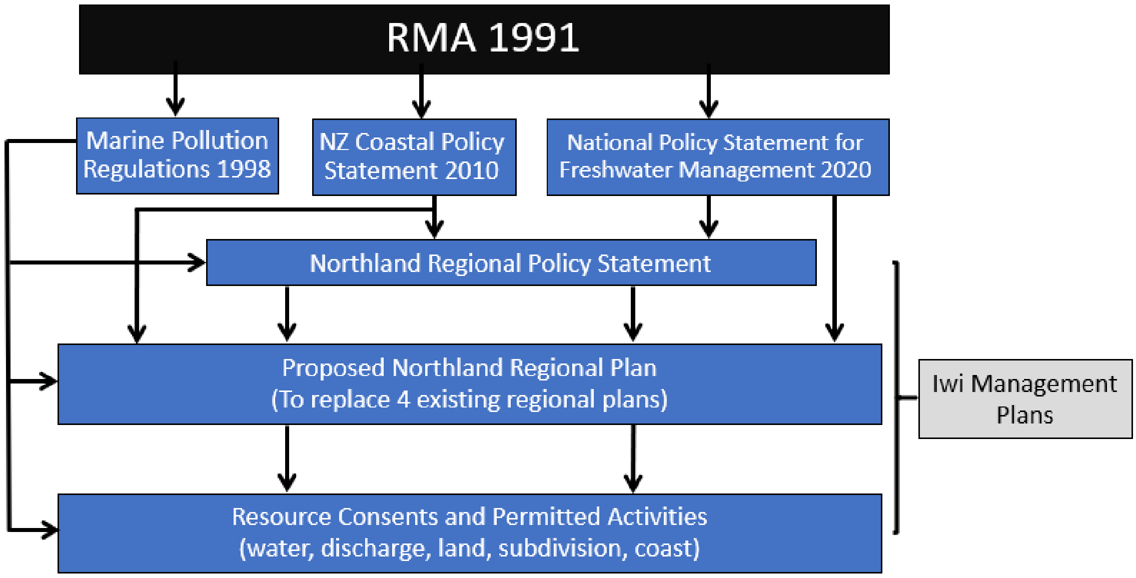

Figure 2-1: Summary of national and regional regulations and policy that guide NRC's management of coastal water quality. Once fully operative, the PNRP will replace NRC's four existing regional plans, including the Regional Coastal Plan and Regional Water and Soil Plan.

2.1 National Policy Statement for Freshwater Management 2020

The NPSFM 2020 provides national direction for freshwater management under the RMA. Of relevance to coastal water quality is Policy 3 which requires fresh water to be managed in an integrated way (*ki uta ki tai* – from the mountains to the sea) that considers the effects of land use and development *"on a whole-of-catchment basis, including the effects on receiving water environments".*

A key requirement of the NPSFM is for regional councils, in partnership with tangata whenua and the community, to establish environmental outcomes for ecosystem health (and other mandatory and relevant freshwater values) at the scale of a freshwater management unit (FMU). In order to achieve these outcomes, which are to be expressed as objectives in a Regional Plan, target state (i.e., condition) for a suite of relevant attributes (e.g., fine sediment) needs to be identified and limits on resource use (e.g., a land-use control, input control or output control) established to maintain or, through time, achieve the target attribute state. Importantly for coastal waters, the NPSFM (in clause 8(a) of Section 3.11) requires regional councils when setting target attribute states to have regard to:

i. the environmental outcomes and target attribute states of any receiving environments,

ii. the connections between water bodies, and

iii. the connection of water bodies to receiving environments.

This means that, in the case of ecosystem health, both instream and downstream receiving environment ecosystem health requirements will need to be taken into account when setting target attribute states. This recognises that depositional environments such as estuaries may be more sensitive to sediment, nutrient and other inputs than the rivers that flow into them. Further, it highlights the need to understand and manage contaminant loads entering estuarine and coastal waters. Figure 2-2 illustrates the proposed 13 FMUs for the Northland Region identified by NRC for inclusion in its PNRP.

Figure 2-2: Proposed freshwater management units for Northland. Source: NRC.

2.2 Proposed Northland Regional Plan for Northland

The PNRP is intended to be NRC's principal 'rule book' for managing activities that impact on Northland's freshwater, CMA and air quality, giving effect to various national policies and regulations established under the RMA (refer Figure 2-1). In terms of coastal water quality, the primary objective in the PNRP is F.1.2 (water quality) which states that the use of land and discharges of contaminants to land and water must be managed so that:

1. existing water quality is at least maintained, and improved where it has been degraded below the river, lake or coastal water quality standards set out in H.3 Water quality standards and guidelines, and
2. the sedimentation of continually or intermittently flowing rivers, lakes and coastal water is minimised, and
3. the life-supporting capacity, ecosystem processes and indigenous species, including their associated ecosystems, of fresh and coastal water are safeguarded, and the health of freshwater ecosystems is maintained, and
4. the health of people and communities, as affected by contact with fresh and coastal water, is safeguarded, and
5. the health and safety of people and communities, as affected by discharges of sewage from vessels, is safeguarded, and

[6 and 7 are omitted because they are not relevant to coastal water quality monitoring]

8. kai is safe to harvest and eat, and recreational, amenity and other social and cultural values are provided for.

The coastal water quality standards set out in Part H.3 (as Policy H.3.3) of the PNRP are reproduced in Table 2-1. Different coastal water quality standards apply to different types of coastal waters; Open Coast, Estuary, Tidal Creek, and (the tidal reach of) Hātea River (Figure 2-2). Each of these coastal waters is considered a 'management unit'. A key component of NRC's coastal water quality monitoring programme is to monitor state and trends in water quality at selected, representative sites across these different 'management units', to help gauge the effectiveness of provisions in NRC's PNRP (and non-regulatory measures such as catchment plans[1]) in managing coastal water quality (Griffiths 2021a).

By December 2024, NRC will need to publicly notify new water quality provisions for inclusion in the PNRP that give effect to the requirements of the NPSFM. This will likely result in changes to some of the existing water quality standards presented in Table H.3 as new FMUs and attributes are incorporated.

[1] The PNRP includes five 'priority catchments' (Mangere, Doubtless Bay, Waitangi, Poutū and Whangārei) which are subject to additional catchment-specific rules. Each catchment has its own Catchment Plan, a non-regulatory document which identifies desired community solutions to issues/problems that are impacting on waterbody uses and values in the catchment.

Table 2-1: Water quality standards for ecosystem health in coastal waters, contact recreation and shellfish consumption in the Northland Region. Reproduced from Table 25 of H.3 of NRC's PNRP. These standards form Policy H.3.1 and apply after allowing for reasonable mixing. The four Coastal water quality management units are Hātea River, Tidal creeks, Estuaries, and Open coastal waters.

Attribute	Unit	Compliance Metric	Coastal water quality management unit			
			Hātea River	Tidal creeks	Estuaries	Open coastal water
Dissolved oxygen	mg/L	Annual median	>6.2	>6.3	>6.9	No discernible change
		Minimum	4.6			
Temperature	°C	Maximum change	3			
pH	pH units are dimensionless	Annual minimum and annual maximum	7.0 - 8.5			8.0 - 8.4
Turbidity	NTU	Turbidity must be maintained at or below the current annual median or at or below pre-existing levels, whichever is lesser.	<7.5	<10.8	<6.9	No discernible change
Secchi depth	m	Annual median	>0.8	>0.7	>1.0	No discernible change
Chlorophyll-a	mg/L	Annual median	<0.003	<0.004	<0.004	No discernible change
Total phosphorus	mg/L	Annual median	<0.119	<0.040	<0.030	No discernible change
Total nitrogen	mg/L	Annual median	<0.860	<0.600	<0.220	No discernible change
Nitrite-nitrate nitrogen	mg/L	Annual median	<0.580	<0.218	<0.048	No discernible change
Ammoniacal nitrogen	mg/L	Annual median	<0.099	<0.043	<0.023	No discernible change
Copper	mg/L	Maximum	0.0013			0.0003
Lead	mg/L	Maximum	0.0044			0.0022
Zinc	mg/L	Maximum	0.0150			0.0070
Faecal coliforms	MPN/100mL	Median	Not applicable		≤14	≤14
		Annual 90th percentile	Not applicable		≤43	≤43
Enterococci	Enterococci /100mL	Annual 95th percentile	≤500	≤200	≤200	≤40

3 Monitoring locations

In this section we examine the representativeness of current water quality monitoring locations in the Northland CMA. We begin by briefly summarising the types of coastal water bodies present across the Northland Region. We evaluate those coastal water bodies that are monitored against freshwater inputs and flushing characteristics as key indicators of potential susceptibility to impacts from land-based contaminants. We then consider major land use in the catchments upstream of each coastal water body, with a focus on evaluating whether land use upstream of the monitored coastal water bodies is representative of the wider land use upstream of all coastal water bodies associated with the FMU. This is important because catchment land use represents a pressure, and most FMUs have more than one downstream coastal receiving water body. To assist our analysis, for each receiving water body, we estimate land-based catchment inputs of two major stressors on coastal water bodies: sediment and nutrients.

3.1 Current monitoring locations

Coastal water quality is currently monitored for aquatic ecosystem health purposes at a total of 44 sites across Northland (Figure 3-1), spanning eight coastal hydrosystems[2] (40 sites) and the open coast (4 sites). Griffiths (2021a) proposes to increase the total number of sites to 46. The current suite of sites spans all four coastal water quality management units specified in the PNRP (refer Table 2-1, Subsection 2.2).

3.1.1 Coastal hydrosystems

Table 3-1 presents a summary of key physical properties of Northland's coastal hydrosystems, including the physical classification (typology) of each according to both the New Zealand Hydrosystems Classification (Hume 2018; Hume et al. 2016; Hume et al. 2007) and Estuary Trophic Index (ETI) (Robertson et al. 2016; Zeldis et al. 2017a). Both of these classification methods incorporate flushing, dilution, depth and exposure characteristics because these characteristics determine the susceptibilities of hydrosystems to contamination from rivers. In general, coastal hydrosystems with a higher proportion of freshwater (less dilution) are more susceptible to contaminant loads from land (e.g., Plew et al. 2020). The estuaries listed in Table 3-1 are limited to those registered in NIWA's Coastal Explorer database.

A limitation of both NZHC and ETI classification approaches is that neither approach fully accounts for differences in dilution and mixing within individual hydrosystems. The Whangārei Harbour System provides a good example of this limitation; while this system overall has a relatively low contaminant load relative to its flushing and dilution characteristics, the Hātea River which flows to the Harbour through Whangārei City is poorly diluted and flushed in its lower, estuarine section and frequently exhibits poor water quality and associated eutrophication effects (Griffiths 2016; Griffiths 2021b). Physical classification using the NZHC and ETI nevertheless provides a useful screening tool to assess a coastal hydrosystem's susceptibility to contaminants.

[2] In this report we use the term 'coastal hydrosystems' in reference to the definition of 'mixohaline' coastal water bodies (i.e., those comprising a mix of freshwater and ocean water with a salinity somewhere between those of fresh waters and ocean water) as defined by Hume (2018). Estuaries are a subset of coastal hydrosystems. See Appendix A for more details.

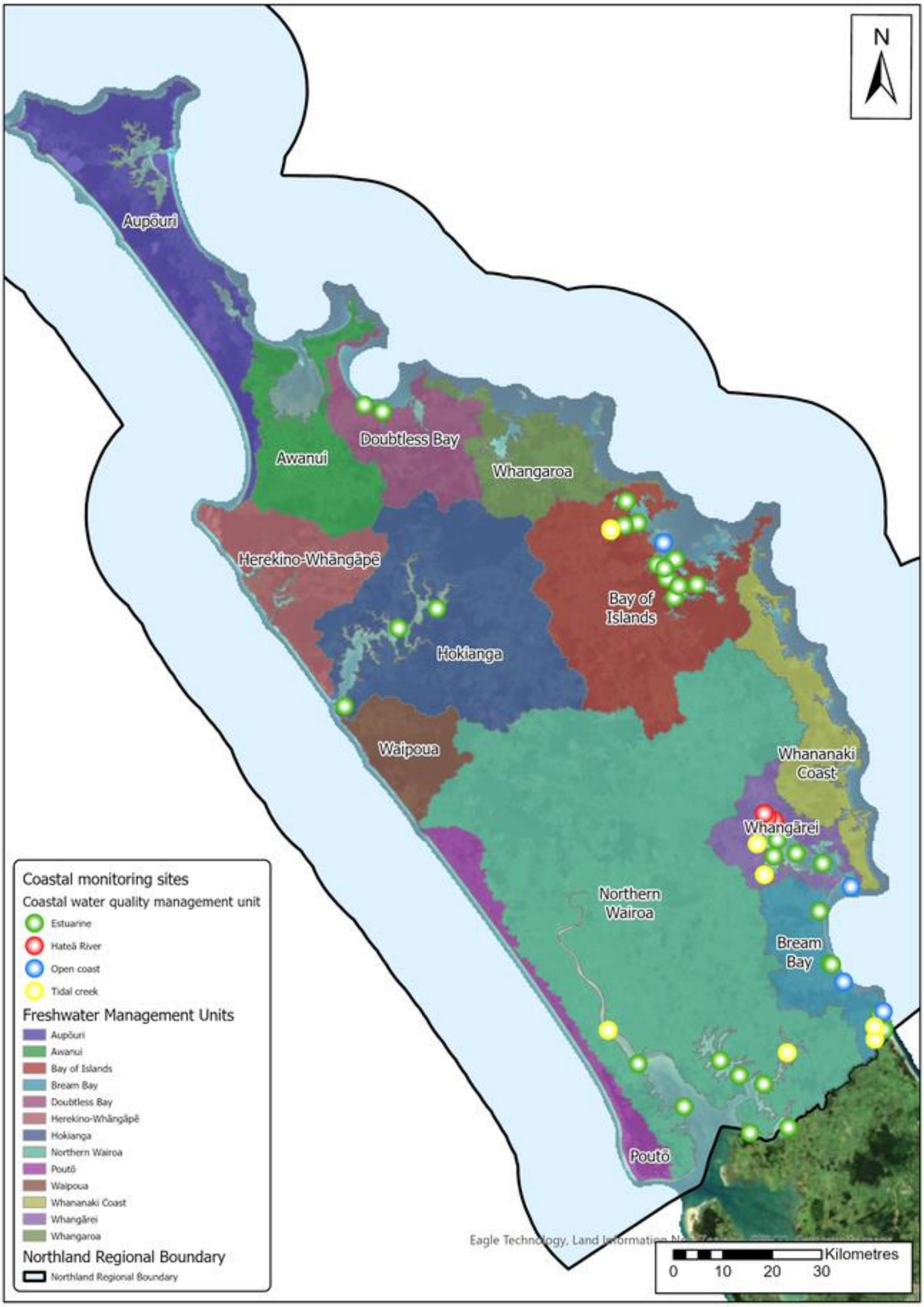

Figure 3-1: Proposed coastal water quality monitoring sites in the Northland Region based on the recommendations of Griffiths (2021a). The light blue area represents the extent of the CMA or New Zealand territorial sea. Source: NRC.

Table 3-1 shows that NRC's current monitoring effort is focussed more heavily towards hydrosystems which have a significant freshwater influence, particularly shallow intertidal dominated estuaries (SIDEs). This suggests that, overall, the programme is more likely to identify where coastal water quality problems are or may occur. While replicating monitored systems across Northland in proportion to the occurrence of hydrosystem types within the region would provide a more representative picture of overall coastal water quality (Dudley et al. 2017), in our view the current focus better informs NRC's management of the effects of land use and development on coastal water quality under the PNRP and the NPSFM 2020. Moreover, including a large number of sites with minimal freshwater influence is likely to produce datasets with large amounts of 'non-detects'. Large numbers of non-detects (i.e., >15% of all sample results) are a particular problem for nutrient and microbial sampling in oceanic waters and sites with many non-detects are typically excluded from temporal trend analysis (Larned et al. 2015).

A possible disadvantage to the current monitoring approach is that changes in oceanic water across the Northland Region are less likely to be well-understood. Understanding changes in open coastal waters (e.g., increasing water temperature) may aid interpretation of water quality state and trends in estuaries and other semi-enclosed coastal water bodies. Increased monitoring in the 'Open Coast' CMU would improve understanding of the causes of changes in sensitive estuary waters. Open coastal monitoring sites are discussed next.

3.1.2 Open coast

Four sites are currently monitored in the open coast, clustered in the south-east of region, offshore from the Bream Bay, Whangārei and Bay of Islands FMUs (Figure 3-1). Consideration could be given to extending (or splitting) the current monitoring effort of the 'Open Coast' CMU across to the west coast to provide data on oceanic inputs to coastal hydrosystems on this coast. For example, a site representing ocean water contributions to Hokianga Harbour would provide a central point on the western coast of the Northland Region. As discussed in Section 4, dilution modelling of catchment contaminant inputs to estuaries requires oceanic water quality data to calculate mixing within an estuary. While these sites do not need to be immediately adjacent to monitored estuaries, they should be in sufficiently close proximity to monitored estuaries that they can provide an indicative understanding of regional ocean water chemistry.

Table 3-1: Physical characteristics of Northland's coastal hydrosystems, ordered from least to most freshwater input. Residence time and dilution data were calculated according to Plew et al. (2020) and intertidal areas were taken from NIWA's Coastal Explorer Database. Bracketed site numbers represent the number of sites recommended by Griffiths (2021a). Waitangi Estuary is included in the Opua Inlet System for this comparison. Refer Appendix A and Hume (2018) for details of the NZCHS and ETI classes.

Coastal hydrosystem name	Ratio freshwater	Flushing time (days)	Intertidal area (%)	No. of monitoring sites	NZCHS class	ETI class
Whangamumu Harbour	0.007	86.9	0.5	-	Coastal embayment	DSDE
Mimiwhangata Bay	0.010	29.9	2.8	-	Coastal embayment	DSDE
Matai Bay	0.011	47.5	6.5	-	Coastal embayment	DSDE
Bland Bay	0.011	26.1	2.8	-	Coastal embayment	DSDE
Awahoa Bay	0.012	15.4	9.5	-	Coastal embayment	DSDE
Oke Bay	0.013	50.2	0.9	-	Coastal embayment	DSDE
Manawaora Bay	0.018	30.8	7.5	-	Coastal embayment	DSDE
Deep Water Cove	0.022	111.6	0.2	-	Coastal embayment	DSDE
Paroa Bay	0.026	16.0	27.3	-	Coastal embayment	DSDE
Whangārei Harbour System	0.029	29.0	58.4	10	Shallow drowned valley	SIDE
Parengarenga Harbour System	0.031	13.7	82.0	-	Shallow drowned valley	SIDE
Takerau Bay	0.039	29.8	1.3	-	Coastal embayment	DSDE
Tutukaka Harbour	0.041	23.3	3.7	-	Deep drowned valley	DSDE
Taiharuru River	0.051	9.9	86.8	-	Tidal lagoon (permanently open)	SIDE
Taemaro Bay	0.056	24.1	3.0	-	Coastal embayment	DSDE
Kaipara Harbour System	0.058	21.3	41.9	9	Shallow drowned valley	SIDE
Rangaunu Harbour	0.068	17.0	77.9	-	Shallow drowned valley	SIDE
Whangaruru Harbour	0.071	18.4	25.9	-	Deep drowned valley	SIDE
Parekura Bay	0.072	22.0	37.0	-	Coastal embayment	SIDE
Houhora Harbour	0.078	10.9	87.1	-	Shallow drowned valley	SIDE
Te Puna /Kerikeri Inlet System	0.084	21.6	11.4	*5 (4)	Deep drowned valley	DSDE
Whangaihe Bay	0.096	19.4	2.9	-	Coastal embayment	DSDE
Mangawhai Harbour	0.101	11.2	67.3	4	Tidal lagoon (permanently open)	SIDE
Helena Bay	0.110	16.9	3.0	-	Coastal embayment	DSDE
Mahinepua Bay	0.114	12.1	2.5	-	Coastal embayment	DSDE

Coastal hydrosystem name	Ratio freshwater	Flushing time (days)	Intertidal area (%)	No. of monitoring sites	NZCHS class	ETI class
Whangaroa Harbour	0.118	18.8	32.4	-	Deep drowned valley	SIDE
Hokianga Harbour System	0.119	15.8	48.7	*0 (3)	Shallow drowned valley	SIDE
Herekino Harbour	0.142	7.1	84.3	-	Shallow drowned valley	SIDE
Opua Inlet System	0.143	14.5	20.2	*8 (7)	Deep drowned valley	DSDE
Ngunguru River	0.161	9.9	54.7	-	Tidal lagoon (permanently open)	SIDE
Pataua River	0.170	6.6	84.6	-	Tidal lagoon (permanently open)	SIDE
Matapouri Estuary MBS	0.175	5.9	96.1	-	Tidal lagoon (permanently open)	SIDE
Tapotupotu Bay	0.176	8.0	0.9	-	Tidal lagoon (intermittently closed)	SSRTRE
Matapouri Bay System (MBS)	0.182	7.1	61.0	-	Tidal lagoon (permanently open)	SIDE
Waimahana Bay	0.192	15.5	8.0	-	Coastal embayment	DSDE
Tanutanu Stream	0.203	6.8	0.8	-	Beach Stream (stream with pond)	SSRTRE
Whāngāpē Harbour System	0.205	6.7	67.1	-	Shallow drowned valley	SIDE
Whananaki Inlet	0.227	6.2	75.3	-	Tidal lagoon (permanently open)	SIDE
Matapouri Bay MBS	0.235	12.0	18.9	-	Coastal embayment	DSDE
Mangonui Harbour	0.236	4.4	68.0	-	Shallow drowned valley	SIDE
Tapuaetahi Creek	0.246	4.5	84.3	-	Tidal lagoon (permanently open)	SIDE
Waiatua Stream	0.255	5.1	5.0	-	Beach Stream (stream with pond)	DSDE
Horahora River	0.287	3.7	69.7	-	Tidal lagoon (permanently open)	SIDE
Ruakaka River	0.298	4.5	50.4	1	Tidal lagoon (permanently open)	SIDE
Taipa River	0.325	3.6	52.4	*0 (1)	Tidal lagoon (permanently open)	SIDE
Tahoranui River	0.327	3.1	24.9	-	Tidal lagoon (permanently open)	SIDE
Waipu River	0.332	3.6	40.6	2	Tidal lagoon (permanently open)	SIDE
Awapoko River	0.347	3.1	47.5	1	Tidal river mouth (spit enclosed)	SIDE
Takou River	0.357	2.2	57.1	-	Tidal lagoon (permanently open)	SIDE
Waimamaku River	0.471	0.9	32.0	-	Tidal river mouth (spit enclosed)	SSRTRE
Waipoua River	0.531	0.7	21.7	-	Tidal river mouth (spit enclosed)	SSRTRE
Waitangi Stream	1.000	4.4	0.4	-	Beach Stream (stream with pond)	COASTAL LAKE
Waitahora Stream	1.000	25.8	0.0	-	Tidal lagoon (intermittently closed)	COASTAL LAKE

3.2 Upstream catchment land use, and linkages with FMUs

Monitoring of coastal hydrosystems stratified across differing contaminant pressures from land use helps deliver a picture of regional coastal water quality representative of 'average' upstream catchment conditions. It also facilitates comparisons of state and trend among selected land use classes. This may include monitoring of 'reference state' coastal hydrosystems to provide context when examining water quality and ecological state in systems under higher pressure. Whether these comparisons are carried out for sites only within the Northland Region, or via inclusion of NRC monitoring data into national SOE reporting, these comparisons are made possible by monitoring water quality in hydrosystems spanning a range of upstream land use types. This topic is already covered well by Griffiths (2021a), but in Table 3-2 we attempt to add value to that work by providing a breakdown of major land use types in the upstream catchment of monitored coastal hydrosystems relative to land use upstream of all coastal hydrosystems in the Northland Region. In Table 3-3 we focus at the FMU scale and compare land use upstream of monitored hydrosystems within each FMU to the overall land use upstream of all hydrosystems in the FMUs they are located in. The Poutō FMU is not represented in Table 3-2 because there are no coastal hydrosystems within this FMU recorded in NIWA's Coastal Explorer Database; freshwater passage to the sea within the Poutō FMU appears to us to likely occur via discharge through or over beach sands.

For the above assessments upstream land use was determined for each of the coastal hydrosystems from the land use layer recently updated for the Catchment Land Use for Environmental Sustainability model (CLUES; Elliott et al. 2016). The land use pertains to the reference year 2017 and was developed with reference to a number of sources, most notably LCDB5 (Maanaki Whenua – Landcare Research)[3] and Agribase (AsureQuality)[4]. The layer is very similar to that used for CLUES modelling of the Northland Region by Semadeni-Davies et al. (2021)[5]. The method used was as follows.

1. Trace the River Environments Classification (REC, version 2.5)[6] stream network upstream from each terminal reach draining to each coastal hydrosystem to map the boundaries of the system's catchments.
2. Intersect the catchment boundaries by the CLUES model land use layer.
3. Calculate the total area of each land use type within each catchment.

The 19 land use classes in the CLUES model were aggregated for reporting into seven classes: dairy, sheep and beef, all other pasture, crops and horticulture, exotic forest, native forest and scrub, and other land uses (including urban and those not specifically classified in the model, such as quarries). The catchment area under each land use class is reported in km^2 along with the land use areas for Northland in total.

[3] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/
[4] https://www.asurequality.com/services/agribase/
[5] There are minor differences following a national roll out of the land use layer that required some reclassification of land covers from LCDB5.
[6] https://niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0

Table 3-2: Summary of upstream catchment land use (km²) for individual coastal hydrosystems in Northland grouped by freshwater management unit (FMU). Percentage catchment area is in parentheses. Bracketed site numbers represent the number of sites recommended by Griffiths (2021a). Waitangi Estuary is included in the Opua Inlet System for this comparison, and the Kaipara Harbour System has been broken into Northland and Auckland (regional) sections.

Coastal hydrosystem name	FMU	No. of monitoring sites	Dairy	Sheep and beef	Deer and other stock	Crops and horticulture	Exotic forest	Native forest and scrub	Other	Total catchment area
Houhora Harbour	Aupōuri	-	7.6 (7.1%)	36.3 (33.9%)	6.3 (5.9%)	5.9 (5.5%)	35.5 (33.1%)	15.3 (14.2%)	0.4 (0.4%)	107
Parengarenga Harbour System	Aupōuri	-	2.3 (1.4%)	49.2 (29.4%)	0.6 (0.4%)	0 (0%)	52.2 (31.2%)	62.6 (37.5%)	0.2 (0.1%)	167
Tapotupotu Bay	Aupōuri	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	12.9 (100%)	0 (0%)	13
Waitahora Stream	Aupōuri	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	5.6 (100%)	0 (0%)	6
Waitangi Stream	Aupōuri	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3.7 (35.1%)	6.9 (64.9%)	0 (0%)	11
Rangaunu Harbour	Awanui	-	109.4 (20.9%)	191.4 (36.6%)	26.9 (5.1%)	7.9 (1.5%)	27.9 (5.3%)	155.2 (29.7%)	4.8 (0.9%)	524
Deep Water Cove	Bay of Islands	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	2.5 (100%)	0 (0%)	2
Manawaora Bay	Bay of Islands	-	0 (0%)	3.2 (31.3%)	0.1 (1%)	0 (0%)	0.1 (0.9%)	6.8 (66.4%)	0 (0.4%)	10
Oke Bay	Bay of Islands	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0.7 (100%)	0 (0%)	1
Opua Inlet System	Bay of Islands	*8 (7)	143.8 (15.9%)	226.9 (25.1%)	31.2 (3.5%)	1.3 (0.1%)	130.6 (14.4%)	364.5 (40.3%)	5.7 (0.6%)	904
Parekura Bay	Bay of Islands	-	0 (0%)	2.8 (13.1%)	0.5 (2.1%)	0 (0%)	1.2 (5.4%)	17.1 (79.3%)	0 (0%)	22
Paroa Bay	Bay of Islands	-	0 (0%)	0.1 (3.7%)	0 (0.8%)	0 (1.1%)	0.7 (22.8%)	2.2 (71.1%)	0 (0.5%)	3
Te Puna /Kerikeri Inlet System	Bay of Islands	*5 (4)	42.7 (19%)	78.2 (34.9%)	19.3 (8.6%)	17.9 (8%)	25.1 (11.2%)	33.4 (14.9%)	7.6 (3.4%)	224
Mangawhai Harbour	Bream Bay	4	13.8 (23.4%)	11.1 (18.9%)	11.6 (19.7%)	1.4 (2.3%)	1.9 (3.1%)	16.2 (27.4%)	3.1 (5.2%)	59
Ruakaka River	Bream Bay	1	28.2 (33.7%)	19 (22.8%)	7.9 (9.5%)	0.1 (0.1%)	2 (2.4%)	25.1 (30.1%)	1.2 (1.4%)	83
Waipu River	Bream Bay	2	6.8 (49.6%)	1.1 (8.3%)	2.7 (19.8%)	0 (0.2%)	0.6 (4.3%)	2.3 (17.1%)	0.1 (0.8%)	14
Awapoko River	Doubtless Bay	1	19 (20.9%)	33.8 (37.2%)	3.4 (3.7%)	0 (0%)	2.6 (2.9%)	32 (35.2%)	0 (0%)	91
Mangonui Harbour	Doubtless Bay	-	22.1 (8.7%)	84 (33.1%)	4.2 (1.7%)	1.6 (0.6%)	31.3 (12.4%)	109.4 (43.1%)	1.1 (0.4%)	254
Matai Bay	Doubtless Bay	-	0 (1.3%)	0.5 (18.4%)	0 (0%)	0 (0%)	0 (0.3%)	2.3 (80.1%)	0 (0%)	3
Taipa River	Doubtless Bay	*0 (1)	13 (10.5%)	28.1 (22.6%)	4.4 (3.5%)	0.2 (0.2%)	19.9 (16%)	58.7 (47.2%)	0 (0%)	124
Takerau Bay	Doubtless Bay	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (100%)	0 (0%)	1

Coastal hydrosystem name	FMU	No. of monitoring sites	Dairy	Sheep and beef	Deer and other stock	Crops and horticulture	Exotic forest	Native forest and scrub	Other	Total catchment area
Herekino Harbour	Herekino-Whāngāpē	-	2.3 (2.7%)	26.8 (30.8%)	2.6 (3%)	0 (0%)	6.7 (7.7%)	48.4 (55.7%)	0 (0%)	87
Tanutanu Stream		-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0.1%)	11 (99.9%)	0 (0%)	11
Whāngāpē Harbour System		-	5.3 (1.8%)	83.7 (28.9%)	5.9 (2%)	0 (0%)	54.7 (18.9%)	140.1 (48.3%)	0.1 (0%)	290
Hokianga Harbour System	Hokianga	*0 (3)	134.6 (9%)	402.5 (27%)	30.9 (2.1%)	2.2 (0.1%)	205.9 (13.8%)	710.4 (47.6%)	5.3 (0.4%)	1492
Kaipara Harbour System (Northland)	Northern Wairoa		1155.5 (27.3%)	1318.4 (31.1%)	191.4 (4.5%)	46.4 (1.1%)	655.4 (15.5%)	861.2 (20.3%)	11.7 (0.3%)	4240
Kaipara Harbour System (Auckland)			188.5 (14.6%)	466.7 (36.1%)	161.1 (12.4%)	22.9 (1.8%)	230.2 (17.8%)	210.4 (16.3%)	14.5 (1.1%)	1294
Kaipara Harbour System (Total)		9	1344 (24.3%)	1785.1 (32.3%)	352.5 (6.4%)	69.4 (1.3%)	885.6 (16%)	1071.5 (19.4%)	26.3 (0.5%)	5534
Waimamaku River	Waipoua	-	17.6 (13.4%)	27 (20.6%)	3.9 (3%)	0.2 (0.2%)	4.2 (3.2%)	78.3 (59.6%)	0.1 (0.1%)	131
Waipoua River		-	0.8 (0.8%)	1.6 (1.5%)	1.5 (1.4%)	0 (0%)	18 (16.2%)	88.8 (80.2%)	0 (0%)	111
Bland Bay	Whananaki Coast	-	0 (0%)	0.1 (5%)	0.2 (8%)	0 (0%)	1.2 (44.2%)	1.2 (42.8%)	0 (0%)	3
Helena Bay		-	0 (0%)	5.9 (23%)	0.6 (2.5%)	0 (0%)	3.7 (14.5%)	15.4 (60%)	0 (0%)	26
Horahora River		-	3 (3.5%)	27.2 (32.4%)	6.3 (7.5%)	1.1 (1.3%)	20.3 (24.2%)	26.1 (31%)	0.1 (0.2%)	84
Matapouri Bay System		-	0 (0.3%)	2.7 (19.9%)	0.9 (6.7%)	0 (0%)	2 (15.3%)	7.4 (55.8%)	0.3 (1.9%)	13
Mimiwhangata Bay		-	0 (0%)	1.5 (59.4%)	0.3 (14%)	0 (0%)	0 (0%)	0.7 (26.6%)	0 (0%)	2
Ngunguru River		-	2.3 (2.9%)	18.7 (23.8%)	3.8 (4.8%)	0.1 (0.2%)	17 (21.6%)	36.3 (46.2%)	0.4 (0.5%)	79
Patua River		-	6.7 (13.7%)	8.7 (17.6%)	4 (8.1%)	0 (0%)	8.7 (17.8%)	21 (42.7%)	0.1 (0.1%)	49
Taiharuru River		-	3.7 (29.1%)	5.2 (41.2%)	1.1 (8.7%)	0 (0.1%)	0.3 (2.3%)	2.3 (18.5%)	0 (0.2%)	13
Tutukaka Harbour		-	0 (0%)	0.7 (18.3%)	0.2 (4.8%)	0 (0%)	0.9 (23.3%)	1.9 (50.7%)	0.1 (3%)	4
Whananaki Inlet		-	2.1 (4%)	11.3 (21.4%)	0.8 (1.5%)	0 (0%)	0.8 (1.5%)	38.1 (71.7%)	0 (0%)	53
Whangamumu Harbour		-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1.3 (100%)	0 (0%)	1
Whangaruru Harbour		-	1.8 (3%)	2.2 (3.6%)	1.9 (3.1%)	0 (0%)	2.7 (4.4%)	52.8 (85.7%)	0.1 (0.2%)	62
Waiatua Stream	Whangārei	-	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (17.4%)	4.6 (82.6%)	0 (0%)	6
Whangārei Harbour System		10	34.3 (13.6%)	43.7 (17.4%)	36.9 (14.7%)	3.5 (1.4%)	25.4 (10.1%)	76.7 (30.5%)	31.2 (12.4%)	252

Coastal hydrosystem name	FMU	No. of monitoring sites	Dairy	Sheep and beef	Deer and other stock	Crops and horticulture	Exotic forest	Native forest and scrub	Other	Total catchment area
Mahinepua Bay	Whangaroa	-	0 (0%)	1.2 (20%)	0.1 (1.9%)	0 (0%)	1 (15.6%)	3.9 (62.6%)	0 (0%)	6
Taemaro Bay		-	0 (0%)	0.1 (1.6%)	0 (0%)	0 (0%)	0.2 (4.2%)	3.9 (94.2%)	0 (0%)	4
Tahoranui River		-	0 (0.1%)	15.5 (57.9%)	0.2 (0.7%)	0.4 (1.5%)	7 (26%)	3.7 (13.9%)	0 (0%)	27
Takou River		-	16.6 (23.4%)	30.9 (43.6%)	0.9 (1.3%)	0.1 (0.1%)	5.6 (7.9%)	16.8 (23.8%)	0.1 (0.1%)	71
Tapuaetahi Creek		-	0 (0%)	6.4 (57.8%)	0.1 (0.8%)	0 (0%)	3.2 (28.7%)	1.4 (12.4%)	0 (0.4%)	11
Waimahana Bay		-	0 (0%)	0.3 (4.5%)	0.2 (2.3%)	0 (0%)	0 (0%)	6.8 (93.2%)	0 (0%)	7
Whangaihe Bay		-	0 (0%)	0.4 (18.5%)	0 (0%)	0 (0%)	1.3 (64.1%)	0.4 (17.4%)	0 (0%)	2
Whangaroa Harbour		-	18.8 (7.8%)	60.8 (25.2%)	4.3 (1.8%)	0 (0%)	21.5 (8.9%)	135.3 (56.1%)	0.4 (0.2%)	241

Table 3-3: Land use by area (km² and percentage) for upstream catchments of monitored coastal hydrosystems in Northland relative to the total land use across the upstream catchments of all coastal hydrosystems within each FMU. Note that monitored hydrosystems include those not currently monitored but recommended by Griffiths (2021a). Rows shaded in grey indicate FMUs in which no downstream coastal hydrosystem is currently monitored.

FMU		Dairy	Sheep and Beef	Deer and other stock	Crops and horticulture	Exotic forest	Native forest and scrub	Other	Total catchment area
Aupōuri	Total	9.9 (3.3%)	85.5 (28.1%)	6.9 (2.3%)	5.9 (1.9%)	91.4 (30.1%)	103.3 (34%)	0.6 (0.2%)	304
Awanui	Total	109.4 (20.9%)	191.4 (36.5%)	26.9 (5.1%)	7.9 (1.5%)	27.9 (5.3%)	155.2 (29.6%)	4.8 (0.9%)	524
Bay of Islands	Monitored hydrosystems	186.5 (16.5%)	305.1 (27%)	50.5 (4.5%)	19.2 (1.7%)	155.7 (13.8%)	397.9 (35.3%)	13.3 (1.2%)	1,128
	Total	186.5 (16%)	311.2 (26.7%)	50.6 (4.3%)	19.2 (1.6%)	157.7 (13.5%)	427.2 (36.6)	13.3 (1.1%)	1,166
Bream Bay	Monitored hydrosystems	48.8 (31.3%)	31.2 (20%)	22.2 (14.2%)	1.5 (1%)	4.5 (2.9%)	43.6 (27.9%)	4.4 (2.8%)	156
	Total	48.8 (31.3%)	31.2 (20%)	22.2 (14.2%)	1.5 (1%)	4.5 (2.9%)	43.6 (27.9%)	4.4 (2.8%)	156
Doubtless Bay	Monitored hydrosystems*	32 (14.9%)	61.9 (28.8%)	7.8 (3.6%)	0.2 (0.1%)	22.5 (10.5%)	90.7 (42.2%)	0	215
	Total	54.1 (11.4%)	146.4 (31%)	12 (2.5%)	1.8 (0.4%)	53.8 (11.4%)	203.4 (43%)	1.1 (0.2%)	473
Herekino-Whāngāpē	Total	7.6 (2%)	110.5 (28.5%)	8.5 (2.2%)	0	61.4 (15.8%)	199.5 (51.4%)	0.1 (< 0.1%)	388
Hokianga	Monitored hydrosystems*	134.6 (9%)	402.5 (27%)	30.9 (2.1%)	2.2 (0.1%)	205.9 (13.8%)	710.4 (47.6%)	5.3 (0.4%)	1,492
	Total	134.6 (9%)	402.5 (27%)	30.9 (2.1%)	2.2 (0.1%)	205.9 (13.8%)	710.4 (47.6%)	5.3 (0.4%)	1,492
Northern Wairoa	Monitored hydrosystems	1,344 (24.3%)	1,785 (32.3%)	352.5 (6.4%)	69.4 (1.3%)	885.6 (16%)	1,072 (19.4%)	26.3 (0.5%)	5,534
	Total	1,344 (24.3%)	1,785 (32.3%)	352.5 (6.4%)	69.4 (1.3%)	885.6 (16%)	1,072 (19.4%)	26.3 (0.5%)	5,534
Waipoua	Total	18.4 (7.6%)	28.6 (11.8%)	5.4 (2.2%)	0.2 (0.1%)	22.2 (9.2%)	167.1 (69%)	0.1 (< 0.1%)	242
Whananaki Coast	Total	19.6 (5%)	84.2 (21.6%)	20.1 (5.2%)	1.2 (0.3%)	57.6 (14.8%)	204.5 (52.6%)	1.1 (0.3%)	389
Whangārei	Monitored hydrosystems	34.3 (13.6%)	43.7 (17.3%)	36.9 (14.6%)	3.5 (1.4%)	25.4 (10.1%)	76.7 (30.4%)	31.2 (12.4%)	252
	Total	34.3 (13.3%)	43.7 (16.9%)	36.9 (14.3%)	3.5 (1.4%)	26.4 (10.2%)	81.3 (31.5%)	31.2 (12.1%)	258
Whangaroa	Total	35.4 (9.6%)	115.6 (31.3%)	5.8 (1.6%)	0.5 (0.1%)	39.8 (10.8%)	172.2 (46.7%)	0.4 (0.1%)	369
Total	**All monitored hydrosystems***	1,780 (20.3%)	2,630 (31.3%)	500.8 (1.6%)	96 (0.1%)	1,303 (14.8%)	2,398 (27.3%)	80.5 (0.9%)	8,788
	Total area	2,105 (16.6%)	3,648 (28.7%)	618.3 (4.9%)	117.1 (0.9%)	2,039 (16%)	4,081 (32.1%)	98.1 (0.8%)	12,707
	Northland area**	1,917 (16.8%)	3,181 (27.9%)	457.3 (4%)	94.2 (0.8%)	1,809 (15.9%)	3,871 (33.9%)	83.5 (0.7%)	11,412

* Including estuaries not currently monitored but recommended for monitoring by Griffiths (2021a). ** Excluding the Auckland section of the Kaipara Harbour catchment.

Table 3-2 illustrates that water quality is currently monitored in one or more coastal hydrosystems located downstream of five of NRC's 12 FMUs[7]; coverage will increase to six FMUs with the addition of monitoring sites in Hokianga Harbour proposed by Griffiths (2021a). Overall, the coastal hydrosystems monitored appear to provide a good representation of FMU land cover (e.g., the two systems monitored in the Bay of Islands FMU collectively capture over 96% of FMU drainage). The possible exception is the Doubtless Bay FMU; currently only one of five downstream coastal hydrosystems is monitored (Awapoko River) and this receives <20% of land drainage from the upstream FMU. The proposed addition of a second coastal system (Taipa River) by Griffiths (2021a) is supported and, as illustrated in Table 3-3, will provide for a more representative understanding of FMU drainage impacts on coastal water quality (Awapoko River has an upstream catchment comprising a greater proportion of dairying than the larger catchments of Taipa River and Mangonui Harbour).

Most of the six FMUs (with any coastal hydrosystems) that lack any downstream coastal water quality monitoring comprise multiple coastal hydrosystems, many of which have relatively small upstream catchments (e.g., Whananaki Coast FMU).[8] The notable exception is the Awanui FMU which drains to a single coastal hydrosystem, Rangaunu Harbour, which receives drainage from a relatively large upstream catchment (524 km^2) comprising significant (>60%) agricultural land use.

Table 3-3 suggests that, overall, land use composition in the upstream catchment of monitored coastal hydrosystems provides a reasonable representation of the land use composition of the total catchment area upstream of all Northland's coastal hydrosystems, albeit with a slight over-representation of dairy and sheep and beef land uses. Were the existing monitoring network to be expanded we would suggest the inclusion of systems in currently un-represented FMUs (Aupōuri, Whananaki Coast, Whangaroa, Waipoua, Herekino-Whāngāpē and/or Awanui). Table 3-1 and Table 3-2 could be consulted to select coastal hydrosystems with upstream catchment land uses representative of those within the greater FMU (e.g., Whāngāpē Harbour System within Herekino-Whāngāpē FMU). Another consideration in any additional coastal hydrosystems is their susceptibility to impacts from upstream inputs. This is addressed next.

3.3 Combined coastal hydrosystem susceptibility and pressure across FMUs

As an extension to the assessment presented in Subsection 3.1 and 3.2, in Table 3-4 we summarise modelled catchment sediment and nutrient loads delivered to downstream coastal hydrosystems, along with the expected susceptibility of these systems to (nutrient-driven) eutrophication across Northland FMUs. While sediment and nutrients are not the only contaminants of concern to coastal hydrosystems, they represent two widely recognised stressors (Hewitt et al. 2014) and currently can be more reliably modelled than other contaminants such as pathogens. The measure of susceptibility to eutrophication is calculated using the methods of Plew et al. (2020) which uses a combination of the sensitivity parameters given in Table 3-1 as well as catchment nutrient loads.

[7] There are 13 FMUs (refer Figure 3-1) but we consider only 12 here with the Poutō FMU excluded (see p.18).

[8] Interestingly all three hydrosystems downstream of the Bream Bay FMU are monitored (including four sites on Mangawhai Harbour), despite these having relatively small upstream catchment areas.

Table 3-4: Summary of sediment loads, nutrient concentrations and susceptibility to eutrophication ratings for coastal hydrosystems in Northland, grouped by upstream FMU. Sediment loads were modelled following Hicks et al. (2019) and nutrient concentration estimates were determined using a customised version of the CLUES model with a regional calibration for Northland (Semadeni-Davies et al. 2021). Eutrophication susceptibility via excessive growth of macroalgae and phytoplankton are also reported; ETI susceptibility band gives an overall susceptibility score assessed using ETI Tool 1. All eutrophication susceptibility scores were calculated following Plew et al. (2020), where Band A = minimal eutrophication and Band D = very high eutrophication.

Coastal hydrosystem name	FMU	No. of monitoring sites	Areal sediment load (g/m^2/year)	Estuary TN mg/m^3	Estuary TP mg/m^3	Macroalgae Susceptibility Band	Phytoplankton Susceptibility Band	ETI Susceptibility Band
Parengarenga Harbour System	Aupōuri	-	103	71.9	12.6	A	A	**A**
Tapotupotu Bay		-	827	102.6	15	B	B	**B**
Houhora Harbour		-	80	116.5	16.1	B	B	**B**
Waitahora Stream		-	387	429.1	48.7	A	C	**C**
Waitangi Stream		-	3,183	560.1	67.9	A	C	**C**
Rangaunu Harbour	Awanui	-	307	145.1	21.3	B	B	**B**
Oke Bay	Bay of Islands	-	70	42.3	6.9	A	A	**A**
Deep Water Cove		-	127	45.1	7.4	A	A	**A**
Manawaora Bay		-	94	52.2	8.4	A	A	**A**
Paroa Bay		-	104	57	9.3	A	A	**A**
Parekura Bay		-	383	69.9	11.7	A	B	**B**
Te Puna /Kerikeri Inlet System		*5 (4)	232	175.5	14	B	C	**C**
Opua Inlet System		*8 (7)	2,484	224.1	39	C	C	**C**
Mangawhai Harbour	Bream Bay	4	599	191.8	28.7	B	B	**B**
Waipu River		2	10,318	586.2	84.7	D	A	**D**
Ruakaka River		1	6,800	771.8	93.4	D	A	**D**
Matai Bay	Doubtless Bay	-	24	50.9	8.9	A	A	**A**
Takerau Bay		-	93	64.1	8.7	A	A	**A**
Mangonui Harbour		-	2,555	222.7	48.2	C	A	**C**
Taipa River		*0 (1)	7,697	312.2	54.2	C	A	**C**
Awapoko River		1	20,777	577.5	132.1	D	A	**D**
Tanutanu Stream	Herekino-Whāngāpē	-	2,022	182.6	18	B	A	**A**
Herekino Harbour		-	1,729	164.7	33.7	B	A	**B**

Coastal hydrosystem name	FMU	No. of monitoring sites	Areal sediment load ($g/m^2/year$)	Estuary TN mg/m^3	Estuary TP mg/m^3	Macroalgae Susceptibility Band	Phytoplankton Susceptibility Band	ETI Susceptibility Band
Whangapē Harbour System		-	413	188.8	46.8	B	A	**B**
Hokianga Harbour System	Hokianga	*0 (3)	1,711	153	34.4	B	B	**B**
Kaipara Harbour System	Northern Wairoa	9	671	117.5	22.2	B	B	**B**
Waipoua River	Waipoua	-	22,016	237.4	29.8	C	A	**C**
Waimamaku River		-	63,965	453.3	106.7	D	A	**D**
Whangamumu Harbour	Whananaki Coast	-	39	41.9	6.7	A	A	**A**
Bland Bay		-	36	44.7	7	A	A	**A**
Mimiwhangata Bay		-	53	48.4	7.4	A	A	**A**
Tutukaka Harbour		-	190	62.1	9.7	A	A	**A**
Whangaruru Harbour		-	389	77.8	12.8	A	A	**A**
Helena Bay		-	800	90.4	17.9	B	B	**B**
Taiharuru River		-	162	116.4	17.6	B	A	**B**
Matapouri Bay System (MBS)		-	908	127.5	20.5	B	A	**B**
Ngunguru River		-	994	145.7	29.3	B	B	**B**
Pataua River		-	34,102	195.4	36.3	B	A	**B**
Whananaki Inlet		-	1,634	198.4	34.6	B	A	**B**
Horahora River		-	3,528	348.9	46.5	D	A	**D**
Whangārei Harbour System	Whangārei	10	143	74.9	11	A	A	**A**
Waiatua Stream		-	3,305	219.8	24.5	C	A	**C**
Taemaro Bay	Whangaroa	-	144	68.4	9.6	A	A	**A**
Whangaihe Bay		-	612	89.8	17.3	B	A	**A**
Mahinepua Bay		-	610	112.9	20.2	B	A	**A**
Waimahana Bay		-	993	129.1	16	B	B	**B**
Whangaroa Harbour		-	1,368	136.2	32.8	B	B	**B**
Tapuaetahi Creek		-	1,597	310.3	63.7	C	A	**C**
Tahoranui River		-	3,754	445.5	50.3	D	A	**D**
Takou River		-	3,892	593.8	52.4	D	A	**D**

Table 3-4 indicates that among FMUs in which downstream water quality is currently not monitored, the following coastal hydrosystems have either high land-derived sediment loads or susceptibility to eutrophication, or both:

- Waitahora Stream (susceptibility to eutrophication) and Waitangi Stream (sediment load and susceptibility to eutrophication) within the Aupōuri FMU,
- Waimamaku River and Waipoua River in the Waipoua FMU (both have relatively high sediment loads and high susceptibility to eutrophication although, particularly in the case of the Waipoua River, eutrophication susceptibility appears driven more by the sensitivity of the estuary (Table 3-1), rather than upstream land use (Table 3-2)),
- Horahora River (eutrophication) and Pataua River (sediment load) within the Whananaki Coast FMU,
- Tapuaetahi Creek, Tahoranui River and Takou River in the Whangaroa FMU have high sediment loads and high to very high susceptibility to eutrophication.

If more 'at risk' coastal hydrosystems were to be monitored in future, those listed above represent a starting point for consideration. Of these, monitoring a system within the Whangaroa FMU may be an obvious initial candidate given the overall classifications in Table 3-4.

3.4 Synthesis

The current suite of 44 coastal water quality monitoring sites span all four coastal management units specified in the PNRP and, with adoption of site changes recommended by Griffiths (2021a), provide information on receiving water quality for six FMUs. Further, land use composition in the upstream catchments of those coastal hydrosystems monitored within each FMU appears to adequately represent the overall composition of FMU land drainage to the coast.

Overall, there is a focus on more heavily freshwater-dominated hydrosystems which means that the programme is more likely to identify where coastal water quality problems are or may occur, thereby informing management of the effects of land use and development on coastal water quality under the PNRP and the NPSFM 2020. If resources permit consideration could be given to:

- extending or reworking the current monitoring effort of the 'Open Coast' CMU (clustered in the south-east of region) across to the west coast to provide data on oceanic inputs to coastal hydrosystems on this coast, and
- establishing water quality monitoring in a coastal hydrosystem downstream of one or more of the FMUs that currently lack receiving water monitoring, using the outputs of Tables 3-1 to 3-4 to guide selection.

We are mindful that any possible additions to current monitoring locations would also require consideration of other factors, such as logistics (e.g., travel and site accessibility), other monitoring priorities (e.g., benthic ecology monitoring) and community needs/interests.

4 Monitoring locations to support coastal water quality modelling

Suitability for modelling is becoming an increasingly important consideration when reviewing monitoring locations. Only a selection of coastal hydrosystems can be monitored, yet integrated management under the NPSFM 2020 requires consideration of downstream coastal waters (especially estuaries) in freshwater limit setting to ensure that contaminant loads delivered from freshwater do not adversely impact on the various ecological, cultural, recreational and other values downstream environments support.

A range of modelling approaches exist for quantifying the impacts of freshwater on coastal water quality and ecosystem health; these include the ETI (Robertson et al. 2016a; Zeldis et al. 2017a), and application of numerical mixing and biogeochemical models such as DELWAQ (Gadd et al. 2020; Zeldis et al. 2019). A key data requirement common to these methods are time series of contaminant loads from rivers. The combination of point-source and non-point-source contributions of contaminants to estuaries often requires modelling approaches for quantification, while all contaminant loading models benefit from calibration and testing against appropriate field data.

The ETI dilution modelling approach to assessing estuary susceptibility to N loads provides an example of monitoring site requirements to enable calculations of the impacts of freshwater contaminant loads on estuaries. The ETI dilution modelling approach calculates ‘potential’ nutrient concentrations of estuarine water and requires as input data local oceanic (i.e., open coast) nutrient concentrations, nutrient concentrations in fresh water flows to estuaries, and freshwater flow rates (Plew et al. 2018). These data are important for relating loads of nutrients entering estuaries from land to changes in estuarine trophic state (e.g., Dudley and Plew (2017), Plew and Dudley (2018)) and linking these predicted trophic state changes with observed data (e.g., Robertson and Stevens 2016). While national-scale modelled nutrient load data are available for all New Zealand estuaries, these data are unlikely to be as accurate as in-situ sampling measurements. Therefore, as outlined below, for ETI assessments we recommend that water column nutrients are monitored in or near terminal river reaches (i.e., a location unaffected by tidal state), within the estuary, and on the adjacent coast (Dudley et al. 2017; Zaiko et al. 2018). The products of this water quality modelling could be extended to calculate trophic condition scores for estuaries via ETI Tool 3;

https://shiny.niwa.co.nz/Estuaries-Screening-Tool-3/

4.1 Terminal river reach monitoring

Monitoring of contaminant concentrations and flow in terminal river reaches allows calculation of contaminant loads to estuaries. It is important to monitor changes in loading because changes in water quality in estuaries can vary due to a range of climate (e.g., warming waters), biogeochemical (e.g., nutrient uptake by algae, and denitrification) and physical processes (e.g., mixing). Trends in water quality at terminal reach sites provide a vital link between management practices within FMUs and the state or condition of estuaries, as measured through key attributes (e.g., sedimentation rate, macroalgal cover). Terminal river reach sampling is necessary to meet riverine flow and nutrient load data requirements of estuary dilution modelling (Plew et al. 2018).

4.1.1 Where on terminal river reaches should monitoring be carried out?

Flow and water quality sampling should be performed at a distance upstream from the sea at which salinity indicates little mixing with ocean water. A suggested specific conductance cut-off would be 5 mS/cm (sea water being ~50 mS/cm). In some cases, landward inflow of ocean water into river estuaries results in high salinities and tidal influence on flows extending a considerable distance upstream. In these cases, flow and nutrient concentration data should be collected at a distance upstream that minimises ocean water and tidal influence while reducing exclusion of tributaries that join the river below the sampling point.

4.1.2 Which terminal river reaches are best for monitoring?

To provide an indication of potentially useful terminal river reach sites in the Northland Region, we estimated the mean annual loads of Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS) delivered from land and point sources to estuaries in the current NRC coastal monitoring network. The nutrient estimates were determined using a customised version of CLUES model with a regional calibration for Northland (Semadeni-Davies et al. 2021). The sediment loadings were taken from national sediment modelling undertaken for the Ministry for the Environment (Hicks et al. 2019). Both models are catchment scale, steady-state models that report instream loadings for each river segment in the REC 2.5 stream network. The total loads delivered (Table 4-1) were determined by summing the instream loads at the terminal river segments draining to each coastal hydrosystem. In addition, for the coastal hydrosystems where there is already monitoring in place, we provide the estimated loads from the rivers that contribute the highest loads (Table 4-2); these are the instream loads estimated for the terminal segment for each of the respective rivers and were calculated using the CLUES methods outlined in Subsection 3.2.

For comparison, NRC's existing river SOE monitoring sites in catchments upstream of monitored coastal hydrosystems are shown on Figures B-1 to B-10 in Appendix B. From this comparison we can see that:

1. Few monitored coastal hydrosystems have upstream water quality monitoring sites at or near the terminal reaches of the rivers that deliver the largest proportion of contaminant loads. Exceptions are shaded in grey in Table 4-2.
2. More coastal hydrosystems have river monitoring sites in the upper reaches of their catchments. These monitoring sites may still be of some use for calibrating model estimates of catchment contaminant loads.

Addition of terminal river reach monitoring sites is best considered on a case by case basis as resources permit, with consideration of such things as:

- the current condition (and susceptibility) of each coastal hydrosystem,
- current and expected future catchment contaminant loads (e.g., potential for land use change), and
- how far upstream existing river sites are from the terminal reach (i.e., in some cases it may be possible to estimate total catchment loads where sites are located in middle or lower reaches.

Looking at Tables 4-1 and 4-2, a site on the lower reaches of the Waima River may be useful in the Hokianga FMU given the large number of terminal river segments that drain to its estuary (202) and the river's significant sediment contribution to the Hokianga Harbour (~30% of the FMU input).

Table 4-1: Estimated mean annual loads of TP, TN and TSS discharged to estuaries in tonnes or kilo-tonnes per year. The number of terminal river segments draining to each coastal hydrosystem is also provided.

Coastal hydrosystem	Number of terminal segments	TN (t/y)	TP (t/y)	TSS (kt/y)
Awahoa Bay	1	0.4	0.1	47.2
Awapoko River	2	58.1	12.1	12,912
Bland Bay	4	1.1	0.1	123.8
Deep Water Cove	4	0.9	0.0	162.8
Helena Bay	5	13.3	1.7	2,231
Herekino Harbour	15	39.4	7.1	8,587
Hokianga Harbour System	202	911.4	111.5	182,244
Horahora River	10	57.3	4.7	5,199
Houhora Harbour	25	104.4	3.9	1051
Kaipara Harbour System (Auckland)	219	1,129	191.5	122,419
Kaipara Harbour System (Northland)	310	3,241	217.6	376,055
Kaipara Harbour System (Total)	529	4,370	409.1	498,474
Mahinepua Bay	3	2.7	0.4	302.7
Manawaora Bay	7	4.8	0.8	619.3
Mangawhai Harbour	21	48.7	5.3	2,891
Mangonui Harbour	23	157.9	19.1	22,194
Matai Bay	4	1.1	0.1	53.9
Matapouri Bay System (MBS)	7	6.0	0.7	830.9
Mimiwhangata Bay	2	1.3	0.3	207.1
Ngunguru River	23	41.6	4.8	5,093
Oke Bay	2	0.3	0.0	47.0
Opua Inlet System	101	588.2	70.8	12,9471
Parekura Bay	8	9.1	0.8	1,372
Parengarenga Harbour System	97	63.3	7.6	6,668
Paroa Bay	7	1.6	0.1	171.9
Patua River	11	27.4	4.0	2,960
Rangaunu Harbour	60	393.2	38.1	31,220
Ruakaka River	8	58.2	8.1	5,626
Taemaro Bay	4	1.5	0.1	101.6
Tahoranui River	2	18.7	2.4	955.9
Taiharuru River	10	9.1	1.7	580.5
Taipa River	9	73.2	9.7	11,906
Takerau Bay	2	0.4	0.0	22.0
Takou River	3	49.4	6.0	2,294
Tanutanu Stream	2	4.5	0.2	345.9

Coastal hydrosystem	Number of terminal segments	TN (t/y)	TP (t/y)	TSS (kt/y)
Tapotupotu Bay	3	3.9	0.2	200.1
Tapuaetahi Creek	5	5.8	1.7	609.7
Te Puna /Kerikeri Inlet System	59	401.6	15.5	8,288
Tutukaka Harbour	4	1.7	0.2	190.6
Waiatua Stream	1	1.8	0.1	132.8
Waimahana Bay	4	2.8	0.2	213.9
Waimamaku River	1	86.6	10.6	14,773
Waipoua River	1	52.9	1.5	2,964
Waipu River	6	10.6	1.7	15,981
Waitahora Stream	2	1.8	0.1	80.0
Whananaki Inlet	9	25.6	3.5	3,426
Whangaihe Bay	1	0.9	0.1	124.9
Whangamumu Harbour	3	0.5	0.0	97.7
Whāngāpē Harbour System	29	140.5	20.2	41,854
Whangārei Harbour System	106	241.9	49.9	14,820
Whangaroa Harbour	50	144.8	26.3	34,756
Whangaruru Harbour	17	29.2	2.2	4,546

Table 4-2: Estimated mean annual nutrient and sediment loads delivered to monitored coastal hydrosystems by the rivers contributing the highest contaminant loads. The percentage of the river load compared to the total load delivered to the estuary is given in parentheses. Grey shading indicates rivers that have upstream freshwater monitoring sites near or on the terminal river reach (see Appendix B).

Coastal hydrosystem	No. of terminal segments	River	TN Load (t/y)	TP Load (t/y)	Sediment (kt/y)
Aurere Estuary (Figure B-1)	2	Aurere Stream	58 (99.4%)	12 (99.7%)	12,884 (99.8%)
Hokianga Harbour System (Figure B-2)	202	Waima River	363 (39.8%)	26 (23.1%)	55,283 (30.3%)
Hokianga Harbour System (Figure B-2)	202	Waihou River	168 (18.5%)	16 (14.2%)	29,030 (15.9%)
Kaipara Harbour System (Figure B-3)	529	Wairoa River	2725 (62.3%)	134 (32.8%)	325,634 (65.3%)
Kaipara Harbour System (Figure B-3)	529	Hoteo River (Auckland)	315 (7.2%)	71 (17.4%)	44,030 (8.8%)
Mangawhai Harbour (Figure B-4)	21	Tara Creek	18 (36%)	1 (28.1%)	1,028 (35.6%)
Mangawhai Harbour (Figure B-4)	21	Mangawhai Harbour south branch	11 (22.2%)	2 (37.8%)	999 (34.6%)
Opua Inlet System (Figure B-9)	101	Kawakawa River	273 (46.4%)	42 (59.9%)	56,714 (43.8%)
Opua Inlet System (Figure B-9)	101	Waitangi River	233 (39.6%)	20 (27.5%)	61,405 (47.4%)
Ruakaka River (Figure B-5)	8	Ruakaka River	53 (91.5%)	7 (91.2%)	5,190 (92.3%)
Taipa River (Figure B-6)	9	Oruru River	59 (80.5%)	7 (73.6%)	7,892 (66.3%)
Te Puna /Kerikeri Inlet System (Figure B-7)	59	Kerikeri River	165 (41.2%)	6 (37.8%)	3,895 (47%)
Te Puna /Kerikeri Inlet System (Figure B-7)	59	Rangitane River	86 (21.5%)	1 (5.5%)	632 (7.6%)
Te Puna /Kerikeri Inlet System (Figure B-7)	59	Waipapa Stream	68 (16.9%)	1 (5.2%)	936 (11.3%)
Waipu River (Figure B-8)	6	Waipu River	9 (84.3%)	2 (90.4%)	15,890 (99.4%)
Whangārei Harbour System (Figure B-10)	106	Otaika Creek	58 (23.8%)	5 (10%)	4,414 (29.8%)
Whangārei Harbour System (Figure B-10)	106	Waiarohia Stream	32 (13.3%)	2 (4.2%)	2,016 (13.6%)
Whangārei Harbour System (Figure B-10)	106	Hatea River	31 (12.6%)	2 (3.5%)	1,457 (9.8%)

4.2 Position of monitoring sites within coastal hydrosystems

Water quality within coastal hydrosystems such as estuaries is affected by dilution, retention time and loss of inflowing water, as well as biological processes affecting nutrient cycling and productivity. These processes cause high temporal and spatial variability in water quality. Spatial variability in estuarine water quality means that time-averaged water quality at a single site is unlikely to be close to average water quality conditions for the whole estuary. Because of this, measurement of water quality in estuaries is often overlooked in favour of more time-averaged measures of water quality such as bioindicators, sediment characteristics, or integrating measures such as the ETI (Barr et al. 2013; Berthelsen et al. 2020; Hewitt et al. 2012; Robertson et al. 2016b). Nevertheless, relatively frequent estuarine water quality monitoring over sufficient duration can show water quality changes that can be linked to changes in estuarine values and catchment processes (Boyer et al. 2006; Zeldis et al. 2017b). We suggest that each monitored estuary is represented by at least one water quality sampling site and note that in most cases NRC has multiple sites within each (refer to Table 3-1). For new sites, we recommend a sampling point at around the midpoint of the estuary between the ocean and the terminal reach sampling point. For existing sites, maintenance of current location is vital for the usefulness of water quality time series, and therefore, where possible, existing site locations should be maintained if a record of several years already exists.

For the purposes of dilution modelling, the location of sites within the estuary are not vital as long as salinity data are collected alongside other water quality measurements (especially nutrients) to enable validation of the modelling. This is discussed further in Section 5.

4.3 Oceanic monitoring sites

Because dilution modelling requires oceanic samples to calculate mixing within the estuary, appropriate sampling from outside the estuary is required. These sites do not need to be immediately adjacent to monitored estuaries, but should be:

1. In areas with minimal contributions from freshwater, and
2. Sufficiently near to monitored estuaries that they provide an indicative understanding of regional ocean water chemistry.

As noted in the commentary on open coast monitoring sites in Subsection 3.1.2, the current suite of four sites is clustered in the south-east of the Northland Region, offshore from the Bream Bay, Whangārei and Bay of Islands FMUs (refer Figure 3-1). We suggest that consideration is given to extending (or splitting) the current monitoring effort of the ‘Open Coast’ CMU across to the west coast to provide data on oceanic inputs to coastal hydrosystems on this coast. For example, a site representing ocean water contributions to Hokianga Harbour would provide a central point on the western coast of the region.

5 Monitoring variables, methods and frequency

In this section we briefly comment on the current suite of water quality variables and associated sampling and measurement methods, including the frequency of sampling. These aspects have been addressed in more detail by Griffiths (2021a).

5.1 Water quality monitoring variables

In Table 4-1 we list all variables recommended for a range of coastal or estuarine water quality monitoring in a selection of recent relevant reports, and those variables listed in Policy H.3.3 of the PRPN with corresponding water quality targets. The relevant reports are:

- Zaiko et al. (2018) – identified estuarine attributes suitable for the establishment of national thresholds on which to manage upstream catchments,
- Dudley et al. (2017) – recommended water quality variables for regional SOE monitoring that, if adopted uniformly across councils, would improve national level SOE analyses, and
- Zeldis et al. (2017b) – listed water quality indicators used in assessment of the trophic state of estuaries in ETI tool 2.

We suggest that (as far as is practicable) water column monitoring in coastal hydrosystems such as estuaries – including the variables measured – should align with the methods and timing of monitoring taking place upstream and in open coastal waters. This alignment aids in attributing changes in estuaries to processes and activities in nearby marine systems and upstream catchments. Standardisation of variables measured across the mountain to sea continuum is echoed in recent MfE reports (Dudley et al. 2017; Zaiko et al. 2018), and aligns with the concept of 'ki uta ki tai' (integrated management) required by the NPSFM 2020 (refer Subsection 2.1).

We note that the variables included in the National Environmental Monitoring Standards (NEMS 2020) for Discrete Water Sampling and Measurement in Coastal Water do not constitute a recommended list of variables, but rather a list of variables typically measured as part of long-term SOE programmes for coastal waters. Therefore, we have not recorded all of the variables listed in NEMS (2020) in Table 4-1, but instead record whether those variables recommended in the other reports have an established method available in the NEMS (2020). The recommended variables in Table 5-1 are routinely monitored in coastal waters, and the rationale for their measurement is not provided here but can be found in recent publications specific to New Zealand coastal water quality monitoring (Dudley et al. 2017; NEMS 2020; Zaiko et al. 2018).

From Table 5-1 we note that of the recommended 'core' variables listed in Dudley et al. (2017) only pH is missing from current monitoring at tidal river, estuary and open coasts sites. We consider acidification of coastal waters an issue of potential concern for Northland and suggest pH is monitored in at least a few locations (including where water column metals are measured). However, we note that standard hand-held pH meters of the type commonly used for coastal water sampling are unlikely to be appropriate for detecting temporal trends in coastal pH. We suggest that NRC contact the administrator of the New Zealand Ocean Acidification Observing Network (NZOA-ON) » NIWA Ocean Survey 20/20 to investigate the possibility of having water samples analysed through this network using methods fitting the required accuracy. We note that several regional councils are already involved with the NZOA-ON.

Table 5-1: Recommended water quality variables for SOE, recreational water quality and regional plan monitoring of coastal and estuarine water quality.

Variable	MfE (Dudley et al. 2017) Core	MfE (Dudley et al. 2017) Support	MfE (Zaiko et al. 2018)	PRPN	ETI tool 2 indicator	NEMS method available?	Currently monitored by NRC?
Major physico-chemical variables							
Salinity	✓		No	No	No	Yes	Yes
Temperature	✓		No	Yes	No	Yes	Yes
Dissolved oxygen	✓		No	Yes	Yes	Yes	Yes
pH	✓		No	Yes	No	Yes	No
Optical variables							
Visual clarity	✓		No	Yes	No	Yes	Yes
Turbidity		✓	No	Yes	No	Yes	Yes
Total Suspended Solids	✓		Yes	No	No	Yes	Yes
Light penetration		✓	No	No	No	Yes	No
CDOM		✓	No	No	No	Yes	No
Munsell Colour		✓	No	No	No	Yes	No
Nutrients							
Total nutrients (TN, TP)	✓		Yes	Yes	No	Yes	Yes
Dissolved nutrients (NOXN, NH4N, DRP)	✓ *		No	Yes	No	Yes	Yes
Dissolved organic nutrients (DON, DOP)	No	No	No	No	No	No	No
Microbiological indicators							
Enterococci	✓			Yes	No	Yes	Yes
Faecal coliforms		✓	Yes **	Yes	No	Yes	Yes
E. coli		✓		No	No	Yes	No
Chlorophyll-*a*	✓		No	Yes	Yes	Yes	Yes
Phytoplankton assemblage		✓	No	No	No	No	No
Other toxicants**	No	No	No	Yes (Pb, Cu, Zn)	No	Yes (metals)	Yes (Pb, Cu, Zn)

* DRP deemed a supporting variable in fully marine (oceanic) waters

** The recommended microbiological indicator is not specified

While TSS concentrations are currently (and have been historically) monitored by NRC, no limits for TSS in coastal waters are present in the PRPN. Total suspended solids (TSS) are recommended as a 'core' variable in Dudley et al. (2017) and are one of seven estuarine 'attributes' selected for potential further development to inform upstream freshwater management under the NPSFM (Zaiko et al. 2018). Total suspended solids data in the terminal reach, estuarine waters and ocean waters may also inform modelling of sedimentation rates in estuaries. We therefore recommend continued inclusion of suspended solids measurements in future monitoring but note monitoring to inform 'source to sink' modelling applications will require some targeted wet weather sampling of terminal riverine reaches to capture the high sediment (and other contaminant) inputs typically delivered to estuaries under wet conditions. These 'event-based' samples should be measured for suspended sediment concentration (SSC), not TSS, to provide for a more robust estimate of sediment loads entering the estuary (e.g., Gray et al. 2000; Selbig and Bannerman 2011).[9]

Metal concentrations have historically been monitored in coastal waters in Northland (Griffiths 2016), but based on the time-series of data we've observed would appear most appropriate for site-specific monitoring in coastal hydrosystems with significant urban land use and/or development in their upstream catchments (e.g., Whangārei Harbour). We note NRC currently monitors total copper and zinc. While useful for many applications, including modelling, we suggest that dissolved forms of copper and zinc are more ecologically relevant to monitor and should be accompanied by supporting measurements of dissolved organic carbon to enable assessment of measured concentrations against toxicity guidelines (see NEMS (2000) for further commentary).

5.1.1 Variables for contaminant load monitoring and estuarine dilution modelling

Dilution modelling approaches (e.g., Plew et al. (2018)) require understanding of contaminant loads carried into an estuary from both oceanic inflow and land-influenced freshwater flows. Typically, salinity data collected within the estuary are used to validate estimates of the mixing of fresh water and ocean water. This approach therefore requires regular monitoring of total nutrient concentrations (TN and TP) and salinity at terminal river reaches entering estuaries, as well as within estuaries and in nearby ocean water (refer Section 4). The results of dilution modelling can then be used to predict the responses of attributes within the estuary. For example, ETI tool 1 (Plew et al. 2020) predicts trophic conditions within the estuary based on modelled nutrient loads from land. The prediction of trophic condition from ETI tool 1 can be validated by comparing with estimates of trophic state available from monitoring. ETI indicators of trophic state in estuaries include water column chlorophyll *a* and dissolved oxygen (DO).

5.2 Sampling and measurement methods

5.2.1 Sampling/measurement point and methods

The locations for field measurements and water sample collection are well described in NRC's monitoring reports. Maintaining consistency in sampling point locations ('site stationarity' in NEMS language) is important to interpret changes in time series of water quality measurements.

In general, Dudley et al. (2017) and Zaiko et al. (2018) recommend use of NEMS methods for water quality sampling in coastal waters (NEMS 2020), as well as use of NEMS protocols with regard to

[9] As outlined in NEMS (2019) for Discrete Water Quality Sampling and Measurement in Rivers, the SSC and TSS tests differ in that TSS is measured on a volumetric sub-sample whereas SSC is measured on the entire sample. The latter is more reliable for capture of rapidly settling sand-sized sediment particles present in water samples from rivers and other natural waters and is the recommended method for use in all catchment or storm sediment load assessments. Use of the TSS method is best restricted to 'clear water' samples at base or low flows.

metadata collection, reporting of measurement uncertainty, and quality coding. Use of NEMS protocols is useful to ensure high data quality, but also beneficial for national-scale reporting where consistent methods across all regional authorities facilitates comparison of water quality across regions.

Specifications for sampling depth, (i.e., 30 cm below the water surface), bottle filling and labelling, stabilisation of samples and sample transport and handling are present in NRC run guides. These specifications match those of NEMS (2020). Assessing vertical stratification in deeper coastal hydrosystems is addressed in Subsection 5.2.4.

5.2.2 Field measurements

We recommend that regular records are kept of field meter specifications, and calibration and validation details. Details on how to do this, including an example calibration form, are provided in NEMS (2020). We note that NRC guides for preparation and use of YSI water meters match NEMS specifications, and specific calibration methods for individual variables are well documented.

We note that NRC has some sampling runs that combine freshwater and coastal sites and currently uses different YSI ProDSS meters to measure specific conductivity at these sites. This approach of using different meters/sensors for fresh and coastal waters is consistent with advice in NEMS (2019) which notes that the accuracy of conductivity measurements taken from very 'clean' freshwaters or very saline waters may be compromised unless the sensor is validated specifically for these sites. However, for logistical reasons, NRC has queried if a single meter/sensor could be used on combined river and coastal sampling run days, citing the results of an in-house experiment (NRC unpublished) that suggests calibration to 1,414 µS/cm (as required in NEMS (2019) for freshwater) has little impact on the accuracy of conductivity measurements made in high salinity waters.

In our view, while this approach would result in a lower quality code assigned to coastal conductivity measurements under NEMS (2020)[10] it is pragmatic (and more cost-effective). However, consistent with the advice given in NEMS (2019, 2020) for single sensor use, it would be more appropriate to validate the sensor using a conductivity standard around 12,880 µS/cm. An added or alternative option, and one that would more strongly support maintaining the highest possible NEMS quality code across all measurements, would be to carry small amounts of the NEMS suggested standard solutions of 1,414 µS/cm, 12,880 µS/cm and 53,000 µS/cm and perform a quick sensor validation in the field between sites where conductivity changes markedly (using the standard that is closest to the expected next measurement value).[11] If this is considered too onerous, another alternative is that conductivity at saline sites is measured on water samples submitted to NRC's contracted laboratory, with field measurements restricted to freshwater sites only.

5.2.3 Laboratory test methods

Table 17 in Griffiths (2021a) lists NRC's current laboratory measurement methods and comments on laboratory measurements methods for phosphorus. Although NRC's contracted laboratory is IANZ accredited for the dissolved reactive phosphorus (DRP) and total phosphorus (TP) methods it uses, these methods differ from those eligible for the highest quality code (QC 600) under the NEMS (2020). We note that the difference is in the type of analyser (discrete vs flow injection) and that in the case of TP, the chemical digestion step prior to measurement does adhere to NEMS

[10] And, potentially to freshwater measurements under NEMS (2019) if a river site was visited after measuring at an estuarine or coastal site.

[11] We note that Dr Peter Robinson, the laboratory representative on the NEMS Water Quality Working Group, strongly supported sensor validation between sites but the majority consensus adopted in the final NEMS provisions was to only require start and end of day sensor validation.

requirements (APHA 4500-P J, although the modification note alongside the method in Table 17 of Griffiths (2021a) is not explained). It is worth noting that the primary reason for adopting flow injection in the NEMS (2020) is that it offers lower detection limits (0.001 mg/L and 0.002 mg/L for DRP and TP, respectively) than discrete analysis. The significance of this depends on typical phosphorus concentrations NRC measures.

Table 17 also indicates that:

- The current laboratory method detection limit for chlorophyll *a* is 0.0006 mg/L, coarser than the 0.0002 mg/L recommended in NEMS (2020). The significance of this depends on typical chlorophyll *a* concentrations NRC measures. Given the predominant focus of monitoring on freshwater-influenced coastal hydrosystems, it is probably unlikely to result in many additional non-detect values compared with adopting a lower detection limit.
- The current laboratory method detection limits for total copper and total zinc are coarser than those recommended in NEMS (2020) and are insufficient for an accurate comparison against some of the water quality standards set out in Table 25 of the PNRP (refer Table 2-1, Subsection 2-2). We recommend that NRC checks its metal measurements to date to identify the number of non-detect values and if adopting a lower detection limit would be significantly reduce these.

5.2.4 Additional information to support modelling

In addition to the water quality data requirements outlined in Subsection 5.1.1, the following data are required for estuary-by-estuary dilution modelling:

- tidal prism of the estuary at spring tide (i.e., the difference in volume of water in an estuary between spring high tide and spring low tide),
- volume of the estuary at spring high tide,
- mean annual freshwater inflow to the estuary,
- volume-averaged salinity at high tide to calculate dilution,
- salinity of ocean water outside the estuary, and
- intertidal area.

Tidal prism, volume and intertidal area are typically calculated from a bathymetry survey and measuring water levels over several tidal cycles (to capture the variation in tides over a spring-neap cycle). A bathymetry survey to obtain physical data could be carried out on estuaries where benthic symptoms of eutrophication are of concern. As an example, Plew et al. (2017) gives bathymetry measurements appropriate for dilution modelling in two shallow estuaries in the Canterbury Region. Freshwater inflow can be estimated from modelled or measured flow data from the terminal reach of rivers entering the estuary. In estuaries where fresh water and ocean water can be assumed to be relatively well mixed and stratification is unlikely, salinity can be calculated from long-term surface sampling records, or from a conductivity, temperature, and depth (CTD) survey of the estuary at high tide. Where stratification of saline and freshwater layers is likely, the CTD survey would need to include vertical profiles at several locations in the estuary.

For deeper estuaries that have high susceptibility to eutrophication via excessive phytoplankton growth (see the 'Phytoplankton Susceptibility Band' column in Table 3-4) we recommend that water samples are occasionally collected across a range of depths to support dilution modelling. Salinity, nutrients (at least TN), chlorophyll *a*, pH and dissolved oxygen should be measured on these samples to check if sufficiently strong stratification is present that could favour potential problems such as reduced oxygen or pH in subtidal sections of the monitored estuary. The sampling for dilution modelling could be scheduled to target a time of year when such conditions might be most likely (potentially summer). If this sampling indicates that the estuary is susceptible to effects from vertical stratification, the routine sampling may warrant amendments to examine this more closely. We note that where regular SOE sampling is normally carried out from shore, the additional logistical cost of mobilising vessels would need to be considered.

5.3 Sampling frequency and timing

Because of the variability of coastal – and especially estuarine – water quality over short time scales, long, relatively intensively sampled time series are required to detect changes in water quality. More frequent sampling increases the power of statistical tests to detect trends. Water quality trend analysis techniques typically rely on multi-year to multi-decadal data series with few missing data points. For example, recent national water quality trend analyses used 8–20 year, monthly- or quarterly-sampled datasets with 80% of the sampling dates in each of 80% of the years present (Dudley et al. 2017; Larned et al. 2015). Hence, for the purposes of SOE reporting, maintenance of existing time series is important. We concur with Griffiths (2021a) that the current monthly sampling frequency is sufficient and consistent with many other long term or SOE-based water quality monitoring programmes. We also consider this frequency appropriate for determination of summary statistics for comparison against the water quality standards set out in Table 25 of the PNRP (although we would suggest that these statistics, especially the annual 90th percentile-based statistics, are better assessed a over a rolling three-year period of monthly measurements).

5.3.1 Tidal state

One of the major sources of variability in coastal water sampling is tidal state. This is largely because at high tide there is greater dilution of freshwater inflows from land by ocean water than at low tide. Tidal dilution therefore creates problems for SOE monitoring which has the twin goals of representative sampling of water quality state and detecting trends in water quality through time. For a monitoring programme that seeks to assess coastal water quality state, it would be most appropriate to randomise for tide, stratify sampling by tide, or simply ignore tide in planning but record it at the time of sampling. All these approaches would be appropriate to characterise 'average' water conditions. However, if the primary monitoring aim is to detect trends in water quality through time, it would be most appropriate to sample consistently at a single tidal state to minimise the effect of tide and increase statistical power. Two potentially appropriate monitoring approaches that fit both of these 'conflicting' monitoring purposes are:

1. Sample regularly (e.g., quarterly or monthly, at both high and low tide).
2. Sample regularly (e.g., monthly, without regard to tidal state (i.e., randomised sampling), while recording time and tidal conditions at the time of sampling).

The first approach has been used successfully in New Zealand (e.g., Invercargill City Council data described in Dudley et al. 2017). This approach allows trend analysis on both high tide and low tide datasets, and when data are considered together should give a reasonable average condition for estuary water. However, this approach may not be practical where travel times between sites are great. The second approach sacrifices statistical power in trend analysis; sampling may need to be more frequent to detect trends in water quality through time.

On consideration of NRC's multiple monitoring needs, and the report of Cornelisen et al. (2011), we consider that the current approach of coastal sampling on randomised tides is acceptable given the good (monthly) sampling frequency. Further, as discussed previously, regular (monthly if possible) sampling of water quality in the terminal river reach (i.e., above areas subject to tidal fluctuations in salinity) will provide a good dataset for assessing trends in pressures on coastal waters.

6 Conclusions

Water quality monitoring is well established in the Northland Region and sites span all four coastal management units specified in the PNRP. In total, 10 of 50 (20%) of the region's coastal hydrosytems are currently or will soon be monitored, and our analysis indicates that the upstream land use composition across these systems adequately represents the overall composition of FMU land drainage to all downstream coastal hydrosystems. Overall, there is a focus on more heavily freshwater-dominated hydrosystems which means that the programme is more likely to identify where coastal water quality problems are or may occur and inform management of the effects of land use and development on coastal water quality under the PNRP and the NPSFM 2020. However, more than half of Northland's FMUs do not have any downstream receiving water monitoring at present and there is a lack of terminal river reach sites on some rivers that are estimated to input significant loads of sediment and/or nutrients.

While we concur with focussing monitoring resources on primarily impacted coastal hydrosystems, oceanic monitoring is currently limited to a small cluster of sites the south-east of region and spatial coverage could be improved. This, along with improved terminal reach coverage, would provide improved data on the state of fresh and oceanic water entering estuaries across the Northland Region.

The suite of water quality variables currently monitored by NRC closely match to those recommended in recent national reports and guidance, and the list of variables in the PRPN with associated water quality standards. However, pH is not currently monitored at any location and the detection limits for some variables do not meet NEMS (2020) requirements. In the case of total copper and total zinc, the current laboratory method detection limits are also insufficient for an accurate comparison against some of the water quality standards set out in Table 25 of the PNRP.

The monthly sampling frequency is considered appropriate for SOE monitoring and adopting a variable tidal state is justified, especially with a reasonable time-series now available for most sites. We suggest that for deeper estuaries susceptible to eutrophication, regular surface sampling programmes could be supported by one-off, estuary-by-estuary bathymetry, water quality and depth profile CTD sampling. This approach would also confirm whether regular subtidal sampling is required in deeper estuaries.

6.1 Recommendations

We make the following recommendations, recognising that NRC will need to consider them within the much larger context of priorities across all environmental monitoring, as well as logistical constraints (e.g., resources, suitable road/site access) and community needs/interests.

1. Extend or rework the current monitoring effort of the 'Open Coast' CMU across to the west coast to provide data on oceanic inputs to coastal hydrosystems on this coast.
2. Establish water quality monitoring in a coastal hydrosystem downstream of one or more of the FMUs that currently lack receiving water monitoring, using the outputs of Tables 3-1 to 3-4 to guide selection.
3. Increase water quality in or near terminal river reaches, using the information in Table 4-1 and Table 4-2 to select sites that contribute the most significant contaminant loads.

4. Investigate participation in the NZOA-ON to track trends in pH at one or few coastal waters sites in Northland.

5. Measure dissolved forms of copper and zinc (and associated supporting variables) in place of, or in addition to, measurement of total forms, with detection limits adopted taking into account NEMS (2020) requirements and toxicity guideline values.

6. Identify estuaries in which catchment contaminant modelling may be required and initiate collection of additional physical information to support this modelling, notably:

   - Accurate measurement of estuary extent and form, including tidal prism, intertidal area, and volume at high tide,
   - salinity measurements inside and outside the estuary, and
   - water sampling at a range of depths in deeper estuaries where stratification of waters is suspected to support dilution modelling.

7 Acknowledgements

We thank Richard Griffiths at NRC for supplying background information, Figures 2-2 and 3-1, the catchment maps in Appendix B and reviewing a draft version of this report. This report was funded through an MBIE Envirolink Medium Advice Grant (MBIE Contract C01X2105).

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Appendix A Coastal hydrosystem and estuary classifications

Two typologies are used in Section 3 to classify coastal water bodies in Northland. The first is the New Zealand Coastal Hydrosystem (NZCHS), consisting of 11 main classes, some of which contain subclasses (Hume et al. 2016). The 11 classes span from lacustrine (i.e., relating to or associated with lakes) through to riverine, estuarine and marine systems. The names of the NZCHS classes are descriptive, with guidance regarding which class to apply to an estuary given by Hume et al. (2016). The 11 NZCHS classes are:

1. *Damp sand plain lake* – small shallow (1-2 m deep), typically freshwater bodies with no connection to the sea (no tidal inflow). Often elongated and located in the depressions between rows of sand dunes on damp sand plains and often associated with vegetated wetlands areas. The basins in which they occur form where wind has removed sand to form shallow depressions down to about the level of the water table. They are fed by rainfall and groundwater and are brackish due to salt spray and evaporation. May be ephemeral. Examples include Parengarena Spit (Northland) and Farewell Spit (Golden Bay).

2. *Waituna-type lagoon* – large (several km^2) shallow (mean depth 2-3 m) coastal lagoons barred from the sea by a barrier or barrier beach (no tidal inflow). They occur most commonly in depressions on coastal land or in valley basins as more elongate shaped water bodies. Typically fresh, fed by small streams, with brackish pockets. Most frequently closed to the sea. They may experience tidal inflows for short periods after natural or artificial breaches of the barrier beach. Subtypes: A = coastal plain depression (e.g., Te Waihora / Lake Ellesmere); B = valley basin (e.g., Wairewa / Lake Forysth).

3. *Hāpua-type lagoon* – narrow, elongated and shallow river mouth lagoons that are, except for usually a single narrow outlet, enclosed along their ocean boundary by coarse clastic barrier beaches formed by strong longshore sediment transport. They occur on coasts that are generally wave-dominated and exposed to high swell wave energies, typically mixed sand and gravel, have micro- to lower meso-tidal ranges, typically have rising backshores, and are characterised by late Holocene erosion, or recent stability trends. Narrow outlet, and usually no tidal inflow. They typically experience a tidal backwater (freshwater) effect in the lagoon where water outflow and/or percolation from lagoon to sea is reduced at high tidal levels. Subtypes: A = large hāpua-type lagoons (e.g., Rakaia); B = medium hāpua-type lagoons (e.g., Waiau; C = small hāpua-type lagoons (e.g., Waipara); D = intermittent hāpua-type lagoons (e.g., Te Aka Aka / Ashley River).

4. *Beach stream* – occur where a very shallow stream flows over the beach face to the sea. This differs from a river where the larger flow cuts a subtidal channel through the beach face to the sea. Some may form a small pond behind a beach barrier or run parallel to the shore for 100s of metres or several kilometres to form "ribbon lagoons". No tidal prism except during storm events coupled with high tides. Subtypes: A = Hillside stream; B = damp-sand plain stream; C = stream with pond (e.g., Waitangi Stream, Northland); D stream with ribbon lagoon (e.g., Saltwater Creek, Timaru); E = intermittent stream with ribbon lagoon.

5. Freshwater river mouth – permanently connected to the sea, occurring where river flow is large enough to cut a permanent subtidal channel through the shoreline and beach to the sea. River flow dominates the hydrodynamics. There may be a tidal backwater effect, but

little or no saline intrusion (inflow). Subtypes: A = unrestricted; B = deltaic; C = barrier beach enclosed.

6. *Tidal river mouth* – elongate, narrow and shallow basins that have a permanent connection or near-permanent connection to the sea. Occur where river and tidal flow are large and persistent enough to maintain a permanent subtidal channel to the sea. River flow delivered during a tidal cycle is a significant proportion of the basin's volume, and greater than the tidal inflow. Hydrodynamic processes are dominated by river flows. Floods can expel all the seawater for days. In deeper systems, and estuarine circulation pattern can be set up where outflowing freshwater is balanced by inflow of entrained seawater and a salt wedge develops. Seawater can intrude several kilometres up-estuary in low gradient coastal plains. Subtypes: A = unrestricted; B = spit enclosed (e.g., Waimakariri River in Canterbury and Awapoko River in Northland); C = barrier beach enclosed; D = intermittent with ribbon lagoon; E = deltaic.

7. *Tidal lagoon* – shallow (mean depth 1-3 m), circular to elongate basins with simple shorelines and extensive intertidal area. A narrow entrance to the sea, constricted by a spit or sand barrier, with strong reversing tidal currents. Tidal prism makes up a large proportion of the total basin volume. River input is small compared to tidal inflow, so hydrodynamic processes are dominated by tides. Subtypes: A = permanently open (e.g., Ihutai / Avon-Heathcote in Christchurch, Taipa River in Northland); B = intermittently closed (e.g., Tapotupotu Bay, Northland).

8. *Shallow drowned valley* – shallow (mean depth generally less than 5 m due to extensive intertidal area) with complex dendritic shorelines and numerous narrow arms leading off a main central basin or channel. Extensive intertidal flats cut by drainage channels. Range in size from small tidal creeks to large harbours. Tidally dominated, with mouth always open and constricted by hard headlands or substantial barriers. The systems are largely infilled with sediment. Large systems tend to be sandy at the mouth and in the central basin, and muddy in the tidal arms and headwaters. They may have tidal sandy deltas present at the inlet. Shallow drowned valleys differ from tidal lagoons differ from tidal lagoons in that they have a greater mean depth. This, along with their planform complexity, means they are not as well flushed. Northland examples include Kaipara, Whangārei and Hokianga Harbours.

9. *Deep drowned valley* – large, deep (mean depth 10-30 m), most subtidal systems formed by the partial submergence of an unglaciated river valley. They remain open to the sea. Typically, they have a straight planform without significant branches, but can be dentritic. Their size seems large for the size of the rivers that current enter the system. Both river and tidal inputs over the tidal cycle are proportions of the total basin volume. In elongate systems an estuarine circulation pattern is set up where outflowing freshwater is balanced by the inflow of entrained seawater. There is also a strong longitudinal gradient in hydrodynamic processes with riverine forcing and stratification dominating in the headwaters, and tidal forcing near the entrance. The systems are poorly flushed, particularly in the headwaters and in more complex systems with multiple arms. They differ from shallow drowned valleys in that they are deeper, do not have sand deltas at the mouth, have far less intertidal area and their hydrodynamics are less tidally-dominated (e.g., Whangaroa Harbour, Northland).

10. *Fjord* – long, narrow, and very deep (mean depth 70-140 m) U-shaped basins with steep sides or cliffs, formed in glacial valleys flooded by the sea following the last glacial and sea-level rise. Subtidal, with only small intertidal areas in the headwaters. Both river and tidal inputs over the tidal cycle are very small portions of the total basin volume. Water movement near the surface is controlled primarily by thermohaline forcing where the circulation is maintained by the large density differences produced by the salinity contrast between freshwater and oceanic water. Wind may modify this circulation and wind-driven circulation may become a dominant force on occasions but is not responsible for the mean circulation over extended periods.

11. *Coastal embayment* – an indentation in the shoreline with a wide entrance, bounded by rocky headlands and open to the ocean. Shallow to medium depth (commonly 4 to 8 m) and circular to elongate in planform. They are mostly sub-tidal with small intertidal areas restricted to the headwaters, or the sheltered side arms. There is little river influence and circulation is weak from tidal and wind-generated currents. The wide entrances allow swell to enter the bay, and hydrodynamic processes are dominated by the ocean. Occur on rocky headland coasts and differ from shallow drowned valleys in that they are largely subtidal and the wide mouths allow ocean forcing by waves. Northland examples include Taemaro Bay and Matai Bay.

The second typology is the Estuary Trophic Index (ETI) typology (Zeldis et al. 2017). This consists of four types, chosen because they capture the main characteristics of coastal water bodies that influence their susceptibility to eutrophication. The four ETI types are:

- *Shallow Intertidally Dominated Estuaries (SIDE)* – generally short residence times, predominantly intertidal, usually well flushed with a large tidal prism relative to freshwater inflow. Sensitive to macroalgal blooms.
- *Shallow Short Residence-time Tidal River Estuaries (SSRTRE)* – tidal rivers that may include well flushed adjoining lagoons. Characterised by limited intertidal area and high freshwater input relative to volume. Often with low salinities which can restrict macroalgal growth, or high velocities which detach or scour macroalgae and so limit accumulation of algal biomass.
- *Deep Sub-tidally Dominated Estuaries (DSDE)* – subtidal, moderately deep or deep with moderate to long residence times. Sensitive to opportunistic macroalgal blooms on intertidal and shallow areas, and phytoplankton blooms in deeper waters.
- *Coastal Lakes* – freshwater or brackish water bodies that are normally closed to the sea or have little or intermittent seawater input. Long residence times and sensitive to phytoplankton blooms.

Subtypes of SIDEs and SSRTREs that intermittently close to the sea are considered Intermittently Closed and Open Estuaries (ICOE). The normal state of ICOEs is open, in contrast to coastal lakes which are normally or always closed.

NZCHS classes can be related to ETI types (Hume 2018) with the most common[12] matches indicated in Table 3-1 in Section 3. Estuaries are technically a subset of coastal hydrosystems (those in which salinity is between marine and freshwater values).

[12] The relationship between NZCHS class and ETI type is not one to one. The NZCHS and ETI use different characteristics to classify hydrosystems, and classification of hydrosystems is not necessarily clear-cut for either typology.

Appendix B Catchment maps for monitored estuaries

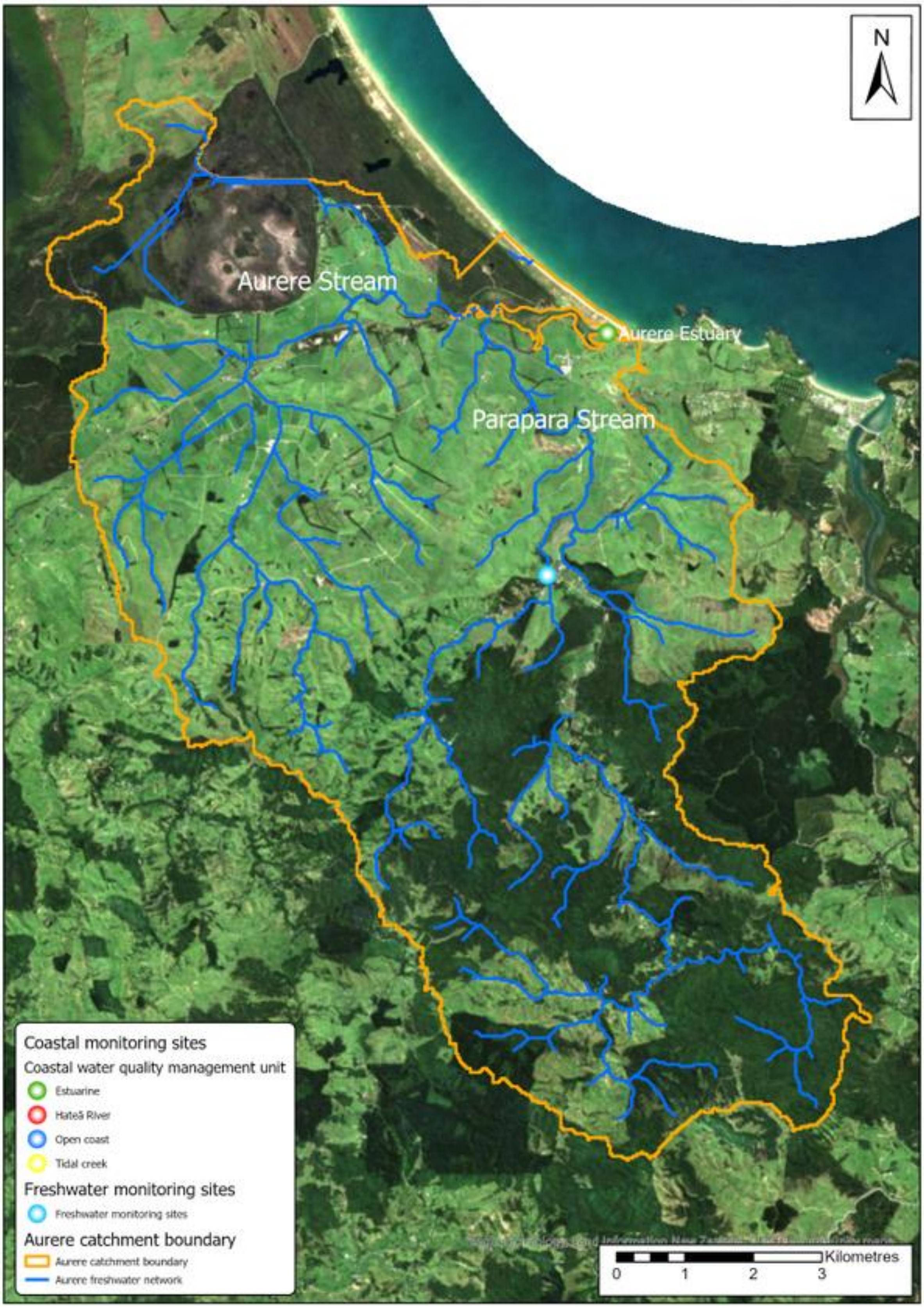

Figure B-1: Freshwater and coastal monitoring sites in the Aurere Estuary catchment.

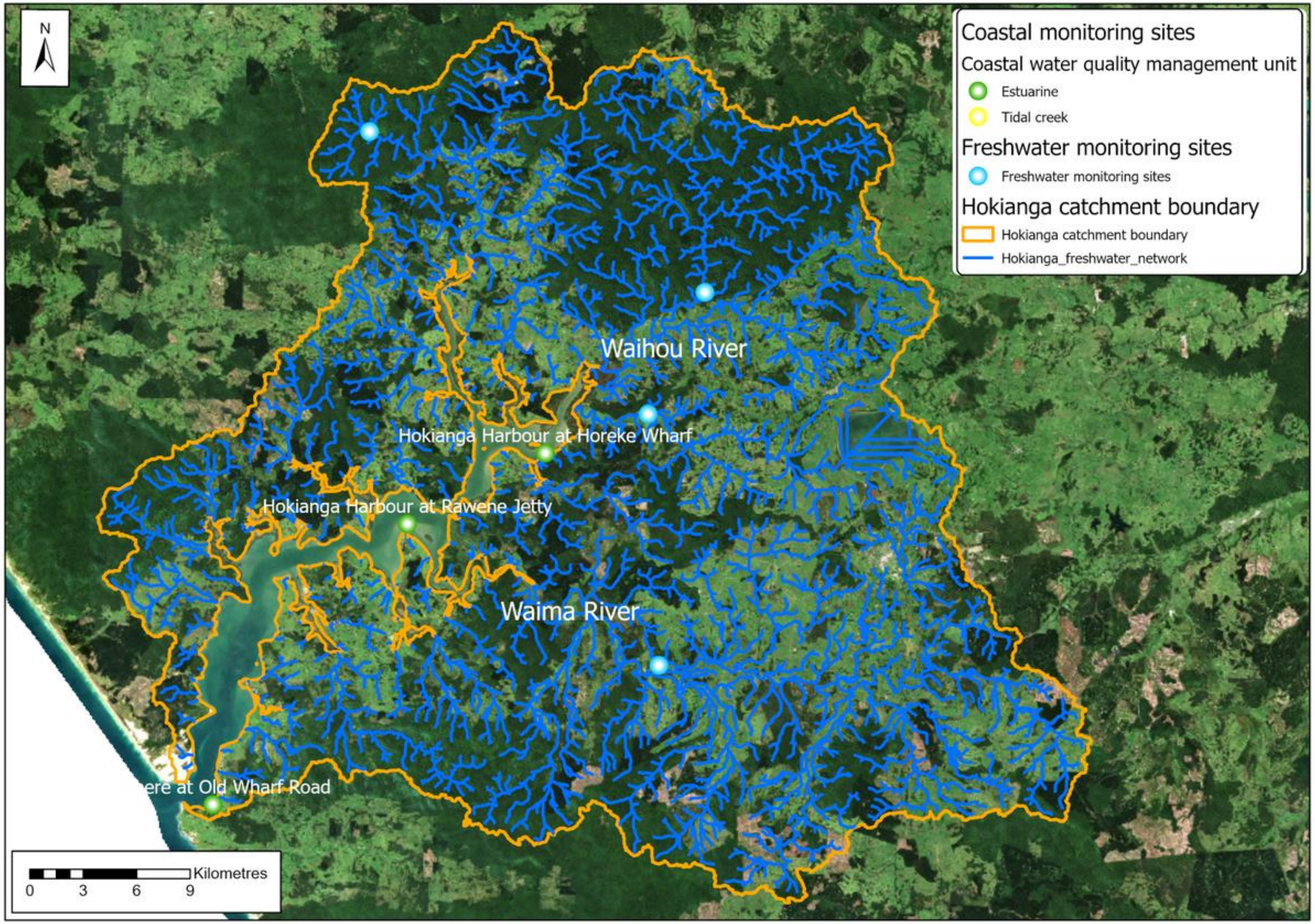

Figure B-2: Freshwater and coastal monitoring sites in the Hokianga harbour catchment.

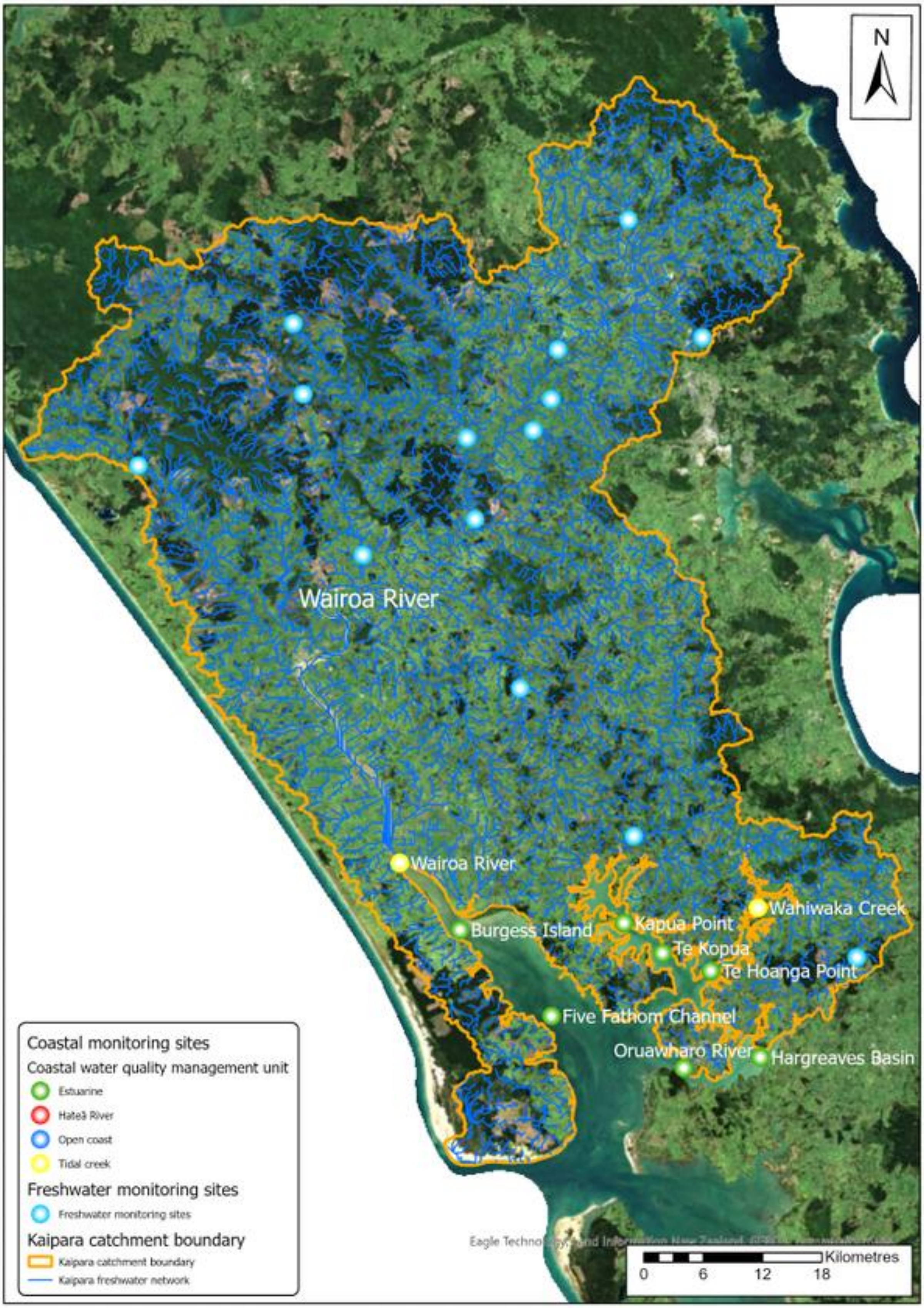

Figure B-3: Freshwater and coastal monitoring sites in the Kaipara harbour catchment.

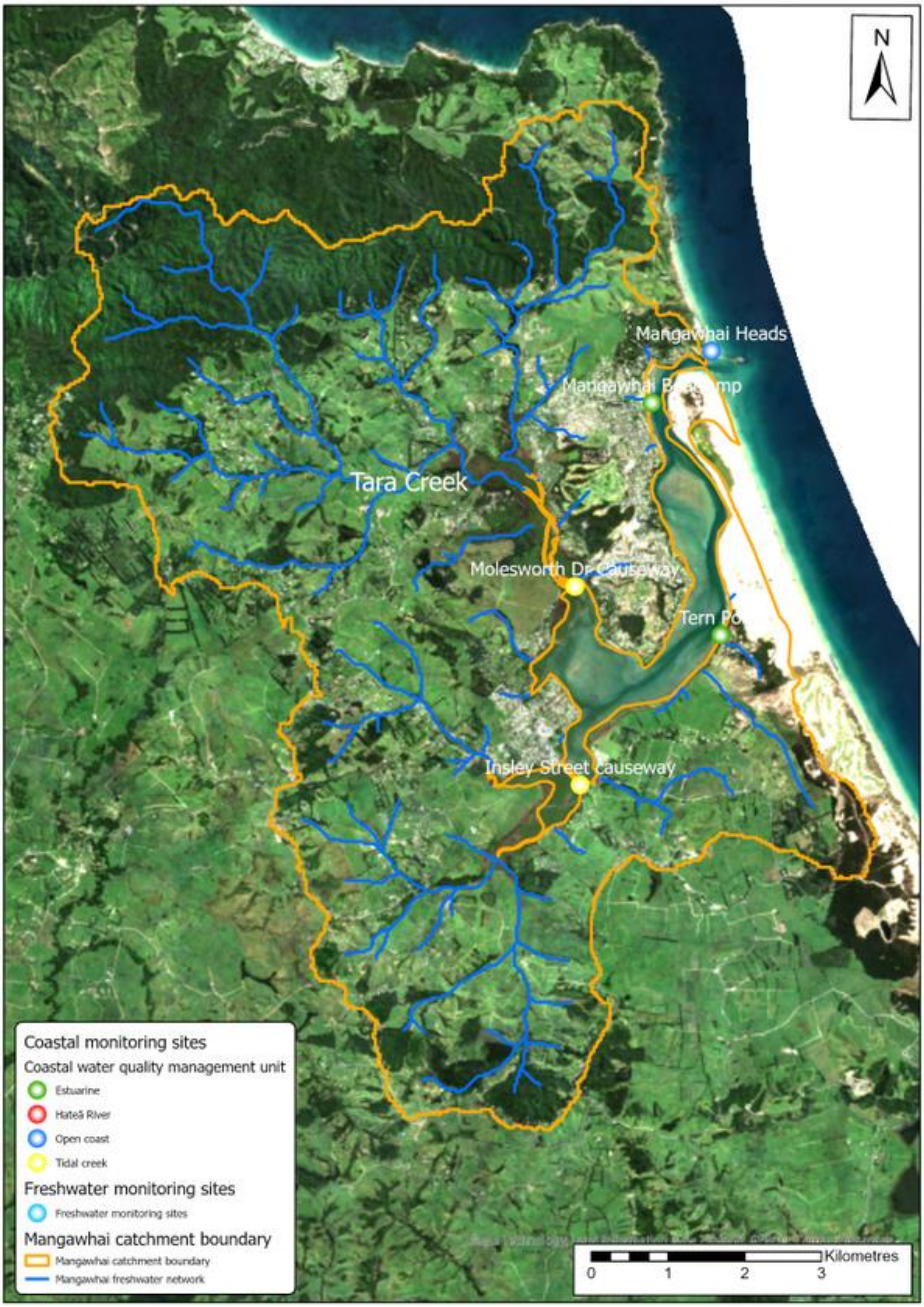

Figure B-4: Freshwater and coastal monitoring sites in the Mangawhai Harbour catchment.

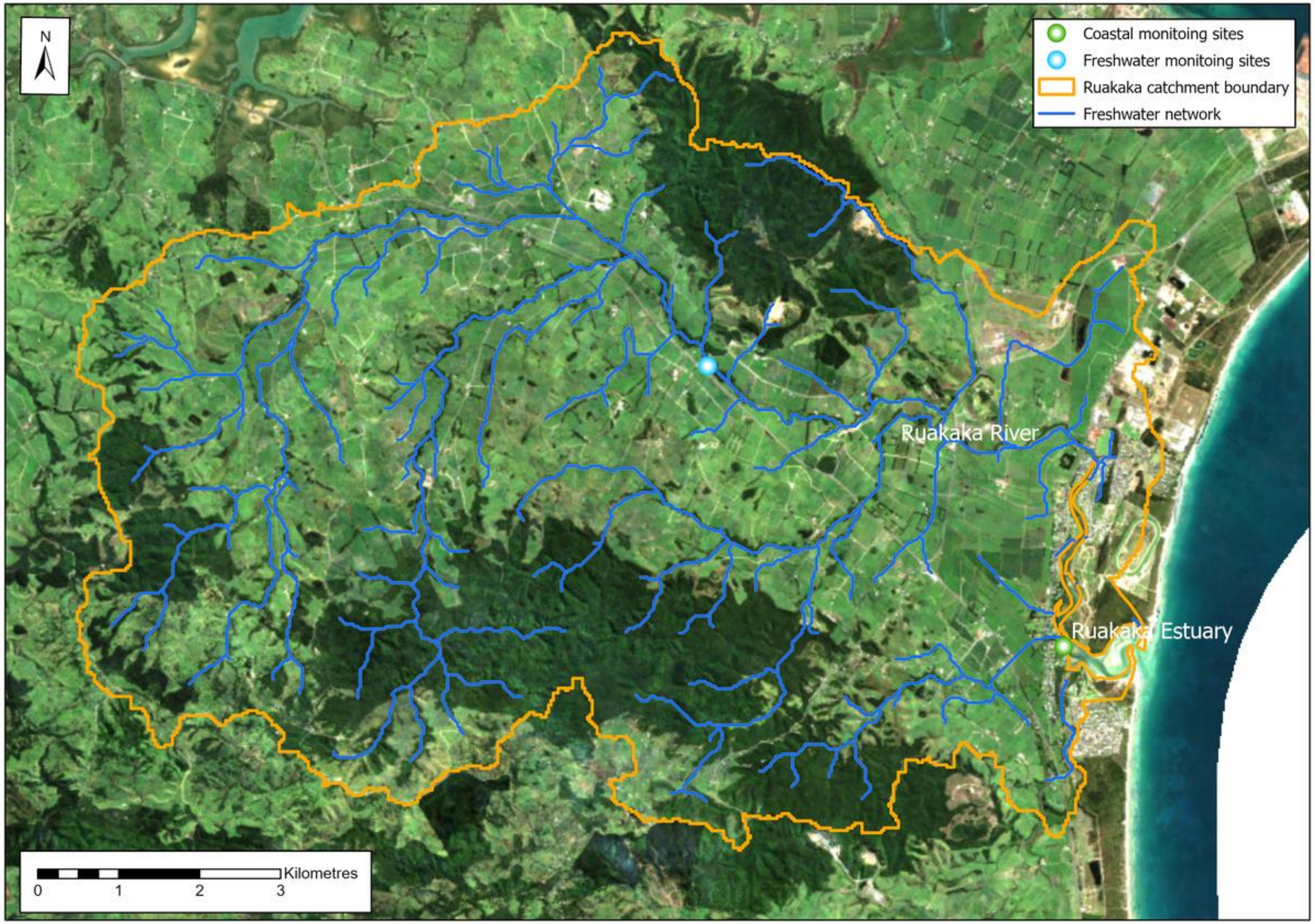

Figure B-5: Freshwater and coastal monitoring sites in the Ruakaka Estuary catchment.

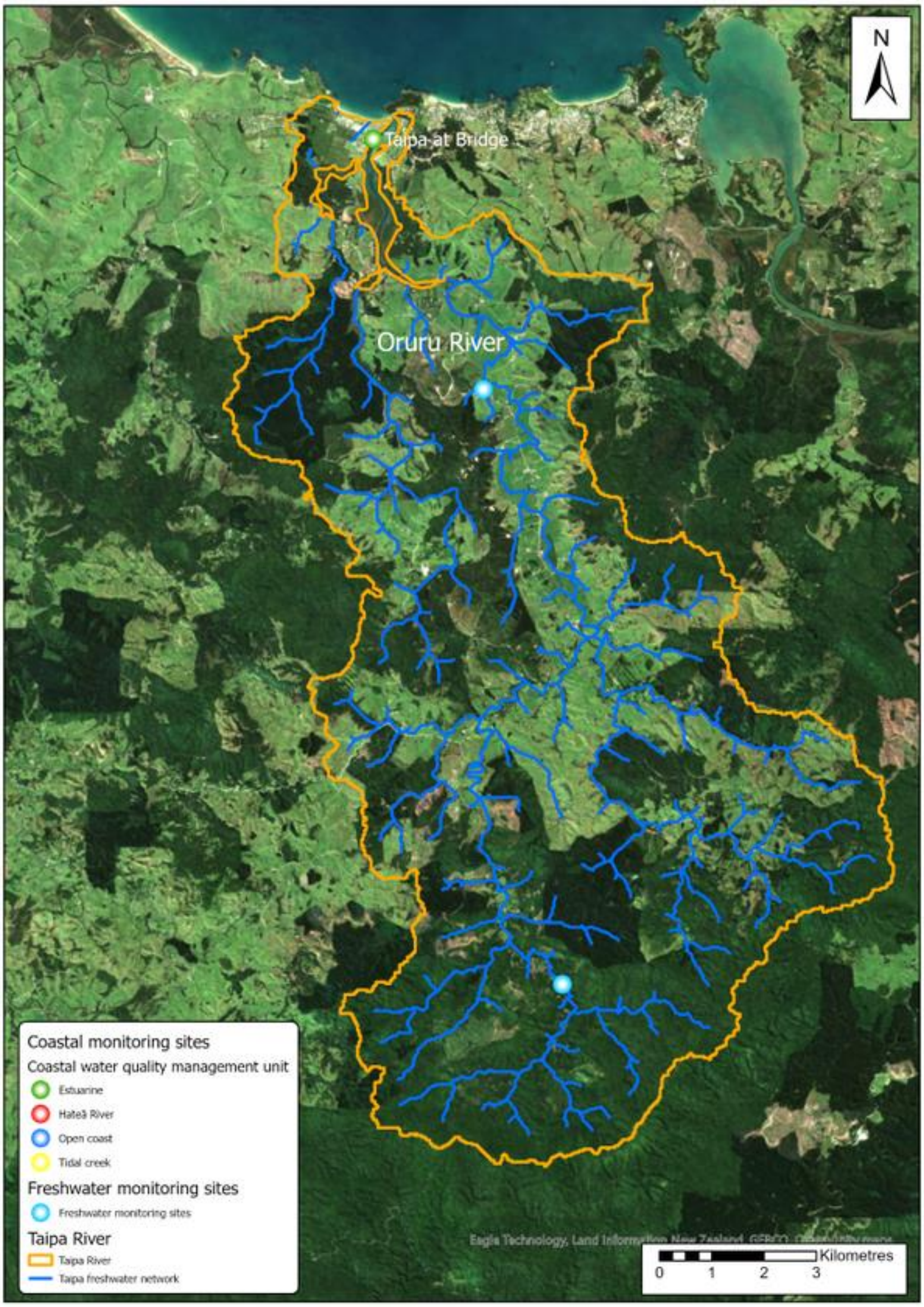

Figure B-6: Freshwater and coastal monitoring sites in the Taipa catchment.

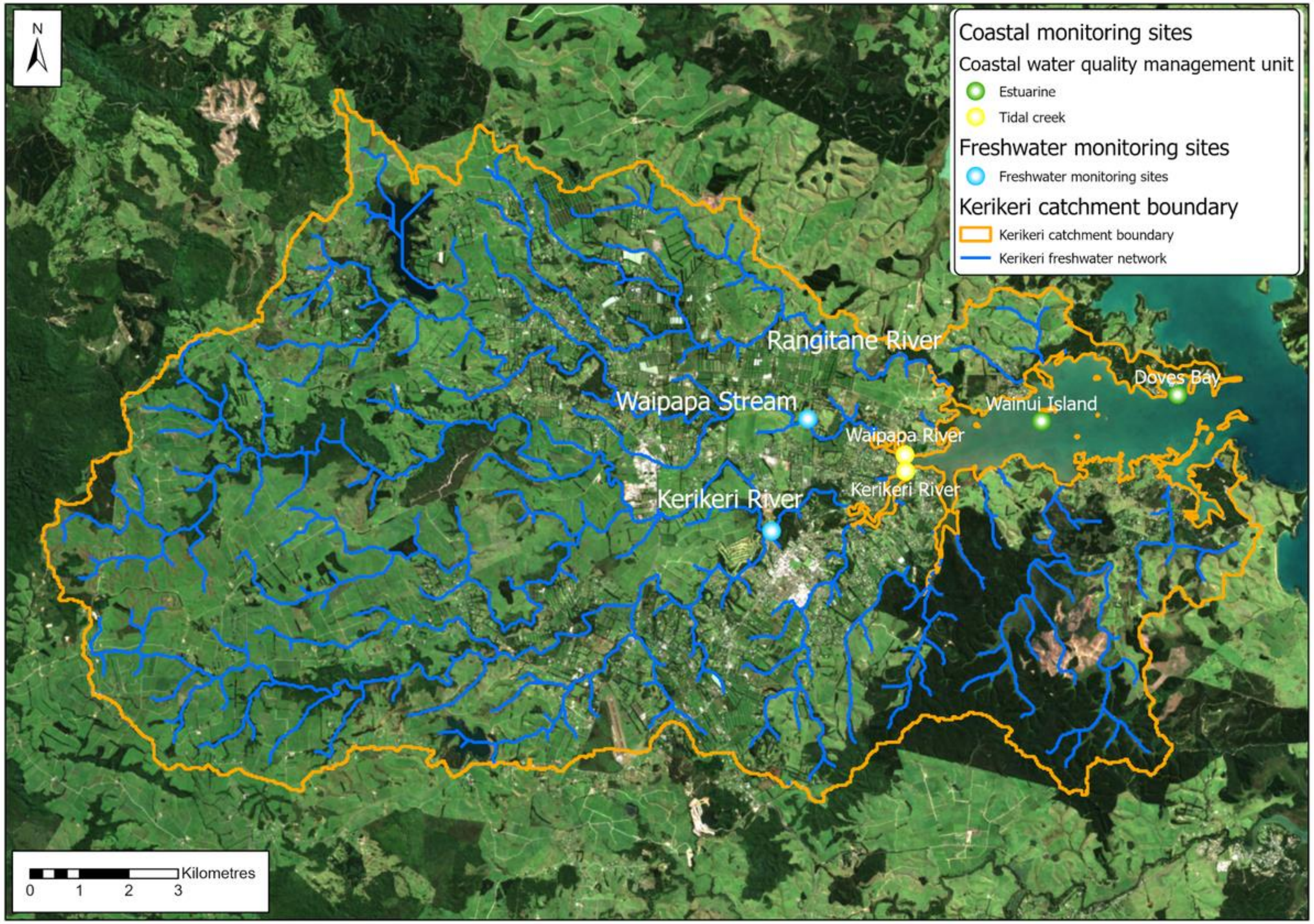

Figure B-7: Freshwater and coastal monitoring sites in the Kerikeri Inlet catchment.

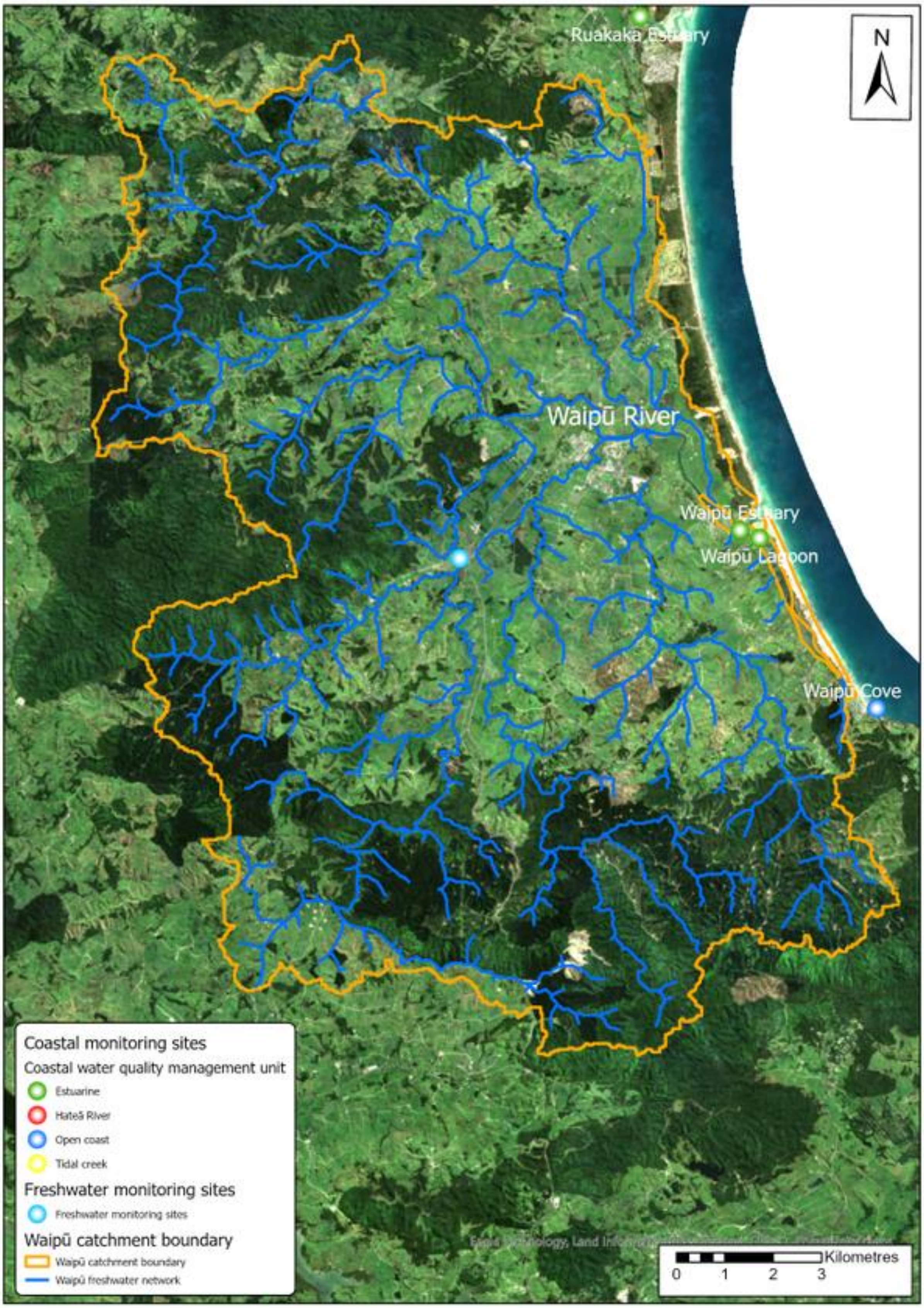

Figure B-8: Freshwater and coastal monitoring sites in the Waipu Estuary catchment.

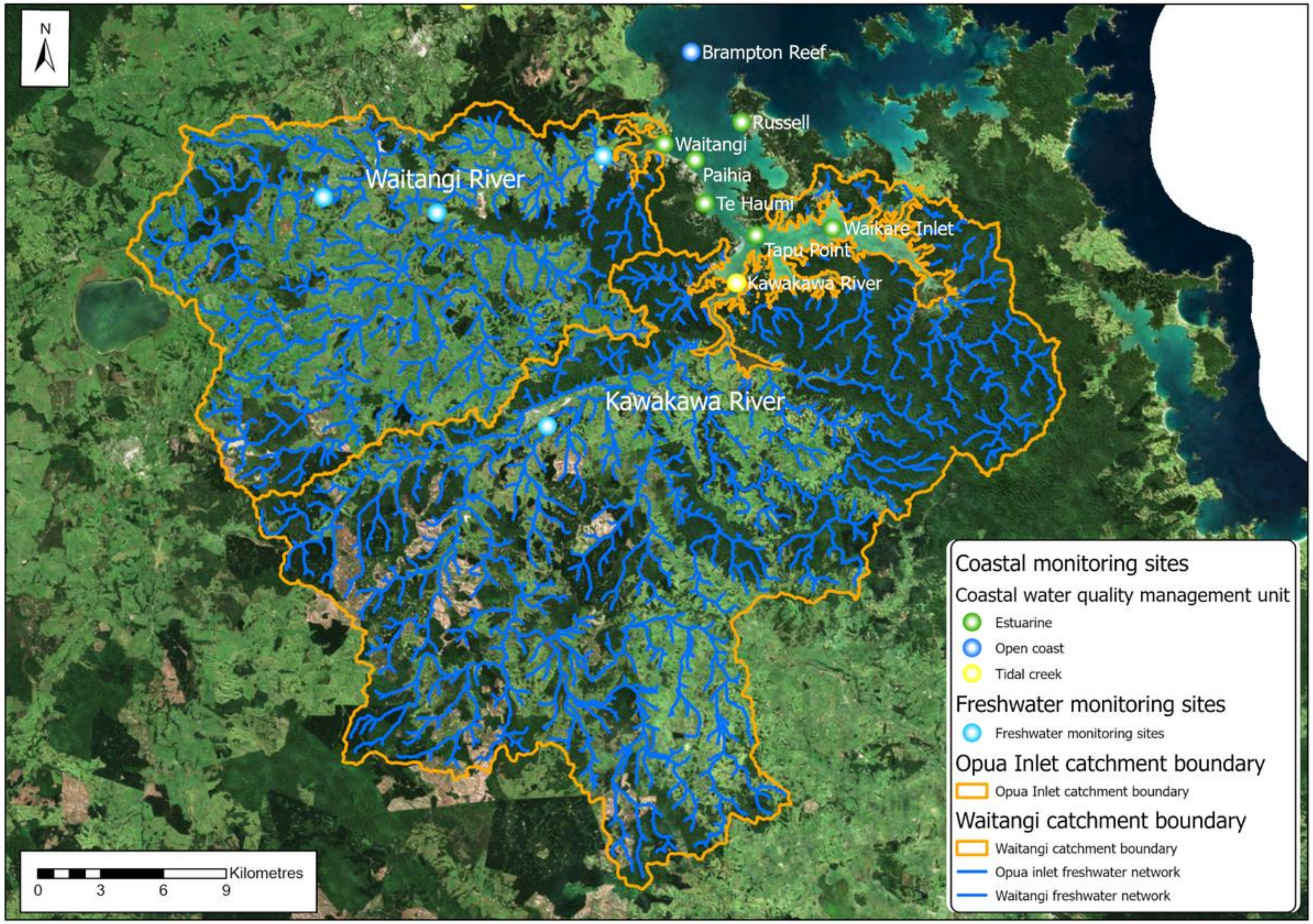

Figure B-9: Freshwater and coastal monitoring sites in the Waitangi and Opua Inlet catchments.

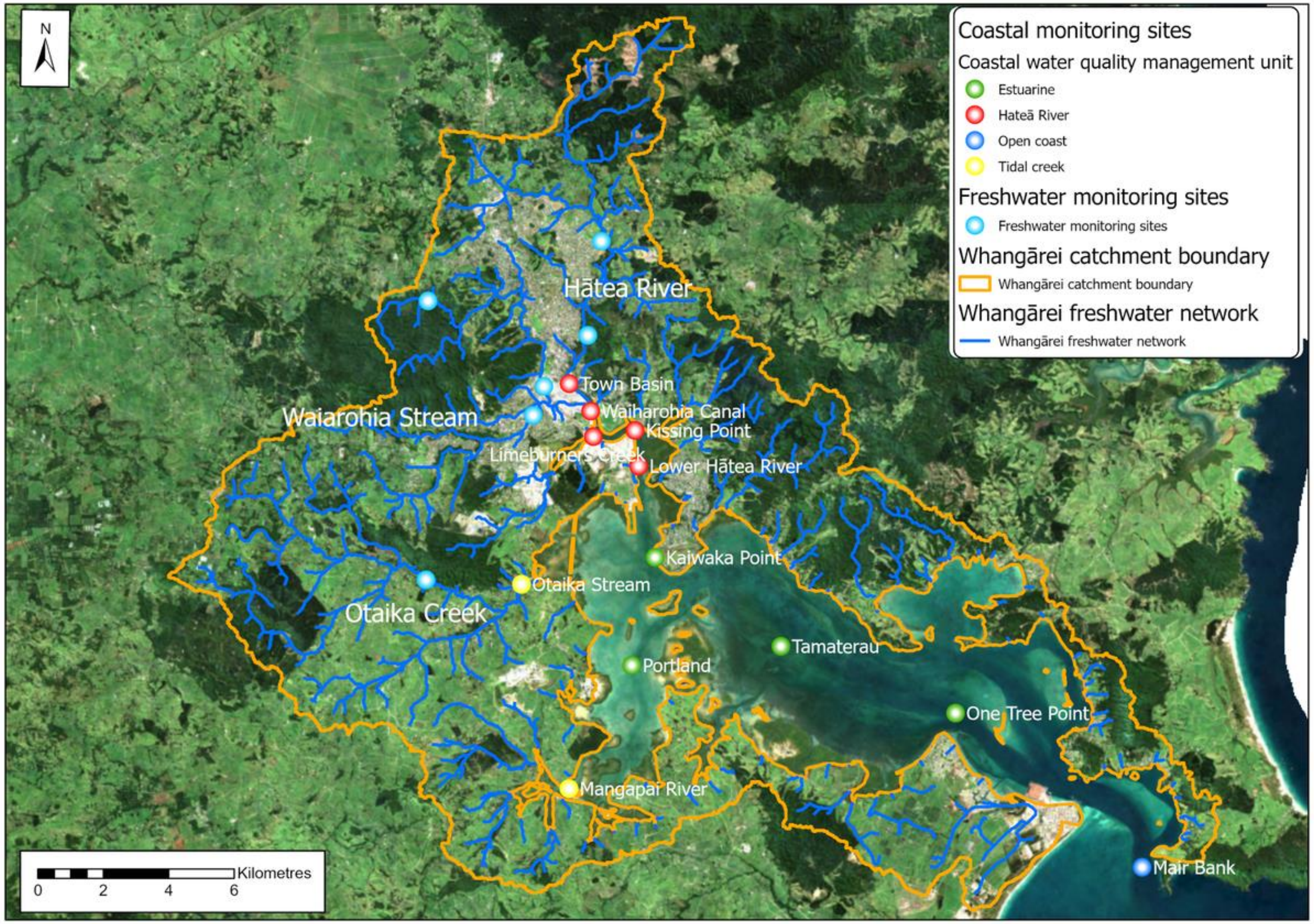

Figure B-10: Freshwater and coastal monitoring sites in the Whangārei Harbour catchment.