Review of Estuarine Water Quality Monitoring for the Horizons Region

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Executive summary

In recognition of a number of national developments, including the release of the national Estuarine Trophic Index (ETI) tool; the 2017 amendments to the National Policy Statement for Freshwater Management (NPS FM); and the draft National Environmental Monitoring Standards (NEMS) for Water Quality; Horizons Regional Council (HRC) has sought a review of the suitability of its current estuarine water quality monitoring programme. This programme supports general state of the environment (SoE), recreation (human health) and Regional Plan (One Plan) effectiveness monitoring.

In this report, we give recommendations on:

- whether the estuaries currently monitored, and whether sites within those estuaries, are likely to give a good representation of estuarine water quality in the Horizons region, and how understanding of estuarine water quality might be improved;
- whether the water quality variables currently monitored, including key supporting metadata, are sufficient for robust assessments of ecosystem health and human health; and
- whether the current sampling methods are appropriate and consistent with current national monitoring guidance and strategies.

We first compared land cover and estuary type of monitored estuaries to land cover and estuary type of all estuaries within the Horizons region. We assessed the number and locations of monitored sites required for both SoE monitoring and for application of ETI tools. We then compared variables currently measured in the HRC estuarine monitoring programme with those associated with variables recommended by several recent national scale reports on coastal or estuarine water quality monitoring, as well as those variables required for ETI implementation. Finally, we compared current HRC sampling methods to NEMS recommendations for coastal water sampling, and best practice methodologies (specific to SoE monitoring, monitoring for human health, and integration of water quality data and ETI tools).

Our recommendations, in order of priority, are:

1. Collection of salinity, suspended sediment and visual clarity data at all coastal and estuarine SoE sites.
2. Structuring the monitoring network to allow comparison of water quality in representative estuaries with water quality in terminal river reaches flowing into them, and on adjacent coastlines.
3. Standardisation, where possible, of monitored water quality variables, and sampling frequency (monthly), at terminal river reaches, within estuaries and in marine waters, without any standardisation of sampling to tidal state.
4. Collection of regular, concurrent salinity and Total Nitrogen (TN) data from the open coast, and salinity, TN and flow data from terminal river reach sites to enable use of the ETI tools to assess estuary eutrophication.
5. Collection of bathymetry, conductivity, temperature and depth (CTD), and tidal height data in one-off field studies on specific estuaries where detailed comparison of

estuarine water quality, contaminant loads and trophic state are required. For deep estuaries where stratification during stable baseflow is considered likely (Robertson and Stevens 2016), one-off field studies should also include collection of water samples to check if sufficiently strong stratification is present that could cause reduced oxygen or pH in subtidal sections of the monitored estuary.

6. Consideration is given to expanding the existing suite of estuaries monitored to include additional estuaries with low native forest cover and high cover of sheep and beef farming to better represent land cover of estuary catchments in the Horizons region (this will also improve the ability to infer water quality in unmonitored estuaries relative to One Plan target values). If the current sites are retained, a representative network with regard to catchment land cover could be reached by adding 4-5 more estuaries with high (80-90%) of catchment land in sheep and beef farming.

7. Retainment of existing estuarine water quality sampling site locations to maintain the value of water quality time series, but establishment of a mid-point shoreline sampling location if new estuaries are monitored.

8. Continued monitoring of both *Escherichia coli* and enterococci at estuarine sites until current microbiological water quality guidelines are reviewed, and facilitation of 'source to sea' tracking of microbial contaminants if desired.

1 Introduction

Horizons Regional Council (HRC) monitors physico-chemical and microbiological water quality across a number of estuaries throughout the Manawatu–Whanganui (Horizons) region as part of its coastal and estuarine monitoring programme. This monitoring is carried out for a range of purposes, including general state of the environment (SoE; 7 estuarine sites and four coastal sites), recreation (human health; 12 sites) and Regional Plan effectiveness monitoring. Estuarine SoE sites are listed in table 8.1. In recognition of a number of developments nationally, including the release of the national Estuarine Trophic Index (ETI) tool (Robertson et al. 2016a, Zeldis et al. 2017c), the 2017 amendments to the National Policy Statement for Freshwater Management (NPS FM, NZ Govt 2017), and the draft National Environmental Monitoring Standards for Water Quality Sampling and Testing (NEMS 2017), HRC has sought a review of the suitability of its current water quality monitoring programme. This review has been funded through an Envirolink Medium Advice Grant (HZLC148, MBIE Contract C01X1727).

1.1 Scope

In relation to HRC's primary monitoring purposes, there are five key components this review addresses:

- The number and location of monitoring sites: Do the number and type of estuaries that are currently monitored provide for a representative picture of estuarine water quality across the Horizons region?
- The number and location of sampling points: Does the current sampling point (or points) within each estuary represent of the typical water quality in the estuary? Should sampling points be moved and/or added?
- The monitored variables: Are the current suite of water quality variables and metadata collected sufficient?
- Sampling methods: Are the current sampling methods, including sampling platform, frequency and timing with respect to tide, robust?
- Water quality and ecological health: What monitoring is required to make a connection between land use, freshwater quality and estuarine ecological health? What information or metadata need to be measured to be collected to enable application of the ETI tools?

1.2 Approach

In Section 2, we briefly outline the legislative context and recent national developments of relevance to HRC's estuarine water quality monitoring programme. We then address each of the five key components of the review as follows:

- firstly, we consider the number and locations of monitored estuaries with regard to representativeness of catchment land use, and estuary types within the Horizons region;

- secondly, we discuss numbers and locations of monitored sites required for SoE monitoring, monitoring for human health (recreation), and monitoring for application of ETI tools;
- thirdly, we compare currently monitored water quality variables with variables:
  - included in the Horizon's Regional Plan (One Plan) with water quality targets;
  - recommended by several recent national-scale reports on coastal SoE monitoring; and
  - required for ETI implementation.
- fourthly, we consider whether current estuarine water quality sampling methods could be improved to fit with recent recommendations of the draft NEMS (2017) for coastal waters, and to best account for tidal variation;
- finally, we review additional information and metadata that are required for use of ETI tools.

2 Legislative context and national initiatives

This section provides a brief overview of key resource management legislation and recent national initiatives for consideration in the review of HRC's estuarine water quality monitoring programme.

2.1 National legislation

2.1.1 New Zealand Coastal Policy Statement 2010

The New Zealand Coastal Policy Statement 2010 (NZCPS) is the principal document for managing coastal and estuarine waters. In terms of water quality, the primary NZCPS policies of relevance to the review of HRC's monitoring are:

- Policy 21: Enhancement of water quality:

  Where the quality of water in the coastal environment has deteriorated so that it is having a significant adverse effect on ecosystems, natural habitats, or water-based recreational activities, or is restricting existing uses, such as aquaculture, shellfish gathering, and cultural activities, give priority to improving that quality by:

  (a) identifying such areas of coastal water and water bodies and including them in plans;

  (b) including provisions in plans to address improving water quality in the areas identified above;

  (c) where practicable, restoring water quality to at least a state that can support such activities and ecosystems and natural habitats;

  (d) requiring that stock are excluded from the coastal marine area, adjoining intertidal areas and other water bodies and riparian margins in the coastal environment, within a prescribed time frame; and

  (e) engaging with tangata whenua to identify areas of coastal waters where they have particular interest, for example in cultural sites, wāhi tapu, other taonga, and values such as mauri, and remedying, or, where remediation is not practicable, mitigating adverse effects on these areas and values.

- Policy 22: Sedimentation

  (1) Assess and monitor sedimentation levels and impacts on the coastal environment.

  (2) Require that subdivision, use, or development will not result in a significant increase in sedimentation in the coastal marine area, or other coastal water.

  (3) Control the impacts of vegetation removal on sedimentation including the impacts of harvesting plantation forestry.

  (4) Reduce sediment loadings in runoff and in stormwater systems through controls on land use activities.

Policy 23 (Discharge of contaminants) is also relevant, in particular Part (1) relating to management of discharges to water. However, because the discharge of contaminants to coastal waters is managed through One Plan rules and resource consents (coastal permits), we have assumed that any monitoring of the effects of significant discharges on the coastal environment will be addressed through resource consent conditions.

2.1.2 National Policy Statement for Freshwater Management 2014

The National Policy Statement for Freshwater Management 2014 (NPSFM) sets out the objectives and policies for freshwater management under the Resource Management Act 1991. Its relevance to the review of HRC's estuarine monitoring is centred around Objective C1:

> "*To improve integrated management of fresh water and the use and development of land in whole catchments, including the interactions between fresh water, land, associated ecosystems and the coastal environment.*"

And Policy C1:

> "*By every regional council:*
> *a) recognising the interactions, ki uta ki tai (from the mountains to the sea) between fresh water, land, associated ecosystems and the coastal environment; and*
> *b) managing fresh water and land use and development in catchments in an integrated and sustainable way to avoid, remedy or mitigate adverse effects, including cumulative effects.*"
> (NZ Govt 2017, p17)

2.2 Regional policy

Coastal resource management issues and rules for the Horizons region are set out in the Horizons One Plan, a combined Regional Policy Statement and Regional Plan. Both the policies of the NZCPS and the NPS-FM (as well as other national regulation) are given effect to by the One Plan. In terms of estuarine water quality, Schedule I of the One Plan addresses coastal marine area (CMA) activities and water management. This includes CMA maps of the west and east coast, and associated river mouths and water management zones (Part A), as well as tables of activity management areas (Part B). Included in the estuary water management sub-zones and seawater management zone are water quality targets for a suite of physico-chemical and biological variables (Table 2-1). These targets have been derived taking into account the different values that apply to each management subzone (Table I-3 of Schedule I). Key values relevant to the review of HRC's monitoring programme include Life-Supporting capacity (LSC), Sites of Significance - Aquatic (SOS-A), Inanga Spawning (IS), Whitebait Migration (WM), Contact Recreation (CR), Shellfish Gathering (SG), and Capacity to Assimilate Pollution (CAP).

Table 2-1: Water quality targets for estuary water management sub-zones and the seawater management zone in the Manawatu-Wanganui Region. Reproduced from Tables I.5 and I.7 of Schedule I of the Horizons One Plan (2014), respectively. Definitions for the targets, including any statistics to apply, are provided in Tables I4 and I6 of Schedule I.

*Water Management Zone**	Estuary *Sub-zone**	Temp (°C)	DO (%SAT)	Algal Biomass	Macro-algae	DRP (g/m³)	SIN (g/m³)	Ammoniacal Nitrogen (g/m³)	Tox.	*E.coli* / 100 ml		Euphotic Depth	Visual Clarity (m)	Visual Clarity (m)
		<	>	Chl *a* (mg/m³)	% cover	<	<	<	%	<50th %ile	<20th %ile	%Δ	>	%Δ
Coastal Manawatu (Mana_13)	Manawatu Estuary (Mana_13CMA)	24	70	4	5	0.015	0.444	0.400	95	260	550	10	1.2	20
Coastal Rangitikei (Rang_4)	Rangitikei Estuary (Rang_4CMA)	24	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Lower Whanganui (Whai_7)	Whanganui Estuary (Whai_7CMA)	24	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Coastal Whangaehu (Whau_4)	Whangaehu Estuary (Whau_4CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Turakina (Tura_1)	Turakina Estuary (Tura_1CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Ohau (Ohau_1)	Ohau Estuary (Ohau_1CMA)	22	70	4	5	0.010	0.110	0.400	95	260	550	10	1.2	20
Lake Horowhenua (Hoki_1)	Hokio Estuary (Hoki_1CMA)	24	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Owahanga (Owha_1)	Owahanga Estuary (Owha_1CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
East Coast (East_1)	Wainui Estuary (East_1CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Akitio (Akit_1)	Akitio Estuary (Akit_1CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Kai Iwi (West_2)	Kai Iwi Estuary (West_2CMA)	22	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Mowhanau (West_3)	Mowhanau Estuary (West_3CMA)	24	70	4	5	0.015	0.167	0.400	95	260	550	10	1.2	20
Waikawa (West_9)	Waikawa Estuary (West_9CMA)	22	70	4	5	0.010	0.167	0.400	95	260	550	10	1.2	20

Management Zone	DO (%SAT)	Algal Biomass	TP (g/m³)	TN (g/m³)	Ammoniacal Nitrogen (g/m³)	Tox.	Visual Clarity (m)		Enterococci		Faecal Coliforms	
	>	Chl a (mg/m³)	<	<	<	(%)	>	%Δ	1 Nov - 30 April	1 May - 31 Oct	<	90th%ile
*Seawater Management Zone**	90	3	0.010	0.060	0.060	99	1.6	20	140	280	14	43

2.3 Recent national initiatives

Five key recent national initiatives of relevance to HRC's monitoring of estuarine water quality are outlined below.

2.3.1 Estuarine Trophic Index

The New Zealand Estuarine Trophic Index (ETI) project initiated by the regional sector's Coastal Special Interest Group (Coastal SIG) was completed in early 2017. The project produced three tools to assist regional councils in determining the susceptibility of an estuary to eutrophication, assess its current trophic state, and assess how changes to nutrient load limits may alter its current state. The tools determine estuary eco-morphological type, where an estuary sits along the ecological gradient from minimal to high eutrophication, and provide stressor-response tools (e.g., empirical relationships, nutrient models) that link the ecological expressions of eutrophication (measured using appropriate trophic state indicators) with nutrient loads (e.g., macroalgal biomass/nutrient load relationships); see (Robertson et al. 2016b, Robertson et al. 2016a, Zeldis et al. 2017a, Zeldis et al. 2017b, Zeldis et al. 2017c).

The ETI tools are of interest to HRC in their management of estuaries in their region (e.g., for determining ecological health and providing guidelines to assess whether or not relevant One Plan outcomes are being met). Key information requirements for using the ETI tools are outlined in Section 6.1.3.

2.3.2 National Coastal Water Quality Assessment

In 2016, MfE commissioned NIWA to collate, review and analyse existing coastal water quality data gathered by the 16 regional and unitary authorities. The resulting report (Dudley et al. 2017) includes state and trend analyses of water quality variables most commonly used by councils for monitoring eutrophication, sedimentation and climate related long-term change. The report also provided recommendations for future analysis and reporting, including water quality thresholds, communication of trends, data quality, and uncertainty in water quality measurements. In addition, recommendations were made for improving monitoring networks at both regional and national levels. The key findings from this national assessment of coastal water quality in relation to programme design are taken into account in our review of HRC's coastal water quality monitoring programme (Sections 3, 4, 5 and 6).

2.3.3 National Environmental Monitoring Standards (NEMS) for Water Quality

Draft NEMS documents addressing sampling, measuring, processing and archiving of discrete water quality data were released in October 2017 and final documents should be available in July 2018. These documents establish best practice for field measurements, water sample collection and laboratory testing across a range of water domains, including estuarine and coastal waters (NEMS 2017, Part 4).

NEMS is primarily focussed on long-term (e.g., SoE) monitoring, making its contents highly relevant to the review of HRC's estuarine water quality monitoring programme. The NEMS includes a process to assign a quality code to individual water quality measurements. Theses codes conform to Open Geospatial Consortium standards, ranging from QC 100 ("Missing record") to QC 600 ("Good quality"). Quality code assignment is guided by a flow chart and series of matrices that address key aspects of sample collection, measurement and laboratory testing that have the potential to influence data quality. These aspects are revisited in Section 6.

2.3.4 Managing Upstream: Estuaries

"*Managing Upstream: Estuaries State and Values"* was a Ministry for the Environment (MfE) commissioned project with the aim to better account for impacts on estuarine values when setting management objectives and freshwater limits under the NPS-FM. The NIWA and Cawthron-led project also sought to increase knowledge of the state of different estuary types in New Zealand. Stage 1 of the project has just come to a close after two years and the outputs included a recommended suite of state variables (e.g., for SoE monitoring), with a smaller subset of these (e.g., rate of sediment deposition) identified for potential estuarine attribute development[1] (Zaiko et al. 2018). The recommended variables address the values of ecosystem health, human health for recreation and mahinga kai, and include a range of water quality, sediment quality and biological measures. The recommended water quality variables include nutrient concentrations (N, P), chlorophyll-*a*, dissolved oxygen, water clarity (e.g., Secchi disk), total suspended sediments, and faecal indicator bacteria. These variables, revisited in Section 5, should be considered in the review of HRC's estuarine water quality monitoring programme.

2.3.5 National Microbiological Water Quality Guidelines

The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas ['the Guidelines' (Ministry for the Environment/Ministry of Health 2003) form a pivotal reference for water quality management in New Zealand. The Guidelines underpin summer recreational water quality monitoring programmes undertaken by regional and unitary councils in collaboration with Territorial Local Authorities (TLAs) and the Public Health Units of District Health Boards (PHUs). This monitoring is carried out to assess the microbiological water quality of freshwater and nearshore coastal areas commonly used for contact recreation. The monitoring results are compared to 'trigger levels' in the Guidelines which provide the basis for informing the public as to when risks of illness may be unacceptable. Monitoring data collated over time are also used by some councils to calculate a Suitability for Recreation Grade (SFRG) for each recreation site or, more recently in the case of freshwater sites, to assess progress against water quality objectives set under the NPS-FM (Milne et al. 2017).

A current MBIE Envirolink Tool project initiated by the regional sector's Coastal SIG in 2015/16 has sought a review of four aspects of the marine component of the Guidelines. Of particular relevance to the review of HRC's estuarine water quality monitoring — and revisited in Section 5.3 — is component 4; the appropriate indicator(s) to use in brackish water bodies for SoE reporting and public health risk management. At present, the Guidelines do not specify whether *Escherichia coli (E. coli)*, enterococci or faecal coliform indicator bacteria should be tested in brackish (e.g., estuarine) waters used for recreational purposes (Bolton-Ritchie et al. 2013). Part of component 2 of the review relating to recreational shellfish-gathering waters is also relevant; whether, better and more timely guidance can be given other than the current reporting an end of season 'pass' or 'fail'. Season and sampling frequency are not defined in the Guidelines (Bolton-Ritchie et al. 2013).

2.4 Other relevant initiatives

The existing HRC estuarine and coastal monitoring programme was informed by a report prepared by Cornelisen (2010). Although not all of the recommendations in that report were implemented by HRC, for completeness of assessment, we have taken into account the advice of Cornelisen (2010) in

[1] In the same way that the NPS-FM 2014 contains variables as attributes (e.g., chlorophyll a and total nitrogen as measures of ecosystem health in lakes).

our review of the current monitoring programme. We have also made use of other resources provided by HRC, most notably recent estuarine ecological health assessments undertaken by Wriggle Coastal Management Ltd (e.g., Robertson and Stevens (2016), and copies of existing sampling run guides and laboratory test method details.

3 Number and locations of monitored estuaries

This section addresses whether the number and type of estuaries that are currently monitored provide for a representative picture of estuarine water quality across the Horizons region.

3.1 Representativeness with regard to catchment land use

Water quality of New Zealand rivers is strongly dependent on land uses found within their catchments (Larned et al. 2016), and water quality of New Zealand estuaries is strongly dependent on the quality of fresh water flowing into them (Plew et al. 2018). Hence, for representativeness of both regional and national-scale estuarine water quality, Dudley et al. (2017) recommend estuarine water quality monitoring networks that are replicated with regard to environmental classes of catchment land cover. Cornelisen (2010) further suggested that comparisons of data among estuaries across a gradient of land-use pressures in the Horizons region would assist in understanding links between water-quality indicators and stressors (e.g., estuarine TN concentrations and catchment agricultural land use). Understanding land-use pressures on unmonitored estuaries which have One Plan water quality targets may also provide information on whether water quality in these estuaries is likely to breach targets. Below, we outline two methods with which we have assessed the representativeness of estuaries currently monitored within the Horizons region with regard to environmental classes of catchment land use.

In the first approach (Table 3-1), we compare the average percentage cover of land-cover classes in monitored catchments to the average percentage land cover for all estuary catchments within the Horizons region, as estimated by Robertson and Stevens (2016). We note that this assessment is not scaled to the total area of catchments. We feel that a non-area-scaled approach is most appropriate because current methods used in national SoE reporting do not scale state and trend analysis to catchment area. For example, Larned et al. (2015) and Dudley et al. (2017) reported numbers of sites with increasing or decreasing trends for each water quality variable.

Table 3-1: Representativeness of HRC monitored estuaries with regard to environmental classes of catchment land use and estuary type. Mean percentage land-cover values are not scaled to estuary catchment size. Original data from Horizons Regional Council.

	Representativeness with regard to environmental classes of catchment land use							
	Urban	Cropping	Dairy	Exotic forest	Horticulture	Native Forest	Sheep/beef	Water
Mean percentage landcover in all estuary catchments	0.5%	0.3%	12%	12.7%	0.2%	10.1%	63.2%	0.2%
Mean percentage landcover in currently monitored estuary catchments	1%	1%	15%	11%	0%	29%	42%	0%

	Representativeness with regard to estuary type		
	Deep Subtidal Dominated Estuary (DSDE)	Shallow, Short Residence Time River Estuary (SSRTRE)	Shallow Intertidal Dominated Estuary (SIDE)
Percentage of estuary type (ETI classification) – all estuaries	0	100%	0
Percentage of estuary type (ETI classification) – monitored catchments	0	100%	0

	Representativeness with regard to estuary sub-type (Robertson and Stevens (2016)			
	Type 1 Short length, low flow SSRTREs	Type 2 Moderate length, low flow SSRTREs	Type 3 Long length, moderate flow SSRTREs	Type 4 Long length, high flow SSRTREs
Percentage of estuary type (Robertson and Stevens 2016 classification) – all estuaries	68.3%	12.2%	4.9%	14.6%
Percentage of estuary type (Robertson and Stevens 2016 classification) – monitored estuaries	14%	14%	14%	57%

A second approach is to compare the representativeness of monitoring networks to specific land-cover types. Previous investigations of land-cover impacts on estuarine ecology in New Zealand have shown strong relationships between estuarine ecological function and the percentage of catchment land cover that is in a 'pristine' state (Bierschenk et al. 2012, Bierschenk et al. 2017). As a proxy for 'pristine' land cover, we have examined the percentage of land cover in the 'Native Forest' land-cover class. In the Horizons region, native forest cover shows a strong inverse relationship to the percentage of land use in non-forestry agriculture (Cropping, Dairy, Horticulture and Sheep and Beef land-cover classes combined). In Figure 3-1, we have plotted estuaries within the Horizons region on axes of native forest land cover and 'non-forestry agriculture'. The locations of this set of estuaries are shown in Figures 3-2 and 3-3.

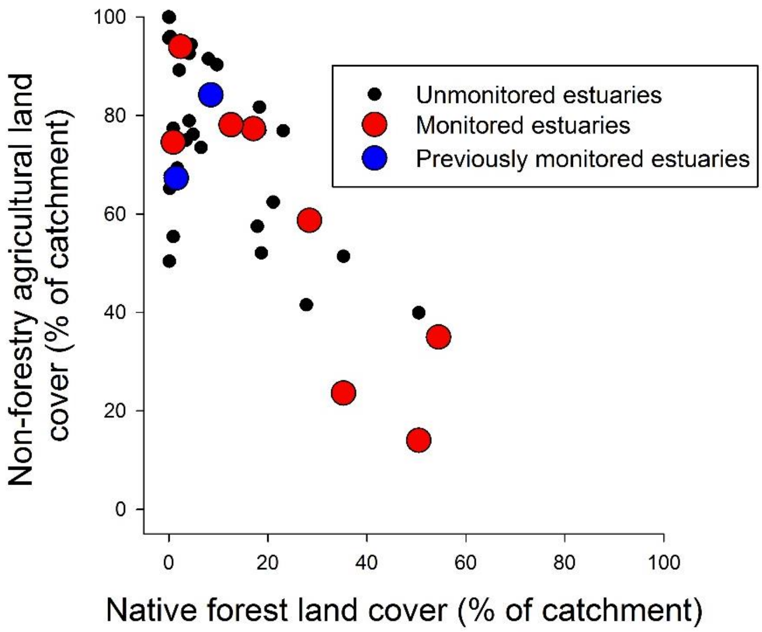

Figure 3-1: Representativeness of currently monitored and previously monitored estuaries across a gradient of Native Forest and Non-forestry agriculture. Unmonitored estuaries are all those not currently monitored that are included in the estuary list of Robertson and Stevens (2016). Previously monitored estuaries are those that are not currently monitored but had data that were utilised by Dudley et al. (2017); these are Turakina River Estuary, and Wairarawa Stream Estuary.

Figure 3-1 suggest that there is a good range of catchment land use pressure across the monitored estuaries, albeit with an over-representation of pristine forest catchment land cover (also see Table 3.1). Were the monitoring network to be expanded we would suggest the inclusion of more estuaries with low native forest cover and high cover of sheep and beef farming to better represent land cover of estuary catchments in the Horizons region. Addition of estuaries with high cover of sheep and beef farming would also increase the degree to which water quality in monitored estuaries could be used to infer whether One Plan water quality target values are likely to be met or not in unmonitored estuaries. If the current sites are retained, a representative network with regard to catchment land cover could be reached by adding 4-5 more estuaries with high (80-90%) of catchment land in sheep and beef farming.

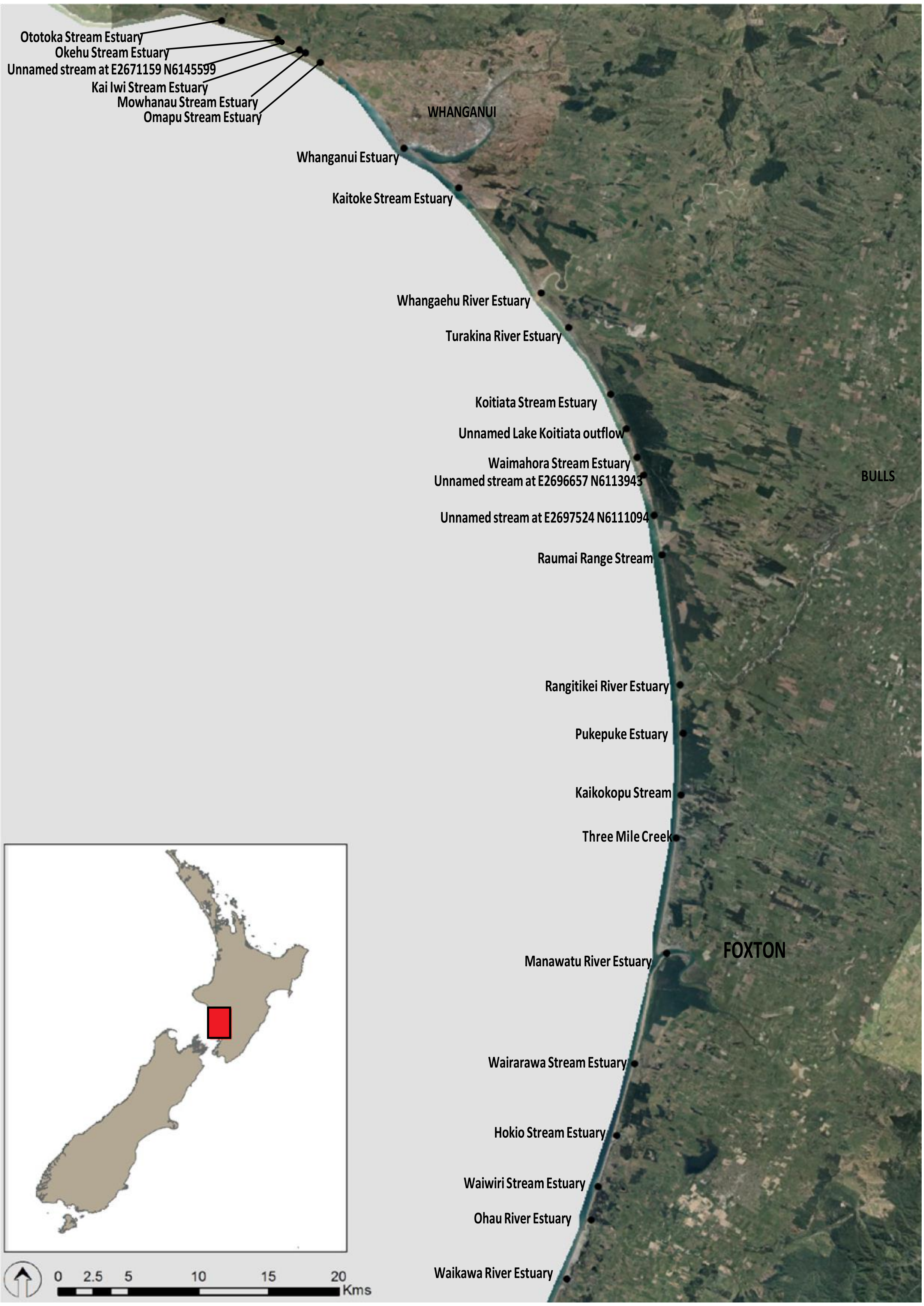

Figure 3-2: Locations of estuaries in the Horizons region - West coast. Reproduced with author permission from the report of Robertson and Stevens (2016).

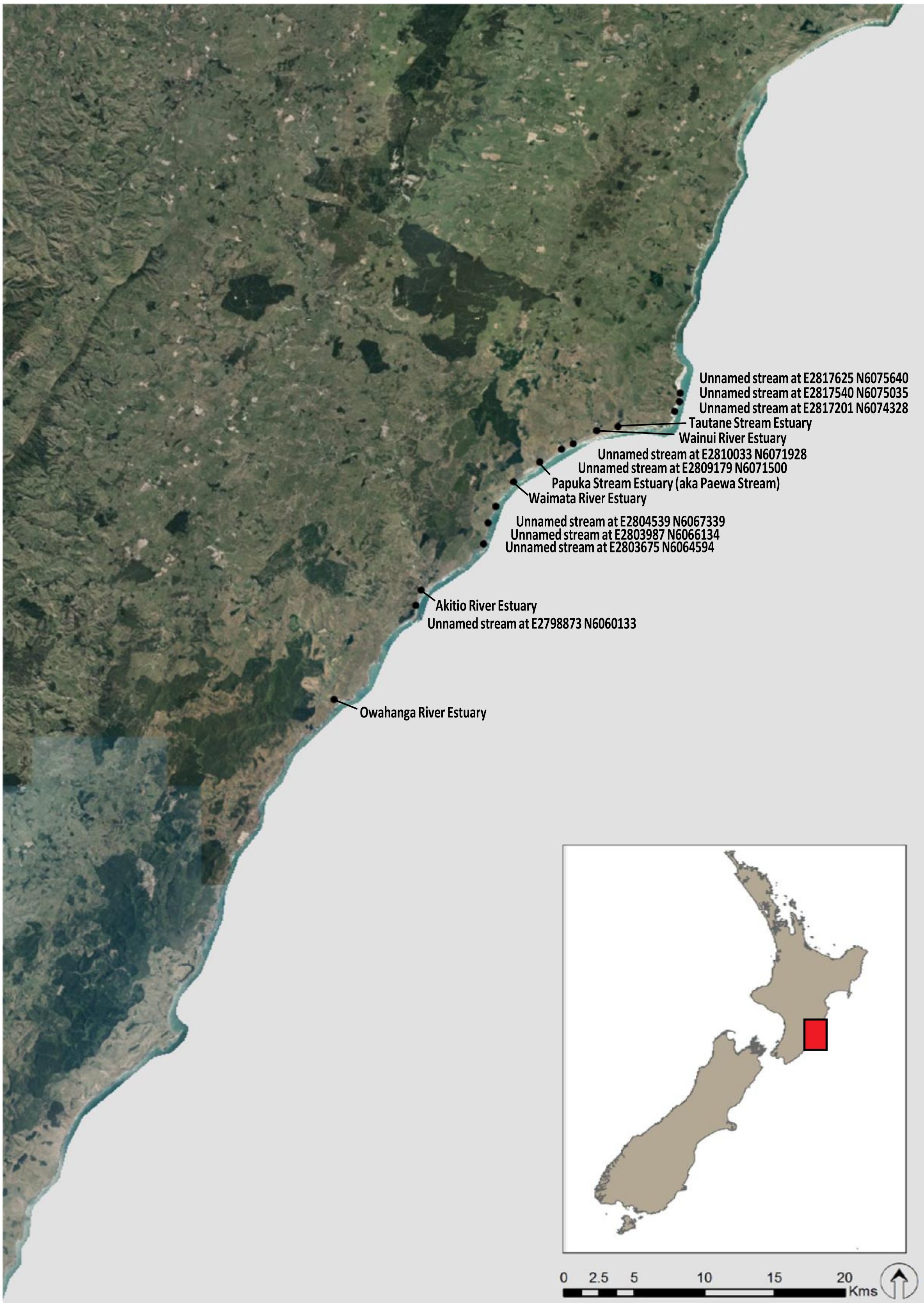

Figure 3-3: Locations of estuaries in the Horizons Region - East coast. Reproduced with author permission from the report of Robertson and Stevens (2016).

3.2 Representativeness with regard to estuary type

Estuaries vary in their physical characteristics so are likely to vary in their susceptibility to land-use change and associated changes in water quality. Grouping estuaries by characteristics of dilution, retention time and loss of inflowing nutrients can therefore help provide a monitoring network that is representative of estuarine water quality within a region. For representativeness in SoE monitoring, Dudley et al. (2017) recommended sampled estuaries are replicated across estuary type in proportion to the occurrence of that estuary type within the region. In Table 3-1, we grouped Horizons estuaries according to the ETI classification system. ETI classifications are designed to reflect the susceptibility of estuaries to eutrophication resulting from nutrient loading and may account for some variation in water quality associated with environmental heterogeneity. Within the Horizons Region, all estuaries fit the definition of shallow, short residence-time tidal river estuaries (SSRTREs) according to Robertson et al. (2016a). However, we note that Robertson and Stevens (2016) further classify the estuaries within the Horizons Region on the basis of estuary length and flow rates; examination of currently monitored estuaries according to this classification suggests that representativeness of the current monitoring network could be improved by increasing the number of short length, low flow SSRTREs monitored. Examples of such 'type 1' SSRTREs in the Horizons region are shown in table 8-1, and notably several of these have high proportions of sheep and beef farming land cover in the upstream catchments. Selection of such estuaries (e.g. Ototoka Stream Estuary, Kaitoke Stream Estuary, Mowhanau Stream Estuary, Papuka Stream Estuary) as additional SoE monitoring sites would also improve representation of estuarine SoE monitoring with regard to land cover in the Horizons region.

4 Number and locations of monitored sites

In this section we consider the number and location of regional-scale SoE monitoring sites, and requirements for the ETI dilution modelling approach to assessing estuary susceptibility to N loads. We have not reviewed the number or location of recreational water quality monitoring sites; such a review requires local knowledge and should be undertaken in collaboration with the relevant local councils and interest groups (e.g., recreational clubs).

The ETI dilution modelling approach calculates 'potential' nutrient concentrations of estuarine water and requires local oceanic (i.e., open coast) total nitrogen (TN) concentration, TN concentrations in fresh water flows to estuaries, and freshwater flow rates (Plew et al. 2018). These data are important for modelling loads of N entering estuaries from land that correspond with changes in estuarine trophic state (e.g., (Dudley and Plew 2017, Plew and Dudley 2018) and linking these predicted changes with observed data (e.g., Robertson and Stevens 2016). While national-scale modelled data are available for all New Zealand estuaries, these data are unlikely to be as accurate as *in-situ* sampling measurements (Plew et al. 2018). Therefore, as outlined below, we recommend that water column nutrients are monitored in 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).

4.1 Terminal river reach sites

Terminal river reach sampling is necessary to meet riverine flow and nutrient load data requirements of estuary dilution modelling (Plew et al. 2018). It is also useful to measure change in overall upstream catchment pressure (e.g., changes in nutrient or sediment loads) and will provide information to indicate how within-estuary water quality compares against the One Plan targets.

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 conductivity cut-off would be 5 mS/cm (sea water being ~50 mS/cm). Recommended water quality variables are discussed in more detail in Section 5. In some cases, landward inflow of ocean water into river estuaries results in high salinities and tidal influence on flows extend 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.

4.2 Estuary sites

Water quality within 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 estuarine 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 (Hewitt et al. 2012, Barr et al. 2013, Robertson et al. 2016c). 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 estuary in the sampling network is represented by at least one estuary water quality sampling site. We suggest that the best use of water quality data from estuary sites is for comparison with long-term change in land use and pollutant loads, not as a spatially representative measure of trophic state (a purpose for which the ETI was created). For new sites, we would recommend a shoreline sampling point at around the midpoint of the estuary between the ocean and the terminal reach sampling point. For existing sites, maintenance of site locations is vital for the usefulness of water quality time series, and therefore existing site locations should be maintained where a record of several years already exists. For the purposes of SoE sampling in estuaries, we believe that the shoreline estuary sites described in Horizons SoE sample run guides are sufficient.

For the purposes of dilution modelling, the location of sites within the estuary are not vital as long as salinity data are collected alongside nutrient measurements to enable validation of the modelling. For reasons stated above regarding consistency of time series, we do not recommend shifting sampling locations solely for the purposes of dilution modelling.

We expect that HRC will continue with existing benthic ecological monitoring across its estuaries. This monitoring should be based on sites that have been selected to represent the overall estuarine habitat and therefore the results of this monitoring, as opposed to data from a single water quality monitoring site, should be used as the *primary* indicator of estuarine health or condition.

4.3 Open coastal sampling

Because the dilution modelling requires open coastal samples (salinity ca. 35) to calculate mixing within the estuary, appropriate sampling from outside the estuary is required. As of 2017 there were four open coastal SoE sites monitored; these are Kai Iwi Beach at Kai Iwi Stream Bridge, Himitangi Beach at Surf Beach, Tasman Sea at Waitarere Beach and Akitio Beach at Surf Club. Having reviewed current sampling sites, we believe that if salinity data is collected at the time of sampling (or can be back calculated) then in most cases the existing SoE sampling sites could be used to collect this open coast data. We suggest that especially for large estuaries, for which catchment management may be a high priority (e.g., the Manawatu and Whanganui estuaries), and therefore dilution modelling may be applied, consideration could be given to establishing nearby open coastal water quality monitoring at sites that have minimal input of freshwater from river plumes. The location of open coastal sites could be optimised by consulting satellite imagery to establish the dispersal of plumes from the major rivers in the Horizons region and selecting sites away from these plumes. This process may indicate that offshore sampling sites would be ideal. Open coastal water quality data used in ETI modelling are annual averages; sampling would not need to be carried out on the same days as estuary sampling.

5 Monitored variables

In this section we address whether the current suite of water quality variables and metadata collected are sufficient for the aims of HRC's estuarine water quality sampling programme. First we consider recommended variables for surface sampling of terminal river reaches, estuaries and ocean waters in relation to State of the Environment (SoE) monitoring purposes. We then revisit variables needed for estuarine catchment modelling purposes before briefly addressing recreational water quality monitoring variables. All of the monitoring outlined supports One Plan effectiveness monitoring.

In Table 5-1 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 Schedule I of the One Plan with corresponding water quality targets (Cornelisen 2010, Dudley et al. 2017, Zeldis et al. 2017b, Zaiko et al. 2018). The relevant reports are:

- Cornelisen (2010) – recommended biological indicators for monitoring environmental conditions in coastal waters in the Horizons region;
- Zaiko et al. (2018)– identified estuarine attributes suitable for the establishment of national thresholds on which to manage upstream environments;
- 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 indicators used in assessment of the trophic state of estuaries in ETI tool 2.

5.1 State of Environment (SoE) monitoring

Cornelisen (2010) suggests that water column monitoring in estuaries – including the variables measured – should align with the methods and timing of monitoring taking place upstream and in coastal environments. 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 fits with the concept of integrated management required by the NPS-FM (refer Section 2.1.2).

Table 5-1: Recommended water quality variables for SoE, recreational water quality and regional plan monitoring of marine and estuarine water quality from selected recent reports. Where recommendations differ between estuarine and fully marine waters, E = Estuarine, M = Marine.

Variable	MfE (Dudley et al. 2017) Core	MfE (Dudley et al. 2017) Support	Horizons (Cornelisen 2010)	MfE (Zaiko et al. 2018)	One Plan	ETI tool 2 indicator	NEMS method available?	Currently monitored by Horizons?
Major physico-chemical variables								
Salinity	✓		E = Yes M = Yes	No	E = No M = No	No	✓	No
Temperature	✓		E = Yes M = Yes	No	E = Yes M = No	No	✓	✓
Dissolved oxygen	✓		E = Yes M = No	No	E = Yes M = Yes	✓	✓	✓
pH	✓		E = Yes M = Yes	No	E = No M = No	No	✓	✓
Optical variables								
Visual clarity	✓		E = Yes M = No	No	E = Yes M = Yes	No	✓	Only at 'Mowhanau Stream at Footbridge'
Turbidity		✓	E = Yes M = Yes	No	E = No M = No	No	✓	✓
Total Suspended Solids	✓		E = Yes M = No	✓	E = No M = No	No	✓	Only at two sites
Light penetration		✓	E = No M = No	No	E = No M = No	No	✓	No
CDOM		✓	E = Yes M = No	No	E = No M = No	No	✓	No
Munsell Colour		✓	E = No M = No	No	E = No M = No	No	✓	No
Nutrients								
Total nutrients (TN, TP)	✓		E = Yes M = Yes	✓	E = No M = Yes	No	✓	✓
Dissolved nutrients (NOXN, NH4N, DRP)	✓*		E = Yes M = Yes	No	E = Yes M = No	No	✓	✓

Dissolved organic nutrients (DON, DOP)	No	No	E = Yes M = Yes	No	E = No M = No	No	No	No
Microbiological indicators								
Enterococci	✓		E = No M = Yes		E = No M = Yes	No	✓	✓
Faecal coliforms		✓	E = No M = No	✓***	E = No M = Yes	No	✓	No
E. coli		✓	E = Yes M = No		E = Yes M = No	No	✓	✓
Chlorophyll-*a*	✓		E = Yes M = Yes	No	E = Yes M = Yes	✓	✓	✓
Phytoplankton assemblage		✓	E = No M = No	No	E = No M = No	No	No	No
Other toxicants**	No	No	E = Yes M = No	No	E = Yes M = Yes	No	✓ (metals)	Not routinely

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

** Listed in (Cornelisen 2010) as including metals and organic chemicals, listed in the One Plan as 'those contaminants not otherwise listed that appear in 2000 ANZECC guidelines Table 3.4.1.'

*** The recommended microbiological indicator is not specified

In addition to the various water quality variables listed in Table 5-1, Dudley et al. (2017) also recommended inclusion of an integrated index of estuarine ecological health to facilitate setting water quality thresholds (i.e., boundaries between bands of environmental state). Because HRC is already undertaking monitoring in line with ETI methodologies (which provides this indicated index), we pay special attention to water quality variables that can be included in ETI calculations.

We note that the variables included in the draft NEMS Water Quality (2017) are not a list of recommended variables, but 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 (2017) in Table 5-1, but instead record whether those variables recommended in the other reports have an established method available in the NEMS (2017). The recommended variables in Table 5-1 are routinely monitored, and the rationale for their measurement is not provided here but can be found in recent publications specific to New Zealand estuarine water quality monitoring (Dudley et al. 2017, NEMS 2017, Zaiko et al. 2018).

From Table 5-1 we note that of the recommended 'core' variables listed in Dudley et al. (2017) only salinity, total suspended solids and visual clarity are missing from current monitoring at most estuary sites. We note however that conductivity data from which salinity could be retrospectively calculated has historically been collected at SoE sites. Salinity is easy to measure and very useful in estuarine dilution modelling because it permits comparison of predicted estuarine nutrient values with those measured in the field; when within-estuary nutrient values are compared with modelled values, salinity gives a measure of mixing between fresh water and ocean water at the point of sampling. As noted in Section 5.2, the dilution modelling approach of Plew et al. (2018) — which enables prediction of upstream nutrient loads that correspond with bands of estuarine trophic state — would also benefit from salinity data. We therefore recommend inclusion of on-site salinity measurements in future monitoring.

Total suspended solids (TSS) are recommended as a 'core' variable in Dudley et al. (2017) and are one of seven estuarine variables selected for potential further development to inform upstream freshwater management under the NPS-FM (Zaiko et al. 2018). Total suspended solids data in the terminal reach, estuarine waters and ocean waters may also inform modelling of estuary sedimentation rates. We therefore recommend inclusion of suspended solids measurements in future monitoring and note that for the terminal riverine reaches, measurement of suspended sediment concentration (SSC), as well as TSS, should be continued to provide for a more robust estimate of sediment loads entering the estuary (e.g., (Gray et al. 2000, Selbig and Bannerman 2011).

Visual clarity is a recommended core variable for national-scale SoE study (Dudley et al. 2017), and there are target values for visual clarity in the One Plan (Tables I-5 and I-7) for 13 estuary sites. However, visual clarity is currently only monitored at one site; the Mowhanau Stream at Footbridge. We therefore recommend inclusion of visual clarity measurements in future monitoring at all sites. The draft NEMS Water Quality (NEMS 2017) provides guidance on a range of options for visual clarity measurements, including the use of a SHMAK tube where waters are very sediment-laden.

5.2 Variables for estuarine dilution modelling and nutrient load prediction

The dilution modelling approach of Plew et al. (2018) requires an understanding of the N loads carried into the estuary from both open coastal inflow and land-influenced freshwater flows. Plew et al. (2018) also use salinity data collected at high tide within the estuary to validate estimates of mixing of fresh water and ocean water within the estuary. This approach therefore requires regular monitoring of total nitrogen (TN) and salinity at terminal river reaches entering estuaries, as well as within estuaries and in nearby ocean water. Given the 'potential nutrient concentration' results of dilution modelling, ETI tool 1 can be used to predict trophic conditions within the estuary, and N-loads from land that correspond to changes in these trophic conditions. The measure of trophic condition from ETI tool 1 can be validated by comparing the ETI tool 1 prediction with estimates of trophic state available from ETI tool 2 (Robertson et al. 2016b, Zeldis et al. 2017b) made using indicators measured within the estuary. These ETI indicators include chlorophyll *a* and dissolved oxygen (DO) in estuary water.

5.3 Recreational water quality monitoring

As outlined in Section 2.3.5, The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas ['the Guidelines', (MfE/MoH 2003)] underpin recreational water quality monitoring in New Zealand. For coastal waters, the Guidelines require measurement of enterococci as an indicator for the risk of illness from swimming and other contact recreation activities. However, where the waters are used for recreational shellfish gathering, faecal coliforms are the recommended indicator[2]. For brackish or estuarine waters, it is unclear in the Guidelines whether enterococci or the freshwater indicator, *E. coli*, should be monitored.

A current review of the marine component of the Guidelines is seeking to provide advice on the preferred microbiological indicator for brackish waters. At this stage, it is expected that the advice

[2] It is hoped in the future that these guidelines might be based on *E. coli* or enterococci. McBride et al. (in prep) propose the use of a new risk-based shellfish uptake-and-depuration model which could be based on enterococci. This would reduce laboratory costs for analysis of coastal water samples.

will be to monitor enterococci in estuaries with a long residence time (>3 days). For estuaries with a shorter residence time *E. coli* is the appropriate choice when near the inflowing river water, but enterococci should be monitored near the mouth. What to monitor between these locations still needs consideration and it appears both indicators should be measured (McBride et al. in prep). Monitoring of *E. coli* along with enterococci would also be advantageous for 'mountains to the sea' microbial modelling.

Water temperature and turbidity are useful supporting variables to measure alongside microbiological water quality indicators. In addition, the collection of metadata, notably tidal height and state, rainfall, and wind direction and intensity, are important for meaningful interpretation of the microbiological water quality data. Regular (at least five-yearly) catchment assessments to check the condition of urban infrastructure and changes in land use are also important in understanding and managing risks to human health from microbiological contamination (MfE/MoH 2003).

6 Sampling and measurement methods

In this section we review the current sampling and laboratory methods, including sampling platform, frequency and timing with respect to tide.

6.1 SoE monitoring

6.1.1 Frequency and timing of SoE monitoring

Because of the variability of estuarine water quality at short time scales, long, relatively intensively sampled time series are required to detect changes in estuarine water quality. As noted by Cornelisen (2010), more frequent sampling (e.g., monthly instead of quarterly) 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 (Larned et al. 2015, Dudley et al. 2017). Hence, as noted in Section 4.2, for the purposes of SoE reporting, maintenance of existing time series is important. Where possible, we recommend sampling terminal reach, estuary and open coast SoE sampling at the same frequency to improve comparison of trends in water quality from fresh water to nearshore ocean water. We think the current monthly sampling frequency is sufficient and consistent with many other long term or SoE-based water quality monitoring programmes.

Tidal state

One of the major sources of variability in estuarine 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 sampling which has the twin goals of being representative of water quality state within an estuary, and detecting trends in water quality through time. For a monitoring programme that seeks to assess estuarine 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 these 'conflicting' monitoring purposes are:

- sample regularly (e.g., quarterly or monthly, at both high and low tide);
- 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 HRC's multiple monitoring needs, we consider that the current approach of within-estuary sampling on randomised tides is acceptable given the high (monthly) sampling frequency. Further, regular (monthly if possible) sampling of water quality in the terminal river reach will provide a good dataset for assessing changes in nutrient and sediment loads entering the estuary over time.

6.1.2 Sample collection

In general (Dudley et al. 2017) and (Zaiko et al. 2018) recommend use of NEMS methods for water quality sampling in coastal waters (NEMS 2017), as well as use of NEMS protocols with regard to metadata collection, reporting of measurement uncertainty, and quality coding. Use of NEMS protocols is particularly beneficial for national-scale reporting, where consistent methods across all regional authorities facilitates comparison of water quality across regions. Below we give a brief comparison of methods currently used for water sampling (as listed in HRC's water quality sampling run guides) with those listed in (NEMS 2017). We note however, that the field run guides do not give extensive details on field procedures; we recommend that instructions in line with NEMS protocols annex B are added in brief form to the field run guides as the NEMS (2017) requires all sampling and measurement procedures to be fully documented in a Field and Office Manual.

Field meters

In line with NEMS, we recommend that field records be regularly 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 2017).

Sampling point

The locations for field measurements and water sample collection are well marked in HRC's run guides. Maintaining consistency in sampling point locations (stationarity in NEMS language) is important to reduce error in time series of water quality measurements.

Some aspects of sample collection are not mentioned in the run guides; we suggest that NEMS recommendations for sampling depth, (i.e., 30 cm below the water surface), bottle filling and labelling, and sample transport and handling are added in brief to run guides. Assessing vertical stratification in deeper estuaries is addressed in Section 6.1.3.

For some assays such as chlorophyll *a* and nitrogen ions (e.g., ammonium and nitrate), microbiological activity should be stopped soon after sampling to ensure consistency between sampling periods. Ice packs can be insufficient for this task – particularly in summer. NEMS recommends immediate stabilisation of samples is carried out using crushed ice.

Laboratory measurements on water samples

As of March 2018, laboratory methods for all variables provided to NIWA by Horizons match those recommended in the NEMS (2017). We note that the updated NEMS will contain a few changes in laboratory methods that should be checked by HRC.

6.1.3 Monitoring for dilution modelling using ETI tool 1

As outlined in Section 2.3.3, the NPS-FM requires freshwater quality and quantity limits to be set with consideration of impacts on downstream water bodies (New Zealand Government 2014). The dilution modelling approach used in ETI tool 1 facilitates this process, because it permits calculation of bands of N loading to estuaries that correspond with bands of estuarine trophic condition (Dudley and Plew 2017, Zeldis et al. 2017c, Plew et al. 2018). In addition to the water quality information requirements for this approach laid out above, the following data are required for estuary-by-estuary assessment of N-load bandings using ETI tool 1:

- 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 measured water levels over several tidal cycles (to capture the variation in tides over a spring-neap cycle). We recommend that a bathymetry survey is carried out on estuaries of interest to obtain physical data. Plew et al. (2017) gives an example of appropriate bathymetry measurements for 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.

We recommend that water samples collected to support dilution modelling are analysed for nutrients (at least TN), chlorophyll *a* and dissolved oxygen 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 surveying indicates that the estuary is susceptible to effects from vertical stratification, an addition to the sampling programme may be deemed necessary to examine it more closely. We note that at least two of the major estuaries of the Horizons region (Manawatu and Whanganui) have bridges within the estuary from which the sampling could be done. For two other major estuaries that are currently monitored (Ohau and Rangitikei) there are no suitable bridges, so the added logistical cost of mobilizing vessels would need to be considered.

6.2 Recreational water quality monitoring

The Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas [‘the Guidelines’, (MfE/MoH 2003)] outline the requirements for collection and analysis of coastal water samples for assessing risk to human health associated with swimming and shellfish gathering. These guidelines recommend water sample collection at knee depth between the hours of 0800 and 1800, and enumeration for indicator bacteria by laboratories with accreditation (e.g., IANZ accredited) for the following methods:

- *E. coli:* Colilert™ (preferred) or EPA Method 1103.1;
- Enterococci: Enterolert™ or EPA Method 1600; and
- Faecal coliforms: Most Probable Number (MPN) method.

We note that these methods are not completely consistent with those in NEMS (2017). For example, NEMS recommends APHA 9222 D for Faecal coliforms, which differs from the MPN method specified in the Guidelines. However, we expect that the methods in the Guidelines will be reviewed in the near future to include NEMS recommended methods as equivalents. The current Freshwater Microbial Sciences Review (FMSR) project linked with a review of the Guidelines intends to utilise several test methods for microbial indicators (Moriarty et al. 2018).

7 Conclusions

The existing HRC estuarine water quality monitoring programme is likely to provide robust data for the purposes of general SoE, recreation (human health) and Regional Plan effectiveness monitoring. However, we see potential to improve the programme though altering the number of monitoring sites to provide for a more representative picture of estuarine water quality across the Horizons region, particularly regarding catchment land-use pressure. Sampling points could also be better placed to monitor source-to-sea contaminant transport and facilitate integration of SoE water quality monitoring with assessments of estuarine ecological health. Improvements could be made to match of the water quality variables currently monitored with the list recommended in recent national reports, and the list of variables in the One Plan with associated water quality targets. Current sampling platform, frequency and timing with respect to tide appear appropriate for HRC's monitoring purposes. However, we suggest integration of water quality and ETI monitoring programmes could be improved by one-off, estuary-by-estuary bathymetry, water quality and depth profile CTD sampling. This approach would also confirm whether subtidal sampling as recommended by Robertson and Stevens (2016) s required in deep estuaries in the region.

7.1 Recommendations

We recommend, in order of priority:

1. Collection of salinity, suspended sediment and visual clarity data at all coastal and estuarine SoE sites.
2. Structuring the monitoring network to allow comparison of water quality in representative estuaries with water quality in terminal river reaches flowing into them, and on the adjacent coast.
3. Standardisation, where possible, of water quality variables monitored, and sampling frequency (monthly), at terminal river reaches, within estuaries and in marine waters, without any standardisation of sampling to tide.
4. Collection of regular salinity and TN data from the open coast, and salinity, TN and flow data from terminal river reach sites to enable use of the ETI tools to assess estuary eutrophication.
5. Collection of bathymetry, CTD and tidal height data in one-off field studies on specific estuaries where detailed comparison of estuarine water quality, contaminant loads and trophic state are required. For deep estuaries, one-off field studies should also include collection of water samples to check if sufficiently strong stratification is present that could cause reduced oxygen or pH in subtidal sections of the monitored estuary.
6. Consideration is given to expanding the existing suite of estuaries monitored to include one or two more estuaries with low native forest cover and high cover of sheep and beef farming to better represent land cover of estuary catchments in the Horizons Region (this will also improve the ability to infer water quality in unmonitored estuaries relative to One Plan target values). If the current sites are retained, a representative network with regard to catchment land cover could be reached by adding 4-5 more estuaries with high (80-90%) of catchment land in sheep and beef farming.

7. Retainment of existing estuarine water quality sampling site locations to maintain the value of water quality time series but establishment of a mid-point shoreline sampling location if new estuaries are monitored.

8. Continued monitoring of both *E. coli* and enterococci and estuarine sites until current microbiological water quality guidelines are reviewed and to facilitate ‘source to sea’ tracking of microbial contaminants, if desired.

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Appendix A List of land cover percentages in catchments of all estuaries in the Horizons region

Table 8-1: Environmental classes of catchment land use in all estuaries in the Horizons region. Mean percentage land cover values are not scaled to estuary catchment size. Original data from Horizons Regional Council, table adapted from (Robertson and Stevens 2016). Bold print indicates estuaries containing current SoE monitoring sites.

Estuary	Estuary Type	Urban	Cropping	Dairy	Exotic forest	Horticulture	Native Forest	Sheep/beef	Water
Ototoka Stream Estuary	SSRTRE Type 1	0.10%	0.70%	13.10%	2.80%	0.30%	3.30%	79.70%	0%
Okehu Stream Estuary	SSRTRE Type 1	0%	0%	2.20%	23.20%	0.20%	17.90%	55.10%	0%
Unnamed stream at E2671159 N6145599	SSRTRE Type 1	0%	0%	0%	0%	0%	0%	100%	0%
Kai Iwi Stream Estuary	SSRTRE Type 2	0.10%	0.10%	1.10%	28.90%	0.10%	18.70%	50.80%	0%
Mowhanau Stream Estuary	SSRTRE Type 1	0%	0.10%	27.40%	2.90%	1%	2.40%	65.50%	0%
Omapu Stream Estuary	SSRTRE Type 1	0.10%	1.10%	52.10%	2.60%	0.30%	0.30%	42.50%	0%
Whanganui Estuary	**SSRTRE Type 4**	**0.40%**	**0%**	**0.80%**	**9.70%**	**0%**	**54.50%**	**34.20%**	**0.20%**
Kaitoke Stream Estuary	SSRTRE Type 1	0.20%	1.10%	5.20%	8.10%	0%	2.10%	82.90%	0.40%
Whangaehu River Estuary	SSRTRE Type 4	0.20%	0.10%	1.60%	11.60%	0.20%	21.10%	60.50%	0.20%
Turakina River Estuary	SSRTRE Type 4	0%	0.50%	2.50%	7.20%	0%	8.50%	81.20%	0.10%
Koitiata Stream Estuary	SSRTRE Type 1	0%	0.80%	1.60%	21.20%	0%	0.90%	75%	0.10%
Unnamed Lake Koitiata outflow	SSRTRE Type 1	0%	1.10%	12.90%	26.40%	0%	1.70%	55.30%	0%
Waimahora Stream Estuary	SSRTRE Type 1	0%	0%	1.90%	43.70%	0%	0.90%	53.50%	0%
Unnamed stream at E2696657 N6113943	SSRTRE Type 1	0%	0%	29.60%	49.50%	0%	0.10%	20.80%	0%
Unnamed stream at E2697524 N6111094	SSRTRE Type 1	0%	0%	34.60%	33.80%	0%	0.20%	30.60%	0%
Raumai Range Stream	SSRTRE Type 1	0%	0%	7.20%	31.40%	0%	0.30%	60.60%	0%
Rangitikei River Estuary	**SSRTRE Type 4**	**0.30%**	**0.40%**	**4.20%**	**3.30%**	**0%**	**28.40%**	**54.10%**	**0.30%**
Pukepuke Estuary	SSRTRE Type 1	0.80%	0%	56%	23.20%	0.70%	0.90%	17.90%	0%
Kaikokopu Stream	**SSRTRE Type 1**	**0.80%**	**0%**	**56%**	**23.20%**	**0.70%**	**0.90%**	**17.90%**	**0%**
Three Mile Creek	SSRTRE Type 1	0%	0%	41.70%	16.60%	0%	4.10%	37.20%	0%
Manawatu River Estuary	**SSRTRE Type 4**	**1.10%**	**0.80%**	**18.10%**	**4%**	**0.30%**	**17.10%**	**58.10%**	**0.20%**
Wairarawa Stream Estuary	SSRTRE Type 1	4.50%	1.30%	45.70%	26.70%	0%	1.50%	20.30%	0.10%
Hokio Stream Estuary	SSRTRE Type 2	12%	3%	18%	3.50%	3.50%	3.50%	50.50%	4.30%
Waiwiri Stream Estuary	SSRTRE Type 1	0%	0.30%	21.80%	16.60%	0%	6.50%	51.40%	3.20%

Ohau River Estuary	**SSRTRE Type 4**	**0.10%**	**1.10%**	**14%**	**9%**	**1.40%**	**50.50%**	**23.40%**	**0.20%**
Waikawa River Estuary	**SSRTRE Type 2**	**0.60%**	**0.30%**	**23.60%**	**12.60%**	**1.20%**	**35.30%**	**26.30%**	**0.10%**
Unnamed stream at E2817625 N6075640	SSRTRE Type 1	0%	0%	0%	0%	0%	18.30%	81.70%	0%
Unnamed stream at E2817540 N6075035	SSRTRE Type 1	0%	0%	0%	0%	0%	23.10%	76.90%	0%
Unnamed stream at E2817201 N6074328	SSRTRE Type 1	0%	0%	0%	0%	0%	0.10%	99.90%	0%
Tautane Stream Estuary	SSRTRE Type 2	0%	0%	0%	1.20%	0%	4.50%	94.40%	0%
Wainui River Estuary	SSRTRE Type 2	0%	0%	0%	18.80%	0%	4.90%	76.20%	0%
Unnamed stream at E2810033 N6071928	SSRTRE Type 1	0%	0%	0%	4.30%	0%	0%	95.70%	0%
Unnamed stream at E2809179 N6071500	SSRTRE Type 1	0%	0%	0%	3.30%	0%	4.10%	92.60%	0%
Papuka Stream Estuary (aka Paewa Stream)	SSRTRE Type 1	0%	0%	0%	2.40%	0%	2.70%	94.90%	0%
Waimata River Estuary	SSRTRE Type 1	0%	0%	0%	30.80%	0%	27.80%	41.50%	0%
Unnamed stream at E2804539 N6067339	SSRTRE Type 1	0%	0%	0%	4.30%	0%	0%	95.70%	0%
Unnamed stream at E2803987 N6066134	SSRTRE Type 1	0%	0%	0%	0%	0%	0%	100%	0%
Unnamed stream at E2803675 N6064594	SSRTRE Type 1	0%	0%	0%	0%	0%	9.70%	90.30%	0%
Akitio River Estuary	**SSRTRE Type 3**	**0%**	**0%**	**0.30%**	**9.20%**	**0%**	**12.60%**	**77.80%**	**0%**
Unnamed stream at E2798873 N6060133	SSRTRE Type 1	0%	0%	0%	0.50%	0%	8%	91.50%	0%
Owahanga River Estuary	SSRTRE Type 3	0.20%	0%	0%	3.30%	0%	18.40%	76.90%	0.10%
		Urban	**Cropping**	**Dairy**	**Exotic forest**	**Horticulture**	**Native Forest**	**Sheep/beef**	**Water**
Mean percentage landcover in all estuary catchments		**0.52%**	**0.31%**	**12.03%**	**12.68%**	**0.24%**	**10.14%**	**63.20%**	**0.23%**
Percentage landcover in monitored estuary catchments		**1%**	**1%**	**15%**	**11%**	**0%**	**29%**	**42%**	**0%**

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