A water quality monitoring programme for estuaries in the Nelson Region

Prepared for Nelson City Council

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Contents

Tables

Figures

Executive summary

In response to a number of national developments, including recognition of downstream receiving environments in the National Policy Statement for Freshwater Management (NPS-FM) and the release of the national Estuarine Trophic Index (ETI) tool, Nelson City Council (NCC) has sought advice on the design of an estuarine water quality monitoring programme for the Nelson region. This programme will support general State of the Environment (SoE) and Regional Plan effectiveness monitoring. It may also provide information to support NCC's existing recreation (human health) monitoring programme.

In this report, we give recommendations on the estuaries to monitor, the number and location of monitoring sites, sampling methods, and water quality variables. These recommendations have been made having regard for national and regional legislation and recent relevant initiatives, including the ETI, national reporting of coastal water quality state and trends, and National Environmental Monitoring Standards (NEMS) for Water Quality.

There are four main estuaries in the Nelson region; Waimea Inlet (jointly administered with Tasman District Council, TDC), Nelson Haven, Delaware Estuary and Kokorua Inlet. A benthic ecosystem health monitoring programme is already established for these estuaries and a water quality monitoring programme would complement this monitoring, providing important information for the management of trophic state. Consistent with the ETI tool approach, regular (monthly) monitoring of water quality on the terminal reaches of significant freshwater inputs and at several open coast sites is the highest priority. Monitoring water quality within each estuary is also important. Estuary monitoring would assist with validation of ETI Tool 1 predictions of estuarine nutrient concentrations and salinity and provide dissolved oxygen and chlorophyll-a data for ETI tool 2 assessments of trophic state.

Our recommendations, in order of priority, are:

1. Structuring the monitoring network to allow comparison of water quality in each of the four major estuaries in the Nelson region with water quality in terminal river reaches flowing into them, and on the adjacent coast.

2. Establishing 1-2 water quality monitoring sites in each estuary. These sites may be along the shoreline but ideally would be near the mid-point between the terminal reach of the major river input(s) and the ocean outflow point.

3. Aligning the water quality variables measured in each estuary with those monitored at 2-3 open coastal sites within Tasman Bay, outside the influence of freshwater plumes.

4. Standardising, where possible, water quality variables monitored, and sampling frequency (monthly), at terminal river reaches, within estuaries and in marine waters. This would require alignment of NCC and TDC sampling of water quality sites in rivers flowing to Waimea Inlet.

5. Collecting 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 areas of 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 estuary.

6. Monitoring of both *E. coli* and enterococci and terminal reach and estuarine sites until current microbiological water quality guidelines are reviewed and to facilitate 'source to sea' tracking of microbial contaminants.

1 Introduction

Nelson City Council (NCC) monitors ecosystem health across four estuaries throughout the Nelson District (region), including the Waimea Inlet[1] and the nationally significant Nelson Haven. This monitoring is based around periodic broadscale assessments of vegetation and substrate coupled with fine-scale assessments of the benthic environment (substrate particle size and contamination, macrofauna and macroflora) at a few locations that are representative of the dominant intertidal habitat. NCC is looking to compliment this monitoring with an estuarine water quality programme that will assist with general State of the Environment (SoE) and Regional Plan effectiveness monitoring. Currently water quality monitoring in the Coastal Marine Area is limited to five popular recreation sites where microbial water quality is assessed weekly over the summer months.

In recognition of a number of developments nationally, including the release of the national Estuarine Trophic Index (ETI) tools (Robertson et al. 2016a, Zeldis et al. 2017a), the 2017 amendments to the National Policy Statement for Freshwater Management (NPS-FM, New Zealand Government 2017), and the National Environmental Monitoring Standards for Water Quality Sampling and Testing (NEMS 2019), NCC has sought advice on the design of an estuarine water quality monitoring programme. This programme design has been funded through an Envirolink Medium Advice Grant (1915-NLCC105, MBIE Contract C01X1809).

1.1 Scope

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

- 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?
- The number and location of monitoring sites: Which estuaries should be monitored to provide for a representative picture of estuarine water quality across the Nelson City Council jurisdiction (hereafter 'Nelson region')?
- The number and location of sampling points: Where and how many sampling points should be monitored within each estuary to represent of the typical water quality in the estuary?
- The monitored variables: What suite of water quality variables and metadata should be collected?
- Sampling methods: What sampling methods, including sampling platform, frequency and timing with respect to tide, are appropriate?

1.2 Approach

- In Section 2, we briefly outline the legislative context and recent national developments of relevance to an estuarine water quality monitoring programme for

[1] Approximately one third of Waimea Inlet is within the Nelson District. The southern and western portions of the Inlet are administered by the Tasman District Council.

NCC. We then address each of the four key components of the report as described below.

- In Section 3, we consider the number and locations of estuaries, their range of catchment land uses, and their estuary types within the Nelson region to provide recommendations on selection of estuaries for monitoring.
- In Section 4, we discuss numbers and locations of monitored sites required for SoE monitoring, monitoring for human health (recreation), and monitoring for application of ETI tools.
- In Section 5 we consider variables that should be monitored based on those:
  - required for ETI implementation;
  - measured in river sampling within the region for comparison with water quality targets, to provide a source-to-sea continuum of monitoring;
  - recommended for monitoring in the Tasman region, which shares jurisdiction of Waimea Inlet; and
  - recommended by recent regional-scale and national-scale reports on coastal SoE monitoring.
- In Section 6, we recommend water quality sampling methods based on recent recommendations of the NEMS (2019) for coastal waters, NCC's existing freshwater monitoring and estuarine ecological monitoring programmes, and to best account for tidal variation. We consider specific method requirements for both SoE monitoring and the 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 design of NCC'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 (New Zealand Government 2010) 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 NCC'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 Nelson Resource Management 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 (NPS-FM, (New Zealand Government 2017)) sets out the objectives and policies for freshwater management under the Resource Management Act 1991. Its relevance to the design of NCC'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."*
> (New Zealand Government 2017, p17)

The Government has signalled that changes are likely to the NPS-FM and a separate National Environment Standard (NES) is also expected for freshwater management. While the details of the changes will not be known before mid-2019, *Essential Freshwater* (Ministry for the Environment and Ministry for Primary Industries 2018) signals that one of the areas being considered for amendments to the NPS-FM is *"better protection for wetlands and sensitive downstream environments (eg, estuaries)"*. This suggests a potential strengthening of the existing requirements to safeguard estuarine environments when managing fresh water and catchment land use.

2.2 Regional policy

Coastal resource management objectives, policies and rules for the Nelson Region are set out in NCC's Nelson Resource Management Plan (NRMP, Nelson City Council 2012), a combined regional and district plan. Both the policies of the NZCPS and the NPS-FM (as well as other national regulation) are given effect to by the NRMP, with the majority of Chapter 13 (Coastal Marine Area) constituting the Regional Coastal Plan.

Four management classes are identified for waters in the CMA (Figure 2-1):

- Class SG – management for the gathering or cultivation of shellfish for human consumption,
- Class CR – management for contact recreation,
- Class FEA – management for fisheries, fish spawning, aquatic ecosystem, and aesthetic purposes, and
- Class C – management for cultural purposes (specifies relevant cultural or spiritual values and also incorporates SG standards).

Objective CM6 addresses estuarine water quality, seeking *"Maintenance and enhancement of the quality of Nelson's coastal water."* An associated policy (CM6.2) sets our coastal marine water quality standards in relation to the four management classes listed above. The FEA class applies to the entire

CMA (Figure 2-2). The associated water quality standards are largely narrative, only comprising numeric criteria for water temperature and dissolved oxygen.

NCC is currently working on a full review of the NRMP and other its plans developed under the RMA 1991 (e.g., the Nelson Regional Policy Statement). Once prepared, the reviewed plan will be called the Whakamahere Whakatū Nelson Plan (the 'Whakamahere', or 'Nelson Plan'). This plan is expected to contain coastal water quality standards (e.g., Newcombe et al. 2016). The Nelson Plan will also include freshwater management units (FMU), as required by the NPS-FM. The current FMUs are shown in Figure 2-3. To support limit setting and freshwater accounting under the NPS-FM, NCC will likely establish 'key nodes' at the bottom of major catchments, upstream of estuarine inputs.

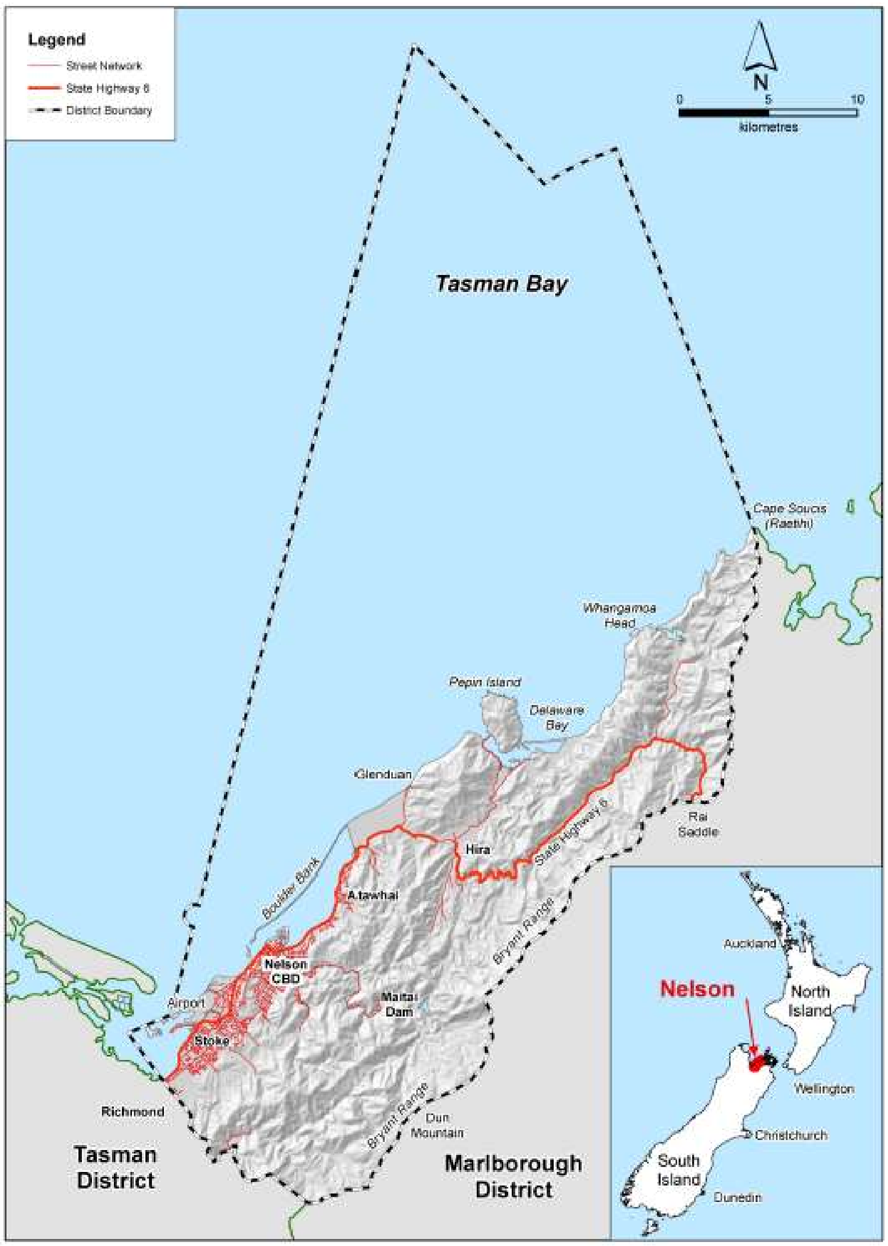

Figure 2-1: The CMA under the responsibility of Nelson City Council. Reproduced from Figure AB1 of the NRMP (Nelson City Council 2012).

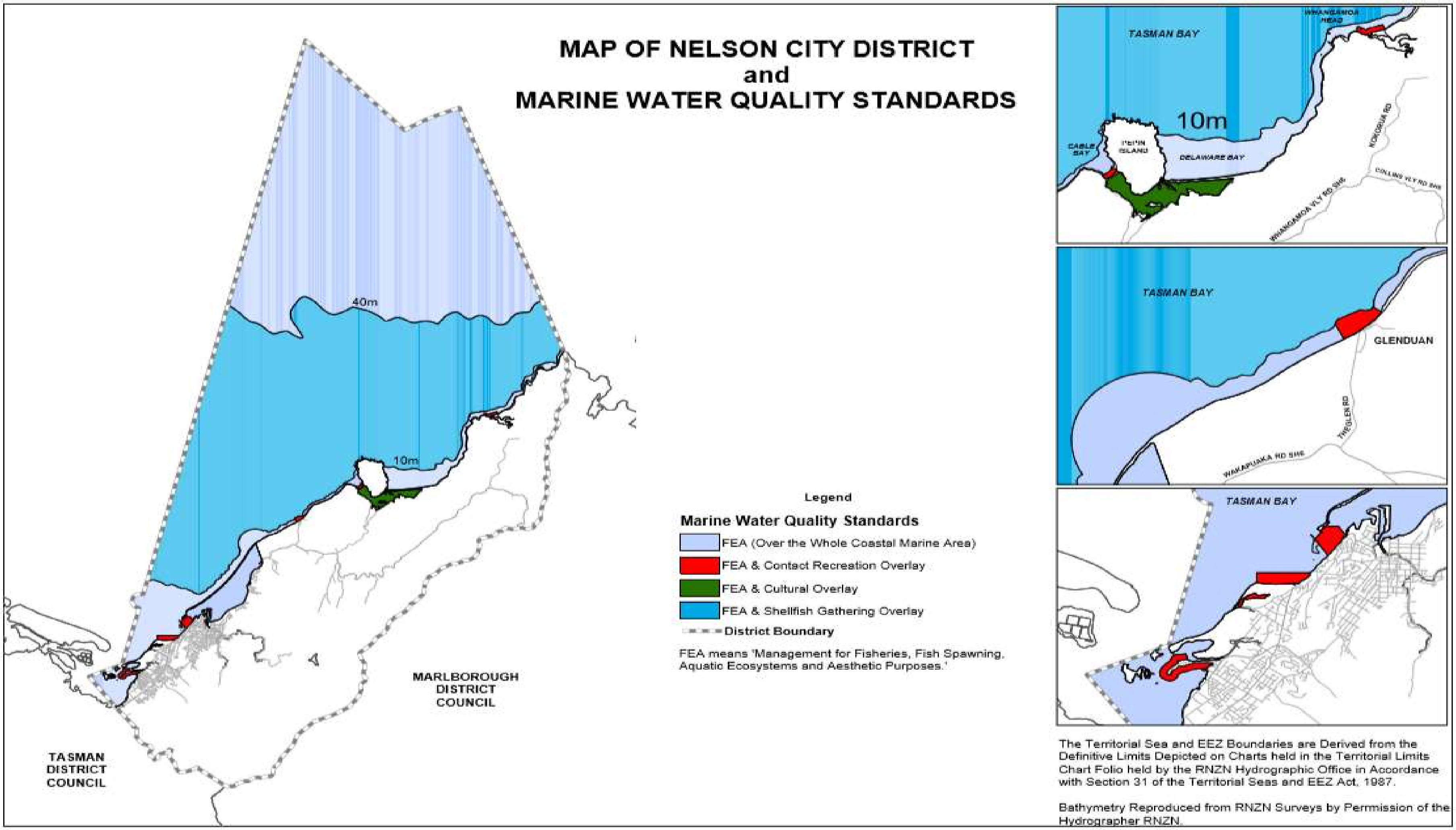

Figure 2-2: The CMA under the responsibility of Nelson City Council. Reproduced from Map A1 of the NRMP (Nelson City Council 2012).

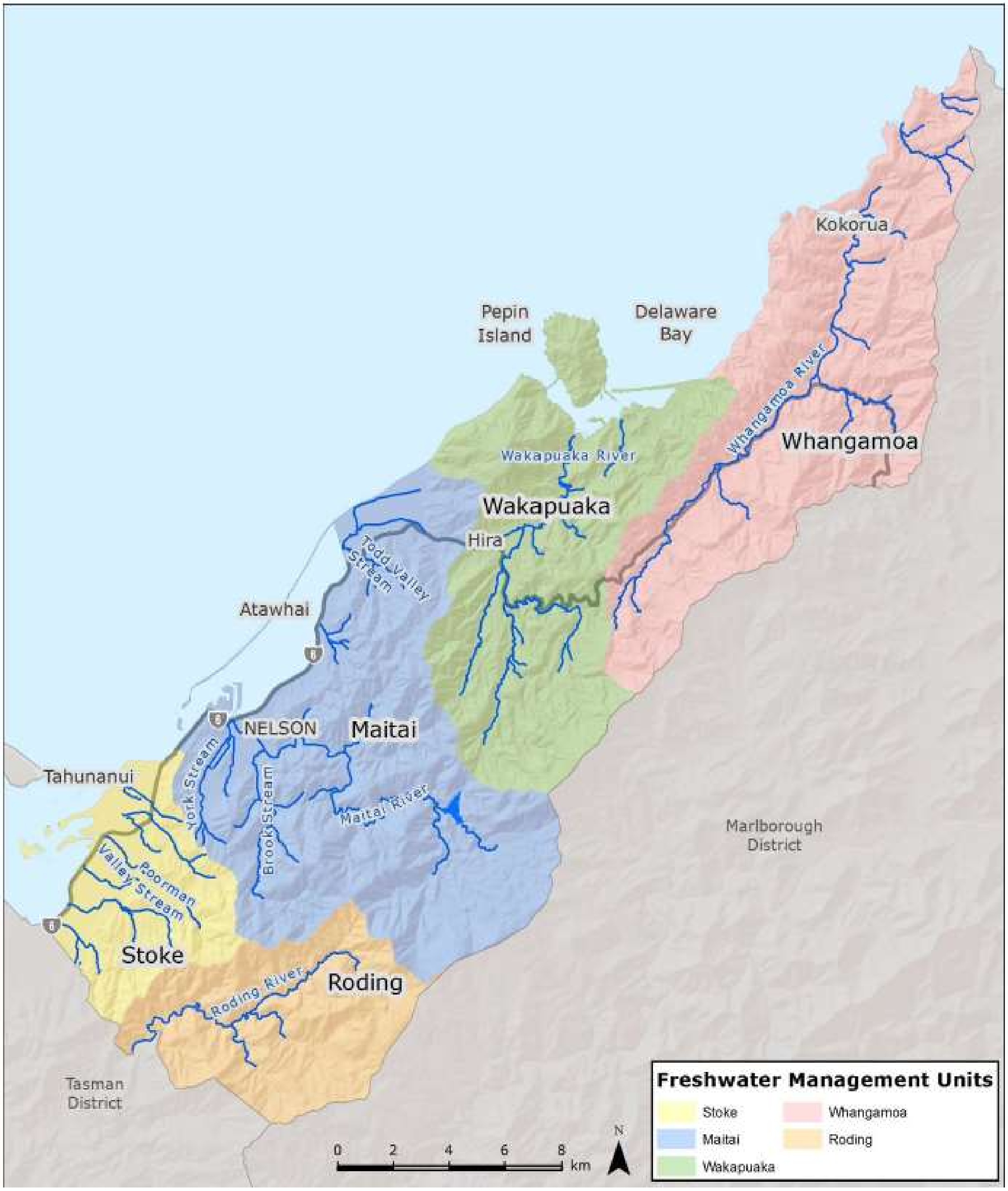

Figure 2-3: Proposed Freshwater Management Units (FMUs) for the Nelson region. Reproduced from McArthur (2015).

2.3 Recent national initiatives

Six key recent national initiatives of relevance to NCC'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. 2017b, Zeldis et al. 2017c).

The ETI tools are of interest to NCC in its management of estuaries in its region (e.g., for predicting changes to ecological health in estuaries that are likely to result from changes in nutrient loading from land). 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, the Ministry for the Environment (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 were considered when forming our recommendations for NCC's coastal water quality monitoring programme (Sections 3, 4, and 5).

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 are due for release in autumn 2019. 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 2019, Part 4).

NEMS is primarily focussed on long-term (e.g., SoE) monitoring, making its contents highly relevant to the design of NCC's estuarine water quality monitoring programme. The NEMS include 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 5.

2.3.4 Managing Upstream: Estuaries

"Managing Upstream: Estuaries State and Values" was an 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[2] (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, are considered in the design of NCC'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 recently completed MBIE Envirolink Tool project initiated by the regional sector's Coastal SIG in 2015/16 reviewed four aspects of the marine component of the Guidelines. Of relevance to the design of NCC's estuarine water quality monitoring — and revisited in Section 5.5 — 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).

2.3.6 Update to the ANZECC (2000) guidelines

The widely used ANZECC (2000) guidelines have been reviewed. The recently published on-line version, known as the Australian New Zealand Guidelines (ANZG 2018), provides tools to aid development of regional water quality standards for freshwater and marine waters in Australia and New Zealand. This report considers the data required for the development of standards according to

[2] 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).

(ANZG 2018) procedures when making recommendations on a possible monitoring programme for NCC.

2.4 Other relevant initiatives

We have also made use of other resources provided by NCC, including recent vulnerability assessment and monitoring recommendations report for Nelson estuaries undertaken by Wriggle Coastal Management Ltd (Stevens and Robertson 2017), the current draft Waimea Inlet Action Plan (Waimea Inlet Coordination Group 2018), advice on coastal water quality standards for the new Whakamahere Whakatū Nelson Plan (Newcombe et al. 2016), locations of existing freshwater SoE sampling sites, recommendations for freshwater monitoring in the Nelson Region described in McArthur (2015), and a review of land use impacts on water quality in the Nelson region (Grant 2017).

3 Number and locations of monitored estuaries

This section addresses which estuaries should be monitored to provide a representative picture of estuarine water quality across the Nelson region. Current NCC fresh and coastal water quality monitoring sites are outlined in Figure 3-1.

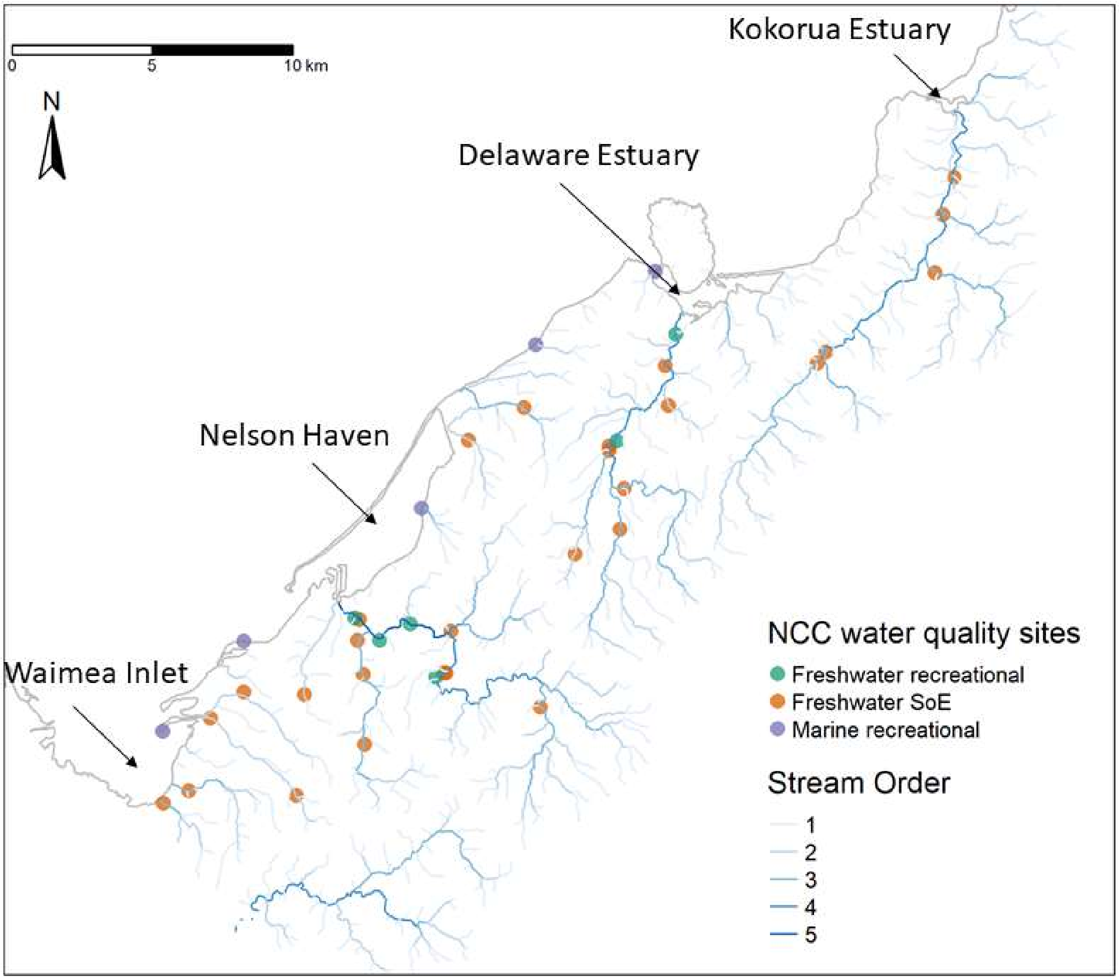

Figure 3-1: Existing water quality sites in the Nelson region.

3.1 Catchment land use and estuary type

Water quality of New Zealand estuaries is strongly dependent on the quality of fresh water flowing into them (Plew et al. 2018b) which, in turn, is strongly dependent on upstream catchment land use (Larned et al. 2016). Comparisons of data among estuaries across a gradient of land-use pressures is likely to assist in understanding links between water-quality indicators and stressors (e.g., estuarine total nitrogen (TN) concentrations and catchment agricultural land use) at both regional and national scales. Hence, we recommend estuarine water quality monitoring networks that are replicated with regard to environmental classes of catchment land cover. In the Nelson region, there are only four main estuaries, limiting the ability for replication. Table 3-1 compares the average percentage cover of land-cover classes in these four main estuaries, using groupings of land cover classes taken from LCDB version 3.

Table 3-1: Breakdown of land cover (%) in the upstream catchment of the four main estuaries in the Nelson region.

Estuary name	Catchment land area (ha)	Upstream catchment land cover (%)								
		Native forest	Exotic forest	Scrub	Tussock	Urban	Dairy	Sheep, beef and deer	Other pastoral land	Other non-pastoral land
Nelson Haven	10,627	40.4	24.3	16.1	2.7	10.6	0.3	3.7	0.8	1.1
Delaware Estuary	8,029	30.9	36.3	13.1	0.0	0.4	0.7	17.5	0.6	0.4
Kokorua Inlet	9,467	46.0	43.4	6.7	0.0	0.3	0.1	3.1	0.1	0.3
Waimea Inlet	91,549	33.4	31.9	4.9	2.1	2.4	3.1	16.1	1.0	5.2

Nelson Haven is distinct from the other three estuaries in Table 3-1 in having the most significant portion of urban land use (11%). The lowest percentages of all high-pressure land uses are in the catchment of Kokorua Inlet, while the percentages of most land use types are similar for the catchments of Delaware Estuary and Waimea Inlet.

Estuaries vary in their physical characteristics so are likely to vary in their susceptibility to land-use change and associated changes in water quality, and this should also be considered when prioritising monitoring. Characteristics of dilution, retention time and loss of inflowing nutrients are encompassed to some extent by the ETI estuary type classification (Robertson et al. 2016a). We note also from Table 3-2 that all four major estuaries in the Nelson region are shallow, intertidal dominated estuaries (SIDE). More detailed physical parameters considered in ETI tool 1 (Plew et al. 2018b) are shown in Table 3-2. Delaware and Kokorua Inlet are particularly notable for being very shallow with high percentages of intertidal area and high freshwater ratios (Plew et al. 2018a). We would consider these estuaries as being the most susceptible to eutrophication driven by land use change, followed by Waimea Inlet and Nelson Haven. We would particularly encourage monitoring of water quality variables indicative of eutrophication – nutrients, dissolved oxygen and chlorophyll-*a* – in terminal reaches entering Delaware Estuary and Kokorua Inlet if land use change is anticipated. We would suggest that growth of nuisance macroalgae is likely to result from excessive nitrogen inputs to these estuaries.

Overall, given the small number of large estuaries in the Nelson region, there is value in monitoring water quality across all four in some capacity. The primary advantage this would bring is improved confidence that the monitoring data are representative of the region's estuarine water quality.

Table 3-2: Physical characteristics of the four main estuaries in the Nelson region.

Estuary name	ETI type	NZCHS code	Estuary water area at mean high water (m^2)	Estuary shoreline length (m)	Estuary water area at spring low water (m^2)	Estimated estuary mean depth (m)	Width of estuary mouth (m)	Intertidal area (% of HW area)	Fresh-water fraction (%)	Flushing time (days)
Nelson Haven	SIDE	7a	1,263	29,232	430	3	604	66	7	10.1
Delaware Est.	SIDE	7a	310	18,343	21.8	2	159	93	18	5.8
Kokorua Inlet	SIDE	7a	42	7,677	10.0	2.63	127.7	76.1	37	1.7
Waimea Inlet	SIDE	8	2,933	93,836	1206	3.40	1,872	58.9	15	8.2

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 nitrogen (N) loads. We have not reviewed the number or location of recreational water quality monitoring sites within any of the four main estuaries; 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. 2018b). 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. 2018b). 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 critical for providing for riverine flow and nutrient load data requirements of estuary dilution modelling (Plew et al. 2018b). It is also useful to measure change in overall upstream catchment pressure (e.g., changes in nutrient, microbial or sediment loads) and will provide load data that can be used to calculate how within-estuary water quality is likely to compare against any future water quality 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.

We recommend that water quality variables measured at the terminal river reach sites identified in Sections 4.1.1 to 4.1.4 be expanded to match those selected for estuarine and coastal water quality sampling, where the estuarine water quality variables are not measured in terminal reaches. Where sites suitable for contaminant load and flow data requirements are not available, NIWA's CLUES or *NZ River maps* models (Elliott et al. 2016, Whitehead and Booker 2018) can be used to provide these data. In general, measured data are preferable especially for the major rivers flowing into estuaries.

4.1.1 Waimea Inlet

The current SoE site at Saxton Creek appears well situated to deliver terminal contaminant load data, although McArthur (2016) noted that this site location may soon be moved. Similarly, NCC sites at Orphanage Stream, Poorman Valley, and Jenkins Creek appear appropriate for terminal reach contaminant load data. A potential issue for ETI modelling of the Waimea Inlet is that many of the terminal reaches, including the large Waimea River, are monitored by Tasman District Council (TDC) and we do not know if TDC may change its monitoring programme. Based on TDC's current monitoring, appropriate sites to provide data are 'Waimea at SH60 Appleby', 'Seaton Valley at Stafford Dr' and 'Redwood Valley at Greenacres Rd'. Contaminant load and flow contributions of the remaining small streams entering the western shores of Waimea Inlet are likely to be minor and could be assessed using CLUES or *NZ River Maps* models. A valuable addition to eutrophication susceptibility calculations for Waimea Inlet would be N load data from the Bell Island wastewater treatment plant (WWTP).

4.1.2 Nelson Haven

The 'Maitai at Riverside' site appears well situated to provide TN data for the Maitai River's contribution to Nelson Haven. If salinity data at this site indicate salt water influence, a more upstream site may be advisable, although this would necessitate separate load calculations for downstream catchments, such as The Brook. The York Stream monitoring site appears too far up the catchment to be useful for terminal reach load calculations, although based on the relatively small size of this stream (i.e., loads are likely to be less than 5% of the total land-derived TN load), modelled loads may be sufficient. Similarly, modelled contaminant inputs and flows would be necessary for the Oldham Stream catchment.

4.1.3 Delaware Estuary

The major river flowing into Delaware Estuary, the Wakapuaka River, appears well represented by the 'Wakapuaka at Māori Pa Rd' site. Modelled contaminant load and flow data may be sufficient for the order 1 and order 2 streams along the western and eastern estuary boundaries. Loads from these streams appear likely to be less than 5% of the total land-derived TN load.

4.1.4 Kokorua Estuary

Terminal reach loads for the Whangamoa River could be approximated by the 'Whangamoa at Kokorua Bridge' site, although this site is some distance upstream from the estuary. Inputs from several side streams, including Frenchman's Stream, entering the Whangamoa River after this point would not be included in loads at this monitoring site and would have to be approximated from modelled data. We estimate based on data from NIWA's *NZ River Maps* web-tool that reaches below the 'Whangamoa at Kokorua Bridge' monitoring site contribute around 12% of the mean annual flow, and around 11% of the annual N load of the Whangamoa River (Whitehead and Booker 2018). Elizabeth Stream, entering the northern end of Kokorua Estuary, also has no suitable terminal reach monitoring site; estimating the load from this terminal reach would require the use of CLUES model estimates.

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. 2017c). For large estuarine sampling networks, we would suggest that each estuary in the sampling network is represented by at least one estuary water quality sampling site. For Nelson, which has four relatively large estuaries in a short distance of coastline we would suggest at least one, and ideally two, sampling points per estuary.

Consistency (referred to as 'site stationarity' in the NEMS) of site locations is vital for the usefulness of water quality time series, and therefore selected site locations should be maintained once sampling has commenced. We suggest that the best use of the water quality data from these estuary sites is as an indicator for change over time that may signal increasing upstream land use impacts, not as a spatially representative measure of trophic state (a purpose for which the ETI was created). This is in part because we recognise the difficulty of obtaining spatially representative estuarine samples. In addition, for the purposes of dilution modelling, the location of sites within the estuary are not vital provided salinity data are collected alongside nutrient measurements to enable validation of the ETI tool 1 modelling results. We therefore recommend sampling points along the shoreline at around the midpoint between the ocean and the major terminal reach sampling points. Where possible, we suggest sites are selected in relatively deep areas such as points with safe existing access further out into the estuaries (e.g., via a jetty or wharf). This is so that the sampling point does not need to be advanced from a high-tide shoreline position out into the estuary channels at low tide.

We expect that NCC will undertake regular benthic ecological monitoring across its estuaries (e.g., (Stevens and Robertson 2017). 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

Dilution modelling requires water samples from the open coast (salinity ca. 35 ppt, indicating no more than minor freshwater influence) to calculate mixing within the estuary. For the current version of the ETI (Zeldis et al. 2017a) this sampling would require collection of salinity data, as well as total nitrogen (TN) and/or dissolved inorganic nitrogen (normally reported as the sum of nitrate, nitrite and ammonia/ammonium). Development of local water quality guideline values with which to assess human-driven effects on open coastal waters in the Nelson region also requires time-series of open coast water quality data (ANZG 2018). Variables used for this purpose are covered in detail in Section 5, but typically include chlorophyll-*a*, suspended solids, turbidity, dissolved and total nutrients, and regular (year-round) faecal indicator bacteria. Based on a recent review of available coastal water quality data in the Nelson-Tasman regions (Newcombe et al. 2016), coastal water quality monitoring conducted in the Nelson area is restricted to summertime faecal indicator bacteria at selected recreational sites.

Of the locations of sites used in national water quality reporting the nearest coastal water samples with suitably low freshwater influence are collected by Marlborough District Council (MDC) in the outer Pelorus Sound at MDC sites PLS-7, PLS-10 and PLS-11 (Dudley and Todd-Jones 2018). Based on the distance and likely oceanographic differences between these sites and coastal water near Nelson we would recommend that NCC considers establishing collections of surface water from at least 3 sites in Tasman Bay, outside estuaries or the influence of large rivers. The location of open coastal sites could be optimised by consulting satellite imagery to establish the dispersal of plumes from the major rivers in Tasman Bay 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 the suite of water quality variables and metadata that NCC should collect for an estuarine water quality monitoring programme based on ecosystem health. We first cover the variables measured routinely in coastal water quality sampling and provide a summary of why each might be recorded. We then consider which of these variables has been recommended for monitoring across a range of relevant recent New Zealand studies, before narrowing down our focus to the variables required for SoE monitoring and modelling of catchment contaminant loads on estuarine ecosystem state. A brief comment is also made on recreational water quality monitoring variables.

5.1 Rationale for inclusion of specific coastal water quality variables in coastal water quality monitoring

Rationale for the measurement of the variables in Table 5-1 is provided in brief form below. More information can be found in recent publications specific to New Zealand estuarine water quality monitoring (Dudley et al. 2017, Zaiko et al. 2018, NEMS 2019).

5.1.1 Salinity

Salinity is easy to measure and very useful in estuarine dilution modelling because it permits comparison of predicted (e.g., ETI tool 1 model) 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. (2018b) — which enables prediction of upstream nutrient loads that correspond with bands of estuarine trophic state — would also benefit from salinity data.

5.1.2 Total suspended solids

Total suspended solids (TSS) are a major cause of both reduced visual clarity in coastal waters and reduced light penetration with depth through the water column (Gall et al. in review). Suspended solids include organic matter (e.g., phytoplankton, or fine particles of decomposing plant matter), and inorganic matter (e.g., inorganic sediment from terrestrial erosion). High suspended sediment concentrations are associated with estuarine and coastal sedimentation, reduced light levels in benthic environments and reduced feeding rates and health of estuarine and coastal animals (Lowe et al. 2015). Suspended solids 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 note that for the terminal riverine reaches, measurement of suspended sediment concentration (SSC) is needed for a robust estimate of sediment loads entering the estuary (e.g., (Gray et al. 2000, Selbig and Bannerman 2011).

5.1.3 Dissolved oxygen

Dissolved oxygen (DO) is influenced by oxygen supply and oxygen consumption taking place in water and sediments. High DO values can reflect high primary production or aeration relative to respiration. Low values can be indicative of high rates of decomposition of organic material in sediments and waters and may result in reduced species diversity and faunal biomass (GESAMP 2001). Dissolved oxygen levels in seawater have both diel and seasonal cycles. During daylight hours, primary producers such as phytoplankton produce oxygen as a product of photosynthesis, while during darkness the oxygen demand from respiration reduces DO concentrations. Similarly, high primary production relative to respiration in spring and early summer tends to result in high oxygen levels in surface water, while reduced primary production relative to rates of decomposition of organic material in late summer and autumn tends to reduce oxygen levels. Eutrophic environments may have both very high oxygen levels (e.g., in daytime, in spring), and very low oxygen levels (e.g., in late summer, at night-time and/or in benthic waters). Therefore, monitoring and data analysis of DO using methods suitable for other parameters (e.g., medians of monthly surface water sampling data) could be insufficient to detect reductions in DO that may kill some species and alter the biological functioning of estuaries.

5.1.4 Water temperature

Water temperature is often measured because temperature controls rates of biochemical reactions plus equilibria (e.g., DO saturation) and can be used for assessing local effects of climate change. We note that the usefulness of seawater temperature time series for assessing climate change effects depends on the site location and the length of the time series (Shears and Bowen 2017). Long-term (multi-decadal) time series at each location are necessary for some climate change applications.

5.1.5 pH

pH of oceanic seawater decreases due to sequestration of atmospheric CO_2 and so pH measurements reflect global changes in CO_2 availability. pH may also reflect more local scale processes caused by eutrophication, that can have detrimental effects on biological processes, and industries such as bivalve aquaculture (Cai et al. 2011). This is because low pH can be harmful to marine organisms with carbonate-based exoskeletons (molluscs, crustacean, corals, urchins, etc.) because carbonate tends to dissolve more readily as the pH drops. In coastal waters interactions between DO, dissolved inorganic nitrogen, and dissolved inorganic carbon and their responsiveness to temperature, acidification and eutrophication can make it difficult to assign a cause to observed changes in pH (Hewitt et al. 2014). However, a time series of accurate pH measurements makes interpretation possible. We note also that the accuracy of the pH measurement method used in most council sampling around New Zealand is likely to be insufficient to detect recent changes in New Zealand's open ocean driven by global atmospheric CO_2 increases, e.g., an annual change of 0.0013 ± 0.0003 in Southern Ocean waters (Law et al. 2018). However, measuring pH may be valuable for detecting changes in trophic state driven by eutrophication, e.g., a shift from pH 8.1 in the oligotrophic outer waters of the Firth of Thames to pH 7.9 in the mesotrophic inner Firth (Law et al. 2018).

Accuracy of in-situ pH measurements can be improved if supported by the collection of water samples measured in the laboratory for dissolved inorganic carbon/alkalinity. These measurements are then used to assist with sensor calibration.

5.1.6 Clarity and turbidity

Clarity and turbidity are optical variables that provide information on the transmission of light through waters. Reductions in visual water clarity result from light attenuation due to absorption and scattering by dissolved and particulate material in water. Turbidity measured with an optical sensor (nephelometer) is an index of side-scatter from a beam of light transmitting through the water sample. Visual clarity and turbidity are monitored because the attenuation of light in waters (and with depth in the water column) affects primary production, plant and animal distributions and ecological health, aesthetic quality and recreational values (Davies-Colley et al. 2003). The NEMS Water Quality (NEMS 2019) provides guidance on a range of options for visual clarity measurements, including the use of a SHMAK tube where waters are very sediment-laden.

5.1.7 Nutrients

The five nutrient species (NOXN, NHXN, DRP, TN and TP) are measured because they influence aquatic primary production – the growth of benthic microalgae (periphyton), photosynthetic bacteria, phytoplankton, macroalgae, and aquatic vascular plants. This influence is because phosphorus (P) and particularly nitrogen (N) are the nutrients that are in shortest supply relative to demand by aquatic primary producers during spring and summer in temperate coastal waters, including in New Zealand (Hanisak 1983, Sharp 1983, Barr 2007). Hence, increases in the availability of these nutrients are associated with increased primary production. Estuaries and open coasts are mixing zones for nutrients that originate in fresh and marine water, which can increase the availability of multiple nutrients (Sharp 1983). In severe cases, nutrient loading in coastal mixing zones results in proliferations of aquatic primary producers that can, in turn, degrade estuarine and coastal habitat, cause water colour and odour problems, and may be toxic to consumers, including humans (GESAMP 2001, Karez et al. 2004).

5.1.8 Faecal indicator bacteria

Enterococci, and *E. coli* or faecal coliform bacteria are monitored as their abundances indicate recent faecal pollution and the possible presence of human faecal pathogens in coastal waters. Hence, they represent the risk of infectious disease from waterborne pathogens (MfE/MoH 2003); enterococci is collected as an indicator of the suitability of water for contact recreation and *E. coli* or faecal coliform bacteria as an indicator of the suitability for gathering shellfish. Recreational water quality is discussed further in Section 5.5.

5.1.9 Chlorophyll-*a*

Chlorophyll-*a* is a measure of phytoplankton biomass. In coastal waters, high chlorophyll-*a* concentrations may occur during periods of high nutrient loading or upwelling of nutrients from deeper ocean waters, and chlorophyll-*a* is a primary indicator of eutrophication.

5.1.10 Other variables

Water column concentrations of metals, such as copper, lead and zinc are measured in some New Zealand estuaries with highly urbanised catchments (Dudley et al. 2017). This measurement is to assess the likelihood of direct toxic effects of urban runoff on the marine environment.

5.1.11 Biological indicators of water quality

The physical, chemical and microbiological measurements described above are highly variable in time. For this reason, many estuarine water quality programmes include time-integrated measures of water quality, such as biological indicators. These variables give information on the presence of nutrients or contaminants at a given point in space over longer timescales than the 'instantaneous' measures given by water sampling. Examples are algal bioindicators to measure nutrient availability (Barr et al. 2013), the NOAA 'Mussel Watch' programme to measure water column contaminants (Farrington et al. 2016), or an integrated index of ecosystem status such as the Estuarine Trophic Index (Zeldis et al. 2017a, Zeldis et al. 2017b, Zeldis et al. 2017c). Integrated indices normally combine several biological elements, together with physico-chemical and pollution elements to quantify ecosystem status.

5.2 Variables recommended in relevant recent reports

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 (Cornelisen 2010, Dudley et al. 2017, Zeldis et al. 2017c, Newcombe 2018, Zaiko et al. 2018). The relevant reports are:

- 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;
- (Zeldis et al. 2017a) and Zeldis et al. (2017c) – variables used to calculate the susceptibility of estuaries to eutrophication in ETI tool 1, and listed indicators used in assessment of the trophic state of estuaries in ETI tool 2;

- Newcombe (2018) – recommended biological indicators for SoE monitoring in coastal waters in Tasman Bay; and
- Cornelisen (2010) – recommended biological indicators for monitoring environmental conditions in coastal waters in the Horizons region.

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	Tasman Bay (Newcombe 2018)	Horizons RC (Cornelisen 2010)	MfE (Zaiko et al. 2018)	ETI tool 1 required	ETI tool 2 indicator	NEMS method available?
Major physico-chemical variables								
Salinity	✓	No	✓	E = ✓ M = ✓	No	✓	No	✓
Temperature	✓	No	✓	E = ✓ M = ✓	No	No	No	✓
Dissolved oxygen	✓	No	No	E = ✓ M = No	No	No	✓	✓
pH	✓	No	No	E = ✓ M = ✓	No	No	No	✓
Optical variables								
Visual clarity	✓	No	No	E = ✓ M = No	No	No	No	✓
Turbidity	No	✓	✓	E = ✓ M = ✓	No	No	No	✓
Total Suspended Solids	✓	No	No	E = ✓ M = No	✓	No	No	✓
Light penetration	No	✓	No	E = No M = No	No	No	No	✓
CDOM	No	✓	No	E = ✓ M = No	No	No	No	✓
Munsell Colour	No	✓	No	E = No M = No	No	No	No	✓

Variable	MfE (Dudley et al. 2017) Core	MfE (Dudley et al. 2017) Support	Tasman Bay (Newcombe 2018)	Horizons RC (Cornelisen 2010)	MfE (Zaiko et al. 2018)	ETI tool 1 required	ETI tool 2 indicator	NEMS method available?
Nutrients								
Total nutrients (TN, TP)	✓	No	No	E = ✓ M = ✓	✓	✓	No	✓
Dissolved nutrients (NO_X-N, NH_X-N, DRP)	✓*	No	No	E = ✓ M = ✓	No	No	No	✓
Dissolved organic nutrients (DON, DOP)	No	No	No	E = ✓ M = ✓	No	No	No	No
Microbiological indicators								
Enterococci	✓	No	No	E = No M = ✓		No	No	✓
Faecal coliforms	No	✓	No	E = No M = No	✓***	No	No	✓
E. coli	No	✓	No	E = ✓ M = No		No	No	✓
Chlorophyll-*a*	✓	No	✓	E = ✓ M = ✓	No	No	✓	✓
Phytoplankton assemblage	No	✓	No	E = No M = No	No	No	No	No
Other variables**	No	No	No	E = ✓ M = No	No	No	No	✓ (metals)

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

** Listed in (Cornelisen 2010) as including metals and organic chemicals.

*** 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 NCC is intending to undertake monitoring in line with ETI methodologies (which provides this integrated index), we pay special attention to water quality variables that can be included in ETI calculations.

We note that the variables included in the NEMS Water Quality (2019) are not a list of recommended variables, but a list of variables that may be measured as part of long-term SoE programmes for coastal waters. Therefore, we have not recorded all of the variables listed in NEMS (2019) in Table 5-1, but instead record whether those variables recommended in the other reports have an established method available in the NEMS (2019).

5.3 State of Environment (SoE) monitoring

Cornelisen (2010) recommends 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 2.1.1).

5.4 Estuarine dilution modelling and trophic state prediction

The dilution modelling approach of Plew et al. (2018b) requires an understanding of the N loads carried into an estuary from both open coastal inflow and land-influenced freshwater flows. Plew et al. (2018b) 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 oceanic water. Given the 'potential nutrient concentration' results of dilution modelling, ETI tool 1 can be used to predict trophic state within the estuary, and N-loads from land that correspond to changes in trophic state. The measure of trophic state from ETI tool 1 can be validated by comparing the ETI tool 1 prediction with the index score of trophic state from ETI tool 2 (Robertson et al. 2016b, Zeldis et al. 2017c) made using biological indicator data measured within the estuary. These biological indicators include chlorophyll *a* and dissolved oxygen (DO) in estuary water. Methods for additional, one-off collections of data that can improve the reliability of ETI tool 1 estimates are covered in Section 6.2.

5.5 Recreational water quality monitoring

As outlined in Section 2.2.5, 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[3]. For brackish or estuarine waters, it is unclear in the Guidelines whether enterococci or the freshwater indicator, *E. coli*, should be monitored.

A recently completed review of the marine component of the Guidelines (McBride et al. 2019) recommends that enterococci is measured 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. 2019). 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).

[3] It is hoped in the future that these guidelines might be based on *E. coli* or enterococci. McBride et al. (2019) 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.

5.6 Recommended monitoring variables

5.6.1 Physico-chemical variables

Based on water quality variable recommendations for national reporting, and the requirements of NCC's monitoring programme we suggest that salinity, temperature, DO and pH are monitored in terminal river reach, estuary and open coastal sites. We note that three of these four variables (temperature, DO and pH) are already monitored in terminal river reach sites in the Nelson region and salinity can be calculated from conductivity data, which is regularly collected (McArthur 2016).

5.6.2 Optical variables

We recommend that the Dudley et al. (2017) core variables visual clarity and suspended solids are monitored at terminal river reach[4], estuarine and coastal water sites. In addition, based on existing NCC freshwater monitoring variables, and recommendations for monitoring for similar coastal SoE programmes (Cornelisen 2010, Newcombe 2018), we recommend that turbidity is also monitored in estuaries and coastal waters.

5.6.3 Nutrients

We recommend that the Dudley et al. (2017) core nutrient species of TN, TP, NO_X-N, NH_X-N, and DRP are monitored in estuaries and open coastal sites, to match their current monitoring in freshwater sites. While these were not recommended for monitoring in Tasman Bay (Newcombe 2018), water column nutrients are monitored in every other regional council/territorial authority coastal water quality programme in New Zealand. As described in subsections 5.1.7 and 5.4, nutrients are valuable for monitoring and predicting future ecosystem change in estuaries, something that future amendments to the NPS-FM may potentially also address. We note that while we believe that phosphorus availability is extremely unlikely to limit primary production in New Zealand's coastal waters, this view is not universally shared amongst coastal scientists. We therefore suggest collection of DRP and TP data in estuarine and open coastal sites to provide evidence for the role of N loading from land in driving trophic change in estuaries in the Nelson region.

5.6.4 Microbiological indicators and chlorophyll-*a*

Based on requirements for recreational monitoring[5] outlined in Section 5.5, and mountains-to-sea monitoring of contaminant loads, we recommend monitoring of *E. coli* along with enterococci at terminal river reach and estuarine sites. We suggest that *E. coli* monitoring is less useful in marine waters, and enterococci need only be monitored at open coastal sites. If NCC would prefer to restrict estuarine sampling to a single indicator bacteria, based on residence times presented in Table 3-2, *E. coli* would likely be the most appropriate pathogen indicator for Kokorua Inlet, while enterococci would be the most appropriate pathogen indicator for Waimea Inlet, Nelson Haven and Delaware Estuary (McBride et al. 2019).

We recommend monitoring of chlorophyll-*a* at terminal river reach, estuarine and open coastal sites.

5.6.5 Other variables

Two additional variables NCC should consider including in the monitoring programme for Nelson Haven, at least for an initial period of 12 months, are copper and zinc. As noted in Table 3-1, Nelson Haven has around 10% urban land cover in its catchment. Elevated concentrations of copper and zinc have been regularly reported in the water column and bottom sediments of urban streams across New Zealand

[4] For terminal riverine reaches, measurement of suspended sediment concentration (SSC) provides for a more robust estimate of sediment loads entering the estuary. See Section 5.1.2.

[5] We recognise that NCC has a separate recreational water quality monitoring programme that specifically focuses on high use coastal sites in the Nelson region. However, we also note that recreation and, in particular, shellfish gathering, can extend across large areas of the Nelson CMA and the collection of additional microbiological water quality data may assist with water management for recreational purposes.

(Timperley et al. 2005, Kennedy and Sutherland 2008, Gadd et al. 2014). It is possible that the NPS-FM will be amended to incorporate these variables in some way, particularly in light of the significant sources of these contaminants in urban areas, including wear and tear from vehicle brake linings (copper) and tyres (zinc), and runoff from galvanized roofs (zinc) (Kennedy and Sutherland 2008). A further likely source of copper for Nelson Haven is copper-based anti-fouling paints, which have risen in use in the last 30 years due to the phasing out of tributyltin (TBT) and some other organic biocides (Jones and Bolam 2007). We recommend the dissolved form of copper and zinc is measured to represent the biologically available fraction which has the most potential to affect aquatic ecosystem health. In order to meaningfully interpret the metal data, it will be necessary to measure both dissolved organic carbon (DOC) and total hardness (at least monthly for one to two years to characterise their respective variation), as well as water temperature and pH (Gadd et al. 2017). Because Nelson Haven has potential sources of copper in both urban runoff and boats within the estuary we suggest that this monitoring is carried out in the terminal reach of the Maitai River, as well as within the estuary.

Table 5-2: Recommended water quality variables for SoE, recreational water quality and regional plan monitoring of marine and estuarine water quality for the Nelson Region.

Variable	Terminal river reaches	Estuarine sites	Open coastal sites
Major physico-chemical variables			
Salinity	✓	✓	✓
Water temperature	✓	✓	✓
Dissolved oxygen	✓	✓	✓
pH	✓	✓	✓
Optical variables			
Visual clarity	✓	✓	✓
Turbidity	✓	✓	✓
Total Suspended Solids (TSS)	✓*	✓	✓
Nutrients			
Total nutrients (TN, TP)	✓	✓	✓
Dissolved nutrients (NO_X-N, NH_X-N, DRP)	✓	✓	✓
Microbiological indicators			
Enterococci	✓	✓	✓
E. coli	✓	✓	No
Chlorophyll-*a*	✓	✓	✓
Other variables			
Dissolved copper and zinc	✓**	✓**	No

* For terminal riverine reaches, measurement of suspended sediment concentration (SSC) a provides for a more robust estimate of sediment loads entering the estuary. See Section 5.1.2.

** For Nelson Haven Estuary only. See Section 5.6.5.

6 Sampling and measurement methods

In this section we recommend 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. 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 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 sites at the same frequency to improve comparison of trends in water quality from fresh water to nearshore ocean water. We think that a quarterly or monthly sampling frequency is sufficient, but more frequent sampling (e.g., monthly instead of quarterly) increases the power of statistical tests to detect trends. Both monthly and quarterly sampling frequencies are used in many other long term, SoE water quality monitoring programmes in New Zealand.

We note that a significant portion of the Waimea Inlet catchment is located within the Tasman District. We recommend that NCC and TDC look to align their terminal reach water quality sampling in the catchment if possible. This logistically may require one council to monitor all terminal reach sites.

For most variables, monthly or quarterly data collected for SoE programmes are likely to be sufficient for regional and national reporting (e.g., see examples for Canterbury (Dudley and Todd-Jones 2018, Dudley et al. 2019)). However, to understand the effects of suspended (or re-suspended) sediments within estuaries on fish – something NCC has indicated they wish to know – much higher resolution data is needed because relevant guidelines are often based on exposure over hourly or daily time frames. For example, the British Columbia Ministry of Environment & Climate Change Strategy (2018) have guidelines for turbidity and total suspended sediments (TSS) to protect aquatic life in marine waters. These guidelines, based on chronic effects on fish, are outlined below:

Turbidity:

Clear waters (or low flow environments):

Maximum increase of 8 NTUs from background levels for a short-term exposure (e.g., 24-h period). Maximum average increase of 2 NTUs from background levels for a longer-term exposure (e.g., 30-d period).

Turbid waters (or high flow environments):

Maximum increase of 8 NTUs from background levels at any one time when background levels are between 8 and 80 NTUs. Should not increase more than 10% of background levels when background is > 80 NTUs.

TSS:

Clear waters (or low flow environments):

Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d).

Turbid waters (or high flow environments):

Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is ≥ 250 mg/L.

We suggest that baseline conditions can be adequately represented by monthly sampling, but NCC would need to implement high frequency (continuous) turbidity monitoring (e.g., through the deployment of an EXOsonde or equivalent) within the estuary for the purposes of understanding chronic effects of suspended sediment on fish.

6.1.2 Characterisation of load/flow relationships at terminal river reaches

Monthly sampling may not be sufficient to provide a good estimate of contaminant load. This is particularly the case for calculations of sediment load from terminal river reaches. Sediment load calculations are best based on relationships between flow and suspended sediment concentrations, or between turbidity and suspended sediment concentrations, at the terminal river reach. The accuracy with which these relationships can be used to predict sediment load to estuaries relies heavily on data collected during periods of high flow, because it is during high flow that most sediment is transported to estuaries. Monthly sampling often under-represents these high-flow periods and therefore Hughes and Hicks (2014) recommend that monthly sampling is supplemented with event-based measurements of suspended solids, turbidity and flow (e.g., via use of continuous sensors and/or automatic samplers). This type of monitoring may be necessary at terminal river reach sites on the larger rivers flowing to estuaries in the Nelson region. Detailed information on this topic is available in Hughes and Hicks (2014) and the NEMS Turbidity.

Nitrogen loading calculations require measurements of both flow and nitrogen concentration at the terminal reaches of rivers. Relationships between these two variables tend to be complex, and often differ between catchments (Borsuk et al. 2004, Hudson in prep.). We would not currently recommend high-frequency measurements of total nitrogen at terminal river reaches as a high priority. However, higher frequency measurements, even if collected via a few event-based sampling campaigns, as well as time-series of flow data in major rivers, will improve estimates of nitrogen loading to Nelson estuaries.

6.1.3 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 <u>and</u> low tide); or
- 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. This approach is not practical where travel times between sites are great or the monitoring network has many sites; NCC is one of the few councils in New Zealand where this approach could be appropriate. The second approach sacrifices statistical power in trend analysis; sampling without regard to tidal state may need to be more frequent to detect trends in water quality through time.

We note that monthly sampling would match the current frequency of NCC's freshwater SoE sampling and facilitate comparison of temporal patterns of freshwater quality to water quality in receiving estuaries. We therefore recommend one of the following sampling approaches with respect to time, in order from ideal to least-ideal:

- Monthly, at high and low tide and timed to coincide with freshwater SoE sampling; or
- Monthly, regardless of tide and timed to coincide with freshwater SoE sampling (but recording tidal state at sampling); or
- Quarterly, at high and low tide (or six-weekly alternating between high and low tide sampling); or
- Quarterly, with no regard to tide (but recording tidal state at sampling).

6.1.4 Sampling platform

We believe that shoreline estuary sampling is appropriate if samples can be taken safely and without mobilising sediments into the water column. Shoreline sampling may also be appropriate for coastal sampling if shoreline sites can be found that are sufficiently unaffected by fresh water plumes. We encourage the use of bridges or other sampling platforms (e.g., boats) if these are available.

6.1.5 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 2019), as well as use of NEMS protocols with regard to metadata collection, reporting of measurement uncertainty, and quality coding. Use of NEMS protocols aids standardisation of methods through time, ensuring that trends measured in time-series of data are not due to changes in methods. Use of NEMS protocols is also particularly beneficial for national-scale SoE reporting, where consistent methods across all regional authorities facilitates comparison of water quality across regions. We recommend that field metadata forms similar to that provided in NEMS (2019) are included in field run guides. This metadata should include specifics of sample collection such as sampling depth, (i.e., 30 cm below the water surface), bottle filling and labelling, and sample transport and handling.

Due to the relatively shallow mean depth of estuaries in the Nelson region the use of black disc for visual clarity at estuary and terminal reach sites would minimise the occurrence of 'greater than' values that will result from being able to see the estuary floor or riverbed. For open coastal sites at greater depth, Secchi disc could also be used if practical. We suggest that a single method should be chosen at each site and used consistently.

6.1.6 Field meters

In line with the 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 (2019).

6.1.7 Sampling point

We strongly recommend that locations for field measurements and water sample collection are well marked in sample run guides. This could be aided with photographs of the sampling point, and/or GPS waypoints if there are no natural landmarks with which the sampler could identify the sampling point.

Maintaining consistency in sampling point locations (stationarity in NEMS language) is important to reduce changes in time series of water quality measurements that are not due to changes in overall water quality of the estuary.

6.1.8 Sample handling and transport

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 (2019) recommends immediate stabilisation of samples is carried out using crushed ice. NEMS (2019) also provides advice and examples for shipping of samples, and an example chain of custody form.

6.1.9 Laboratory measurements on water samples

National standard laboratory methods for all variables we recommend for analysis by NCC are given in Table 5.1 of NEMS (2019). We note that some of the methods listed do differ from the 2017 draft NEMS so the details should be checked by NCC. To improve comparison of trends in water quality from fresh water to nearshore ocean water we recommend that all samples from terminal river reach, estuary and open water sites are analysed using comparable methods where possible.

Efforts should be made to minimise the occurrence of 'less than' values in water quality reporting, as these greatly complicate state and trend analyses, and reduce the confidence with which trends in water quality can be detected. A typical cut-off point for inclusion of sites in national trend analysis is 'no more than 15% of data as less-than values' (Larned et al. 2016, Dudley et al. 2017). We recommend liaising with laboratory staff several months after sampling commences to check the appropriateness of the method detection limits and reporting procedures for nutrient analyses at each site, with the goal of minimising the reporting of 'less-than' values.

6.2 Monitoring for dilution modelling using ETI tool 1

As outlined in Section 2.1.2, the NPS-FM requires freshwater quality and quantity limits to be set with consideration of impacts on downstream water bodies (New Zealand Government 2017). 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. 2017a, Plew et al. 2018b). In addition to the water quality information requirements for this approach laid out in Section 5.4, 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 around a month (to capture the variation in tides over a spring-neap cycle). Water level timeseries data should be collected at a frequency of at least 10 min and referenced to the same datum as the bathymetry 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. This is very likely to be the case for all four main estuaries in the Nelson region.

We recommend that water samples collected to support dilution modelling are analysed for nutrients (at least TN), salinity and chlorophyll-*a*, with DO measured in-situ. The sampling for dilution modelling could be scheduled to target a time of year when low oxygen conditions are most likely (potentially summer). If this initial one-off surveying indicates that an estuary is susceptible to low-oxygen conditions in deep areas in contact with sediments, an addition to the monitoring programme may be deemed necessary to examine these issues more closely.

7 Conclusions

The existing freshwater SoE water quality monitoring network in the Nelson region provides a good foundation on which to build an estuarine water quality monitoring network focused on ecosystem health. Freshwater SoE sites near the terminal reach of major rivers are well situated to calculate contaminant loads entering all four major estuaries. Calculation of contaminant loads to Waimea Inlet requires data from three further terminal reach river sites from the Tasman District Council surface water quality monitoring network. The addition of 1-2 water quality monitoring sites within each of the four main estuaries, and 2-3 sites in Tasman Bay, would provide robust data for the purposes of both SoE monitoring and Regional Plan effectiveness monitoring, particularly regarding catchment land-use pressure. Monitoring of terminal river reach, estuary and open coastal sites at close to the same time schedule would aid monitoring of source-to-sea contaminant transport and facilitate integration of SoE water quality monitoring with assessments of estuarine ecological health. The current list of variables monitored at freshwater SoE sites is close to that we would recommend for estuarine and coastal sampling. We suggest integration of water quality and ETI monitoring programmes could also be improved by one-off, estuary-by-estuary bathymetry, water quality and depth profile CTD sampling.

7.1 Major recommendations

We recommend:

1. Structuring the monitoring network to allow comparison of water quality in in each of the four major estuaries in the Nelson region with water quality in terminal river reaches flowing into them, and on the adjacent coast.
2. Establishing 1-2 water quality monitoring sites in each estuary. These sites may be along the shoreline but ideally would be near the mid-point between the terminal reach of the major river input(s) and the ocean outflow point.
3. Aligning the water quality variables measured in each estuary with those monitored at 2-3 open coastal sites within Tasman Bay, outside the influence of freshwater plumes.
4. Standardising where possible, water quality variables monitored, and sampling frequency (monthly), at terminal river reaches, within estuaries and in marine waters. This would require alignment of NCC and TDC sampling of water quality sites in rivers flowing to Waimea Inlet.
5. Collecting 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 areas of 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 estuary.
6. Monitoring of both *E. coli* and enterococci and terminal reach and estuarine sites until current microbiological water quality guidelines are reviewed and to facilitate 'source to sea' tracking of microbial contaminants.

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