Manaaki Whenua
Landcare Research

Ki uta ki tai: mātāpono me te pūtaiao, ngā korero whakamahuki ma te kaitiaki – whenua

From mountains to the sea: values and science for an informed kaitiaki/guardian – land

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From mountains to the sea: values and science for an informed kaitiaki/guardian – land

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Alexander Herzig, Andrew Neverman, Robbie Price, Michelle Barnes

Manaaki Whenua – Landcare Research

Reviewed by:	*Approved for release by:*
John Dymond	Paul Mudge
Principal Scientist	Portfolio Leader
Manaaki Whenua – Landcare Research	Climate Change Adaptation and Mitigation

Content

Summary

Project and client

- Manaaki Whenua – Landcare Research was contracted by the Our Land and Water National Science Challenge to assess the impacts and implications of meeting contaminant reduction targets for estuaries on catchment land-use and management.

Objectives

- Estimate the time distribution of contaminant loads at sub-annual scales.
- Estimate catchment contaminant loads to all case-study estuaries, i.e. Kaipara Harbour, New River, and Waihi, and to all New Zealand estuaries under changed climate and mitigations.
- Identify catchment land-use scenarios for a range of contaminant reduction targets for estuaries.

Methods

- Dymond and Dymond (2021) used statistical summaries and transformations to develop contaminant discharge distributions that are independent of mean water discharge to inform Sustainable Seas analysis of freshwater contaminant inputs to estuaries at sub-annual scale.
- Geographic Information Systems and the Land-Use Management Support System (LUMASS) modelling and optimisation framework were used to integrate spatial catchment, landscape, land-use, and management information for geospatial and optimisation-based modelling.
- Mitigation scenarios were applied to estimate the effect of adopting all current and future available mitigation options on all dairy and sheep & beef land.
- Optimisation-based land-use change scenarios were used to identify opportunities for further nutrient and sediment reduction potential through land-use change, while maximising cost-effectiveness.
- The Estuary Trophic Index Tool (Zeldis et al. 2017; Plew et al. 2020) was used to assess the potential change in susceptibility to eutrophication in response to modelled land-use scenarios.
- Scenario nitrogen (N), phosphorus (P), and sediment sub-catchment loads were routed down the river network to assess whether National Policy Statement for Freshwater Management (NPS-FM) bottom line standards for total nitrogen (TN), total phosphorus (TP), and suspended sediment (SS) were achieved in (critical) catchments that are currently failing the standards.

Results

- Adopting all currently available N, P, and typical sediment mitigation options on all dairy and sheep & beef land achieves:
  - N, P, and sediment reductions of about 20%, 30%, and 40%, respectively, across all estuary catchments

  - about 30%, 20%, and 30% (N), 30%, 45%, and 45% (P), and 50%, 60%, and 50% (sediment) reductions for the Kaipara Harbour, New River, and Waihi case-study estuary catchments, respectively.
- Adopting all current and future available nutrient and typical sediment mitigation options by mid-century under a future climate (RCP 4.5) on all dairy and sheep & beef land achieves:
  - N, P, and sediment reductions of about 40%, 45%, and 15%, respectively, across all estuary catchments
  - about 50%, 45%, and 50% (N), 45%, 50%, and 60% (P), and 5%, 60%, and 35% (sediment) reductions for the Kaipara Harbour, New River, and Waihi case-study estuary catchments, respectively.
- Climate change reduces net sediment mitigation effects compared to baseline across all case-study estuary catchments towards the end of the century with higher greenhouse gas concentrations in the atmosphere. This effect is strongest in the Kaipara Harbour catchments, and despite mitigations shows a significant net increase in erosion for the RCP 8.5 scenario for the end of the century.
- Nutrient reductions of 60% and more in estuary catchments require the conversion of some pastoral farming land to either exotic forest or natural vegetation, and most of pastoral farming land to adopt all current and future available nutrient mitigation options.
- Due to their high profitability, total horticulture and dairy land areas in estuary catchments remain largely unchanged in the land-use change scenarios targeting 20%, 40%, and 60% N reduction (whilst maximising cost-effectiveness).
- In the land-use change scenario targeting 60% N reduction, about 50% of each case-study estuary's total catchment area remains mainly in agricultural use, with a greater relative decrease in exotic forest area.
- About a quarter of all estuaries, receiving freshwater and contaminant inputs from about 40% of the total New Zealand estuary catchments' area, show moderate to very high eutrophication susceptibility. Almost 10% of the estuaries, receiving freshwater and contaminant inputs from about 25% of the total New Zealand estuary catchments' area, show very high eutrophication susceptibility.
- About 60%, 70%, and 55% of New Zealand estuary catchments contain one or more critical catchments that do not meet the NPS-FM bottom line standard for TN, TP, and SS.
- Reducing the N load of estuary catchments by 60% would see more than 90% of critical catchments achieve the national bottom line for TN in more than 80% of estuary catchments containing critical N catchments.
- Implementing current and future available P and typical sediment mitigation measures alongside N mitigation measures targeting a 60% N reduction would see more than 90% of critical catchments achieve the national bottom line for TP and SS in about 40% and 80% of estuary catchments containing critical P and sediment catchments, respectively.
- Implementing current and future available P mitigation measures alongside N mitigation measures targeting an 80% N reduction would result in more than 90% of

critical catchments achieve the national bottom line in more than 50% of estuary catchments containing critical P catchments.

Conclusions

- The adoption of feasible mitigation options in combination with targeted moderate land-use change will be able to sustain a significantly improved ecological health of New Zealand estuaries and rivers.
- Increased effort implementing sediment mitigation measures is required to keep up with climate-driven exacerbation of sediment generation, especially in soft-rock hill country.
- For estuaries susceptible to eutrophication or whose catchments exceed NPS-FM bottom lines for one or more contaminants, implementing P and sediment mitigation measures alongside N mitigation measures targeting a 60% N reduction could sustain a considerably improved ecological health of estuaries and rivers.

1 Background

The National Policy Statement for Freshwater Management (NPS-FM) gives effect to Te Mana o te Wai and therefore prioritises:

- the health and well-being of water bodies and freshwater ecosystems
- the health needs of people (such as drinking-water)
- the ability of people and communities to provide for their social, economic, and cultural well-being, now and in the future.

It is the mauri, or well-being, of ecosystems that will support human needs and well-being.

The Our Land & Water National Science Challenge (OLW) has contributed positively to freshwater limit-setting processes and how catchment activities link to them. However, the links between NPS-FM attributes, catchment management, and estuarine health or function have yet to be established. Current methods do not allow for assessment of the effects of interactions between loadings of different contaminants on the health and functioning of the estuary, now or under a changed future climate, nor can safe bounds be quantified that will provide for within-estuary activities and local community, whānau, hapū, or iwi aspirations.

Establishing these links requires a combined approach across the terrestrial, freshwater, and estuarine knowledge bases, which provides an opportunity for the Sustainable Seas National Science Challenge and OLW to run a combined programme of work. This report describes the OLW components of the joint research project with Sustainable Seas that was undertaken in partnership with the Ministry for the Environment (MfE). Together, the research projects aim to achieve impact by addressing the hierarchy of priorities of Te Mana o te Wai.

The outcomes of the research and related activities undertaken by OLW aim to contribute estimated freshwater contaminant loads to New Zealand estuary catchments historically, now, and under a changed climate. In focal estuaries Sustainable Seas will then use the freshwater inputs supplied to determine critical stressor thresholds and buffers that support mātauranga Māori-informed objectives and translate these to limits for freshwater inputs. OLW will then look at the impact of limits derived from the estuaries on land management in the catchment (if and how they can be met), now and under a changed climate.

The pathway to impact is through setting achievable contaminant thresholds for mātauranga Māori-informed objectives for estuaries, and for the implementation of mitigation measures to meet those thresholds in estuary catchments. MfE will share the understanding developed through the process and fund separate pieces of work that will contribute to a nationally relevant process for setting freshwater objectives that allow for the restoration and maintenance of the mauri of the estuary.

In the spirit of enacting Te Mana o Te Wai, OLW and Sustainable Seas will collaborate on research that assesses and links Māori values and aspirations in estuarine environments to solutions for restoration both in the estuary and up the catchment. The research includes an emphasis on place-based research that has a critical mass of Māori interest and capability to achieve contextualisation within a kaupapa Māori framework.

The joint research recognises that Māori have a range of objectives in relation to freshwater and estuaries that reflect their needs in relation to, for example, wāhi tapu, mauri, mahinga kai, and kaitiakitanga, and that extend beyond biophysical states. The activities described in the companion Sustainable Seas programme will ensure the engagement of Māori at the beginning of the research process, by involving them in defining the outcomes sought, the knowledge used, and the methods by which constraints on freshwater and terrestrial activities are determined.

2 Objectives

The programme worked at three different scales:

- national (OLW)
- focal estuaries (Sustainable Seas)
- three case study estuaries (Kaipara Harbour, Waihi, and New River), where mātauranga Māori-informed objectives were determined.

A national map of estuaries and their current loads of the four contaminants – suspended sediment, nitrogen (N), phosphorus (P), and *E. coli* – was created using NIWA's Catchment Land Use for Environmental Sustainability (CLUES, Elliot et al. 2016) model and existing data collated by NIWA.

The data were used by Sustainable Seas to investigate the spatial and temporal exposure of estuarine macrofauna to freshwater-driven contaminant inputs, as well as climatic and oceanic drivers, to determine their impact on estuarine ecological health (Lam-Gordillo & Lohrer 2023). This investigation also drew on an OLW component (Dymond & Dymond 2021, see section 3.1), enabling the temporal disaggregation of annual average contaminant loads and river-flow data.

The objective of the Sustainable Seas analysis was to determine thresholds for freshwater contaminant loads entering estuaries that could inform catchment land management strategies that contribute to estuarine rehabilitation. Although the analysis showed that freshwater contaminants influence the abundance, richness, and diversity of macrofauna (Lohrer et al. 2023), no consistent pattern between freshwater contaminant variation and variation in macrofauna could be established (Lohrer et al. 2023). As a result, no freshwater contaminant thresholds could be derived to inform this project's objective of analysing the implications of estuary contaminant limits for catchment land-use management.

In lieu of specific limits for individual contaminants and estuaries or types of estuaries, we modelled a wide range of potential contaminant reduction targets for all New Zealand estuary catchments and analysed the associated potential:

- impact on New Zealand estuary ecological health
- implications for New Zealand estuary catchments' land use and management
- impact on New Zealand estuary catchments achieving NPS-FM bottom lines.

While this approach does not provide an assessment of land-use implications for specific contaminant reduction targets for New Zealand estuaries, it does provide decision-makers and policy development with guidance on what level of contaminant reductions are achievable for each of New Zealand's estuaries at what level of land-use (management) change. Our analysis also provides an estimate of the associated impact on achieving NPS-FM bottom lines for New Zealand estuary catchments. This provides decision-makers and communities with a rich data set of trade-offs between estuary ecological health and implications for land-use and freshwater management.

Specifically, in this report we describe the following OLW components of the joint research programme:

- estimate the time distribution of contaminant loads – this component enables an assessment of seasonal variations of contaminant concentrations entering estuaries, based on modelled mean annual average contaminant loads
- estimate catchment contaminant loads to all New Zealand estuaries under a changed climate and mitigations – this component assesses the potential impact of realistic mitigation measures on contaminant loads entering estuaries and provides an estimate of the maximum possible load reductions if all mitigation measures were implemented across estuary catchments
- identify catchment land-use implications for a range of contaminant reduction targets for estuaries – this component identifies land-use scenarios that implement realistic mitigation options and land-use change to achieve a range of contaminant load reductions in estuaries.

3 Methods

3.1 Time distribution of contaminant loads into New Zealand tidal estuaries

Below we provide a summary of the methodology used for this component of the project. Please refer to Appendix 7 for the full methodology.

Snelder et al. (2017) have collated monthly measurements of total nitrogen (TN), total phosphorus (TP), and *E. coli* in New Zealand rivers from the 16 regional councils and unitary authorities, and from NIWA. The raw data came from monthly samples collected at 1,113 sites distributed across New Zealand, most of the samples are dated between 2000 and 2017. There are over 100,000 measurements each of TN, TP, and *E. coli.* Most of the TN, TP, and *E. coli* measurements have been associated with a water discharge measurement or estimate. The water discharge estimates have been used to convert the TN, TP, and *E. coli* concentration measurements (with units of mass/volume) to TN, TP, and *E. coli* discharge measurements (with units of mass/time) by multiplying concentration by discharge.

The mean contaminant discharge is estimated at each site. Each measurement of contaminant discharge is then transformed by dividing by the mean and taking the natural log. This results in a near normal distribution of transformed contaminant discharge for each site, which appears to be independent of mean water discharge. We have lumped measurements of contaminant discharges from all sites (>100,000) to estimate a national average distribution, from which percentiles of contaminant discharge at any estuary can be estimated (see following sections).

The Snelder et al. 2017 data set does not include suspended sediment, which is a contaminant of interest for estuaries, so an analysis of turbidity was performed using data provided by Whitehead (2018). Turbidity is linearly related to suspended sediment concentration, so the percentiles should be the same. (However, we are uncertain of the robustness of the turbidity measurements, so we currently recommend assuming that the percentiles of transformed suspended sediment discharge are the same as the percentiles of transformed TP discharge). The Snelder et al. 2017 data set does not include water temperature, so this analysis could not be performed.

The time distribution of contaminant discharge for any river flowing into an estuary can be estimated from the percentiles (national average) of transformed contaminant discharge, estimated above, combined with the mean contaminant discharge of the river (see Appendix 7). Mean contaminant discharge (or annual contaminant load, as it is commonly referred to) for rivers flowing into estuaries is provided by Semadeni-Davies et al. 2021. A summary is provided by Dymond & Dymond (Appendix 7, Appendix B). For those rivers flowing into estuaries where water discharge is measured (or modelled) as a time series, such as the case-study estuaries, it is possible to disaggregate mean contaminant discharge into a time series with the use of rating curves (see Appendix 7). The section in the appendix 'Rating curves for contaminant discharge' shows how these rating curves can be inferred from the percentiles (national average) of transformed contaminant discharge.

3.2 Land-use scenario modelling

The objective of the land-use scenario modelling we carried out was to assess:

- the impact of implementing realistic mitigation options for pastoral farming to address contaminant loads entering estuary catchments (Appendix 1, Figure A1.1)
- the implications for land use of contaminant reduction targets for estuary catchments.

Because contaminant losses are influenced by spatially variable factors (e.g. rainfall, soil, slope, and land cover), we conducted spatially explicit land-use scenario modelling, drawing on available spatially explicit data layers (e.g. contaminant sources – dairy and sheep & beef typologies), land cover, and topography (section 3.2.1).

The catchment-scale modelling outputs from NIWA's Catchment Land Use for Environmental Sustainability (CLUES, Elliot et al. 2016), generated for the joint research programme (Semadeni-Davies et al. 2021), could only be partly integrated into this study. Relevant input data prepared for the CLUES modelling (i.e. the land-use baseline) could, unfortunately, not be made available to this study due to licensing restrictions imposed by a CLUES input data source. In response, we generated our own land-use layer (section 3.2.1) and an associated baseline contaminant loss scenario as inputs for assessing contaminant-loss reduction potentials and their implications for estuary catchments' land use.

We followed two different modelling approaches. First, we modelled the maximum possible reductions that could be achieved by implementing (i) all current available mitigation options and (ii) all current and future available mitigation options (section 3.2.2, Table 2). Second, we modelled the impact of set contaminant reduction targets (section 3.2.3, Table 3) on catchment land use and management under a cost-effectiveness maximisation regime.

3.2.1 Land use

To carry out land-use scenario modelling, we produced a data set that combines spatially explicit information of land use and cover, land-use management and its environmental and economic performance, estuaries, and the catchments and the contaminant status of waters draining into them. The data set was derived from the following sources:

- Land Cover Data Base v5.0 (Manaaki Whenua – Landcare Research 2021)
- dairy and sheep & beef typologies, and feasible current and future available mitigation options and effectiveness (McDowell et al. 2020; Monaghan, Manderson, Basher et al. 2021; Monaghan, Manderson, Basher, Spiekermann et al. 2021; McDowell et al. 2023)
- estuaries, catchments, and attenuation factors (Semadeni-Davies et al. 2021)
- catchment contaminant status, critical point catchments, and load compliance ratios from Snelder et al. 2020 and Snelder et al. 2021.

Spatial input layers were rasterised (15 × 15 m pixel) using the GDAL software library, and a map of unique combinations of input pixel values was derived using the Land-Use Management Support System (LUMASS)[1] modelling and optimisation framework. The set of unique combinations defines the spatial decision units (SDUs); i.e. the smallest geometries with common attributes across all input data sets. Based on the land-cover data and the dairy and sheep & beef typologies, we derived six land-use types and assigned land-use performance indicators to them (see Table 1, Figures 1 and 2).

[1] https://manaakiwhenua.github.io/LUMASS

Table 1. Land-use types* and baseline performance indicators and values

Indicator / land use	Dairy	Sheep & beef	Horti-culture[a]	Arable[a]	Exotic forest[a]	Natural vegetation[b]
Nitrogen loss (kg ha^{-1} yr^{-1})	24–103[c]	4–21[c]	29	36	6	2
Phosphorous loss (kg ha^{-1} yr^{-1})	0.6–6.6[c]	0.1–4.6[c]	0.48	0.56	0.1	0.1
Sediment loss (t/ha/yr)	Spatially variable data (Neverman et al. 2023)					
Gross margin (NZD ha yr^{-1})	3,759–5,262[d]	199–1,434[d]	15,822	2,214	1,150	0
Operating profit (NZD ha yr^{-1})	Spatially variable data (Harris et al. in prep.)	N/A	N/A	N/A	N/A	N/A

* All other land-use types not represented in the table are grouped into the type 'other'.

[a] Average data based on McDowell et al. 2023.

[b] Average data based on Davis 2014.

[3] Spatially variable data based on McDowell et al. 2020, Monaghan, Manderson, Basher, Burger et al. 2021, and Monaghan, Manderson, Basher, Spiekermann et al. 2021.

[4] Spatially variable data based on McDowell et al. 2023.

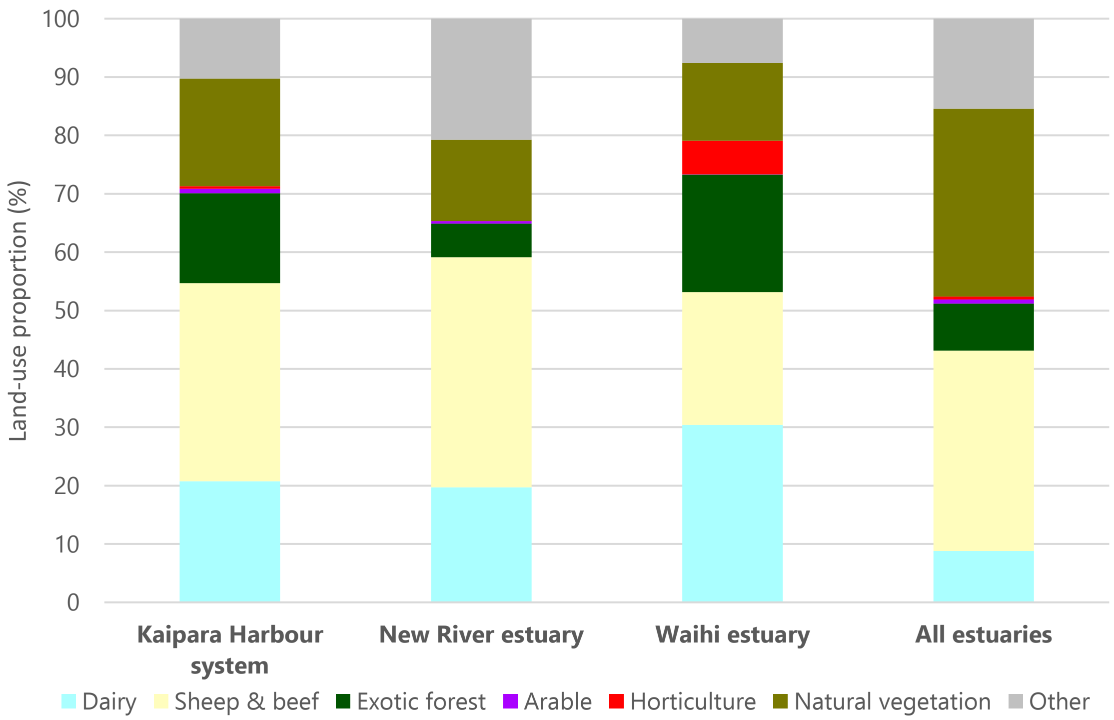


Figure 1. Land-use distribution of case-study estuary catchments and all estuary catchments.

To enable spatially explicit land-use scenario modelling, we used the land-use map generated and the associated indicators for N, P, and sediment to calculate a baseline scenario of contaminant losses.

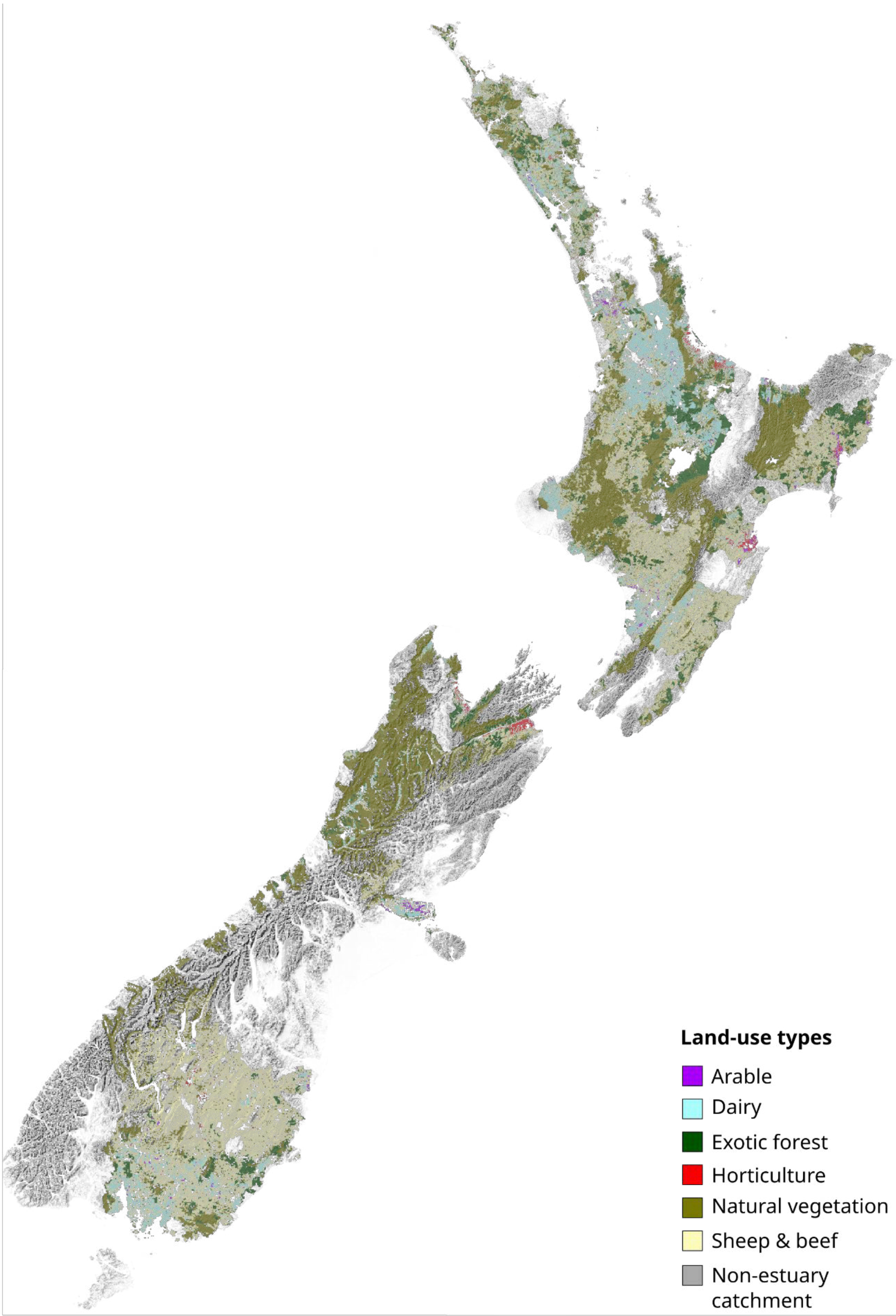


Figure 2. Baseline land use in estuary catchments.

3.2.2 Mitigation scenarios

The six land-use types shown in Figures 1 and 2 represent 90% of the land area for 75% of all estuaries included in the study. Therefore, we focus on these land-use types in our analysis and, in particular, on the pastoral farming types with regard to mitigation options and scenarios. Agricultural land-use types have been well studied in the past by the OLW and other projects, and a good database for parameterising mitigation options (McDowell et al. 2020; Monaghan, Manderson, Basher, Burger et al. 2021; Monaghan, Manderson, Basher, Spiekermann et al. 2021) and assessing their impact on contaminant load changes to estuaries has been made available.

To represent current and future available mitigation options, we drew on these data and added further performance indicators to the baseline data set (Table 1). Three times and four states of mitigation implementation (Table 2) were modelled to reflect the variable uptake and availability of mitigations over time and the impact of climate change. Data to reflect the impact of climate on the considered contaminants was only available for sediment (Neverman et al. 2023). Climate scenarios were modelled for three different representative concentration pathways (RCP: 4.5, 6.0, and 8.5; van Vuuren et al. [2011]). To assess the impact of realistic mitigation options on contaminant discharge for potentially compounding climate effects, we focused on likely and worse climate scenarios. This also helped to reduce the number of modelled scenarios.

Due to the heterogeneous input data sets and their respective dates of creation, the modelled long-term annual average sediment losses under climate change, and the uncertainty of the potential uptake of future mitigation practices, the modelled states and times represent broad states and times only.

While we assume no implemented mitigations for the baseline sediment scenario, in reality a lot of mitigation work has already been implemented, especially afforestation and reversion to natural vegetation. This is the most effective mitigation against New Zealand's dominant erosion sources, and it will be reflected in the 2018 land-cover baseline data and hence be accounted for in all our modelled scenarios. However, already-implemented space planting of hill country, fencing, riparian planting, and other edge-of-field mitigations for reducing shallow landslides, earthflows, bank and surficial erosion are not reflected in our scenarios. This results in an overestimation of the mitigation effect on sediment in our modelled scenarios.

Modelled sediment losses under climate change were adopted from Neverman et al. 2023. Sediment mitigation options were adopted for hillslope erosion processes (i.e. landslides, earthflows, gullies, and surficial erosion), as well as for bank erosion and sediment runoff into waterways in lowland areas. The implementation of sediment mitigation measures for pastoral farmland was allocated based on the erosion domains devised by Neverman et al. (2023). Whole-farm plans were modelled to be 70% effective (Dymond et al. 2010, 2016) in reducing soil erosion for pastoral farmland in soft-rock and hard-rock hill country. Fencing and riparian planting were modelled to be 80% effective in reducing bank erosion and sediment runoff (assuming 5 m riparian planting, following Neverman & Smith 2022) for non-forested lowland areas.

Nutrient mitigation options for dairy and sheep & beef farming systems were sourced from Monaghan, Manderson, Basher, Spiekermann et al. 2021, Monaghan, Manderson, Basher, Burger et al. 2021, and McDowell et al. 2020, and grouped into bundles. No nutrient mitigations were modelled for horticulture, arable cropping, exotic forestry, or natural vegetation.

Table 2. States and times of modelled nutrient and sediment mitigations

Scenario (time)	Nutrient mitigations[a]	Sediment mitigations[b]
Baseline (c. 2018)	Adopted mitigations at the time	No implemented mitigations assumed
Current (c. 2018)	All currently available mitigations implemented	Fencing, riparian planting, and whole-farm plans for current sediment yield
Mid-century (c. 2040)	All future available mitigations implemented	Fencing, riparian planting, and whole-farm plans for mid-century sediment scenarios under climate change (RCP 4.5, 6.0, 8.5)
End of century (c. 2090)	All future available mitigations implemented	Fencing, riparian planting, and whole-farm plans for end-of-century sediment scenarios under climate change (RCP 4.5, 6.0, 8.5)

[a] Monaghan, Manderson, Basher, Spiekermann et al. 2021; McDowell et al. 2020

[b] Dymond et al. 2010, 2016; Neverman et al. 2023; Neverman & Smith 2022

The current, mid-century, and end-of-century scenarios (Table 2) assume that all current mitigation options and all current and future available mitigation options are implemented on all dairy and sheep & beef land for current, mid- and end-of-century times, respectively. They show the maximum possible reduction that could be achieved with (currently known) mitigation measures. As mid-century and end-of-century scenarios feature an identical set of nutrient mitigation options, they show identical nutrient reduction results. However, since mid- and end-of-century scenarios incorporate the effect of a changing climate on soil erosion, they highlight the potential consequences of climate change on sediment generation.

3.2.3 Land-use change scenarios

In addition to the mitigation scenarios, we modelled optimisation-based land-use change scenarios using the LUMASS spatial modelling and optimisation framework. LUMASS is a free and open-source spatial modelling and optimisation framework and employs the mixed-integer linear programming system 'lp solve' (Berkelaar 2007) to solve multi-objective spatial optimisation problems. It has been described in more detail by Herzig et al. (2013) and Herzig et al. (2018), and it has been utilised in various spatial optimisation case studies in New Zealand (Herzig et al. 2016; Thomas et al. 2020) and abroad (Herzig et al. 2018).

Modelled land-use change scenarios include all current and future available nutrient mitigation options (Table 2), but also the option of land-use change. Hence, they provide another land-management tool to enable potentially greater contaminant reductions by replacing pastoral agriculture with either natural vegetation or exotic forestry, and exotic forestry with natural vegetation. The potential reduction in nutrient losses due to the retirement of agricultural land or exotic forestry is determined by the difference of the losses given for the individual land uses in Table 1. Sediment losses from agricultural land can be reduced by 80% (Vale et al. 2021) or 90% (Dymond et al. 2010; Dymond et al. 2016) through conversion to exotic forestry or natural vegetation, respectively. Conversion of exotic forestry to natural vegetation can reduce sediment losses by 50%.

Since no specific contaminant reduction targets for maintaining ecological health in New Zealand estuaries were available, we modelled a wide range of potential reduction targets. Scenarios were modelled for mid- and end-of-century times, and for different future climate projections (Table 3).

Table 3. Land-use change scenarios and names for set nitrogen reduction targets and different climate scenarios

Nitrogen reduction target	Mid century			End of century		
	RCP 4.5	RCP 6.0	RCP 8.5	RCP 4.5	RCP 6.0	RCP 8.5
20%	N20_m45	N20_m60	N20_m85	N20_e45	N20_e60	N20_e85
40%	N40_m45	N40_m60	N40_m85	N40_e45	N40_e60	N40_e85
60%	N60_m45	N60_m60	N60_m85	N60_e45	N60_e60	N60_e85
80%	N80_m45	N80_m60	N80_m85	N80_e45	N80_e60	N80_e85

The implementation of mitigation measures on dairy and sheep & beef land, or the replacement of any of the considered agricultural farming land with exotic forestry or natural vegetation, was driven by the contaminant reduction targets for individual sea-draining catchments. Because (i) N is considered to be the primary limiting nutrient for production in coastal waters (Hanisak 1983; Hurd et al. 2004; Howarth & Marino 2006; Larned et al. 2011, cited in Plew et al. 2018), (ii) N and P losses are often correlated (Moran et al. 2017), and (iii) all farmland susceptibility to erosion is by and large independent of the actual farming system, we only set explicit reduction targets for N (i.e. 20%, 40%, 60%, and 80%).

However, whenever mitigation measures were selected by the optimisation process, mitigation measures for all considered contaminants were implemented according to Table 2 (i.e. N, P, and sediment). The exact type of mitigation measures implemented were selected based on the respective dairy or sheep & beef farm system at the given location (McDowell et al. 2020; Monaghan, Manderson, Basher, Burger et al. 2021; Monaghan, Manderson, Basher, Spiekermann et al. 2021) and the location's erosion domain (Neverman et al. 2023).

Although the N reduction targets forced land-use management and land-use change, the actual selection of where change was going to occur was controlled by the objective of maximising profitability. The uptake of mitigation measures affects farm profitability through various mechanisms (e.g. implementation costs, increased operating costs, or reduced effective farming areas). It may also require improved management skills and/or knowledge to be successfully implemented and operated (DairyNZ 2014; Moran et al. 2017). This creates an inherent resistance to the uptake and implementation of land-use (management) change.

While available data on the reduction of farm profitability in response to a reduction of N loss through mitigation measures on dairy farms reveal great variability across different farm types, they do show a trend. We represented this in our model for dairy land with a generalised and simplified linear relationship derived from published data (DairyNZ 2014; Moran et al. 2017):

$$rop = 0.576 * nr - 1.622 \quad (R^2=0.7) \qquad (1)$$

where:

- rop is reduction of operating profit (%)
- nr is reduction of N loss (%).

Equation 1 relates a relative reduction of N loss to a relative reduction in operating profit, so we first related operating profit sourced from Harris et al. (in prep.) to gross margin, and then applied the relationship to the appropriate portion of the gross margin.

Available data (Matheson et al. 2018; Moran et al. 2017) on the impact of implementing mitigation measures on the profit of sheep & beef farms does not show as clear a trend as the data available for dairy farms. Therefore, we applied a fixed reduction of $50 and $150 of operating profit for the implementation of mitigation bundles for all current (Snb (c)) and future available mitigations (Snb (m)), respectively.

Land-use (management) change was modelled according to the following rules.

- Dairy and sheep & beef types may adopt any of the mitigation bundles represented by the baseline, current, or mid-century mitigation scenarios (Table 2).
- Agricultural land may be converted to exotic forestry or natural vegetation.
- Exotic forestry may be converted to natural vegetation.
- Increase of exotic forestry is limited to an additional 456,000 ha distributed across estuary catchments based on their proportion of intensive land-use area (i.e. dairy, sheep & beef, arable, and horticulture).

Limits on nutrient losses and the extent of exotic forestry are set individually for each sea-draining catchment relative to its respective baseline values. However, depending on the baseline land-use proportion, not all sea-draining catchments are able to achieve all set reduction targets. Therefore, we capped the actual N reduction target for a given scenario and sea-draining catchment at the maximum possible reduction that could be achieved by replacing all agricultural land (i.e. dairy, sheep & beef, arable, and horticulture) with natural vegetation. The overall 456,000 ha limit on additional exotic forest area represents 60% of the maximum new exotic forest area (760,000 ha) required to achieve the New Zealand government's 2050 emission reduction target according to the Climate Change Commission's low emissions future scenarios (He Pou a Rangi – Climate Change Commission 2021). The selected value of 60% reflects the proportion of current exotic forest area (c. 1.23 million ha, MWLR 2021) in estuary catchments of the total area (c. 2.03 million ha, MWLR 2021) of exotic forest in New Zealand.

To keep the number of modelled scenarios manageable, we grouped the 210 estuaries into 24 optimisation regions (Figure 3) to distribute the 1.2 million SDUs that control the size of the individual optimisation problems as evenly as possible while not splitting estuary catchments across optimisation regions. The largest regions represent New Zealand's two largest rivers (the Waikato and Clutha), with 136,991 and 133,276 SDUs, respectively.

Although this set-up provided for problems that could be solved in an acceptable time frame (about 5–14 h for the presented scenarios), it also created a caveat for regions that comprised more than one estuary. The objective of maximising revenue applied to the whole optimisation region rather than individual estuaries, which led to trade-offs between revenue maximisation and N reduction across estuary catchments. However, individual contaminant reduction targets had to be satisfied by each individual sea-draining catchment.

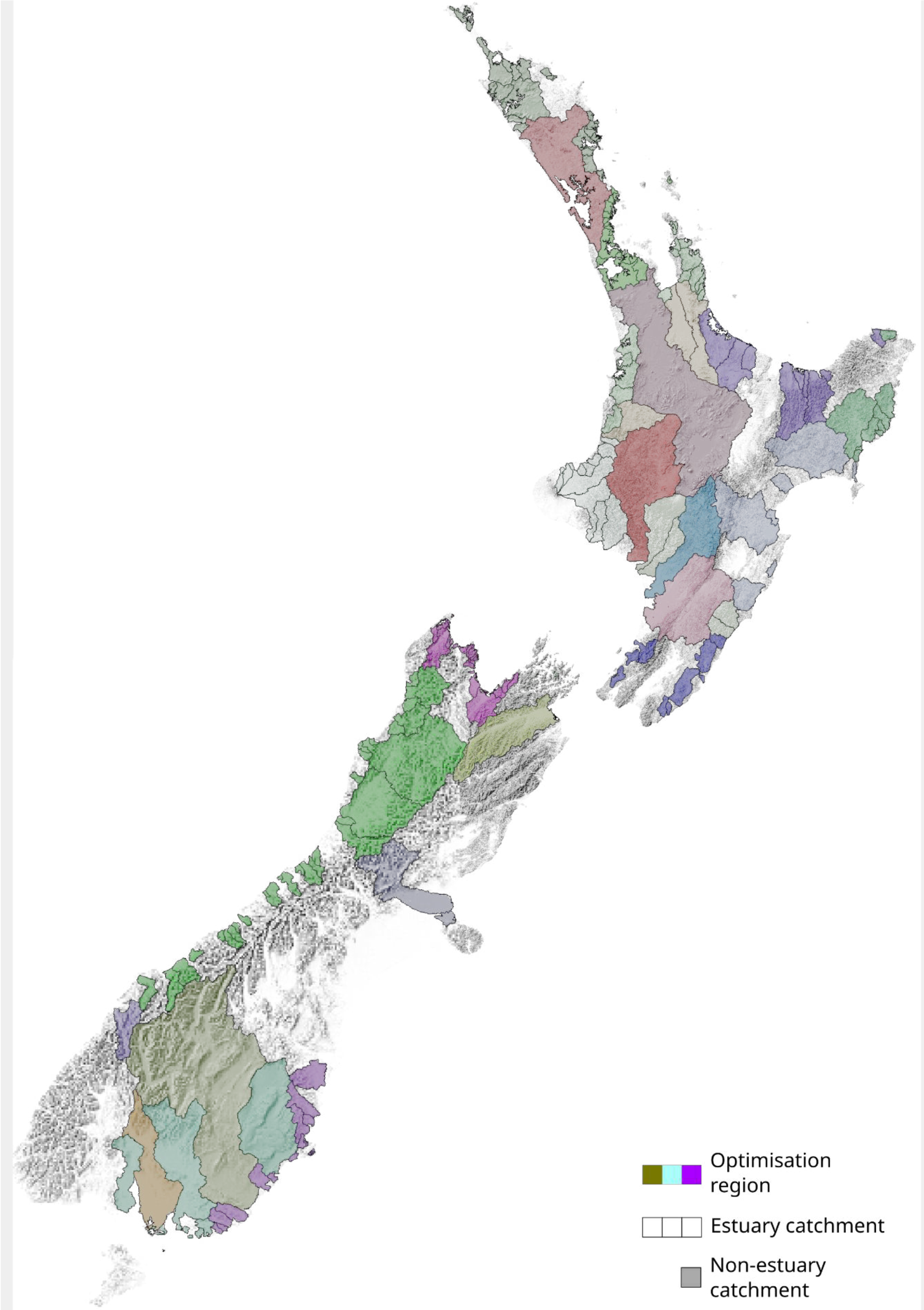


Figure 3. Grouping of 210 estuaries into 24 optimisation regions.

3.3 Impact of contaminant load changes on estuaries

Analyses done by the Sustainable Seas companion project (Lohrer et al. 2023) related disaggregated annual average freshwater contaminant loads (see Appendix 7) and monthly data on sediment mud, organic matter, and chlorophyll α content (predictor variables) to monthly data on macrofaunal abundance, taxonomic richness, H' diversity, and *Austrovenus stutchburyi, Macomona liliana,* and *Heteromastus filiformis* abundance (response variables) for three sites in each of six estuaries in the Auckland and Waikato regions. They calculated a distance-weighted exposure metric that used daily contaminant loads delivered by individual terminal river reaches and the distances along tidal channels from each site to each reach. Using multivariate generalised linear models (GLMs), Lohrer et al. (2023) tested whether the observed variation in macrofaunal characteristics (response variables) could be explained by the variation of the predictor variables.

Because the results from Lohrer et al. (2023) did not allow us to link our land-use scenario modelling to individual case-study estuaries and specific impacts on estuarine ecological health, we employed the Estuary Trophic Index tool (ETI, Zeldis et al. 2017; Plew et al. 2020) to assess the potential change in susceptibility to eutrophication as a response to our modelled scenarios for all estuaries. The ETI was developed to provide a nationally consistent approach to assess the eutrophication of estuaries and the effect of nutrient load changes on the trophic state of estuaries (Plew et al. 2018). In a recent study, Snelder et al. (2023) used ETI and associated thresholds (Table 4) in lieu of national bottom lines for estuaries.

The ETI tool utilises estuary typology (Plew et al. 2018; Robertson et al. 2016), empirical data on macroalgae occurrence in estuaries (Robertson et al. 2016; Zeldis et al. 2017), and an analytical model for estimating phytoplankton biomass (Plew et al. 2022) to assess the impact of nutrient concentrations on the ecological state of estuaries (Table 4). Potential concentrations of TN, nitrate (NO_3), TP, and dissolved reactive phosphorous (DRP), as well as flushing times of estuaries, are estimated using a simple dilution model (Plew et al. 2018).

Based on the proportion of the intertidal area of an estuary, primary symptoms for eutrophication based on individual susceptibilities to macroalgae and phytoplankton blooms are balanced to determine an overall susceptibility to eutrophication. For estuaries with greater than 40% intertidal areas, the overall susceptibility is based on the susceptibility to macroalgae, whereas for estuaries with less than 5% intertidal area it is based on susceptibility to phytoplankton. The overall susceptibility to eutrophication for estuaries with intertidal areas between 5% and 40% is based on the worst overall susceptibility.

Table 4. Macroalgae susceptibility to potential total nitrogen (TN) concentrations based on annual loads and annual mean flow (Plew et al. 2020)

Macroalgae susceptibility	**A**	**B**	**C**	**D**
Eutrophication level	Minimal	Moderate	High	Very high
Potential TN concentration (mg/m^3)	TN ≤ 250	250 < TN ≤ 450	450 < TN ≤ 650	TN > 650
Expected ecological state	Ecological communities (e.g. birds, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover is <5%, and there is low biomass of opportunistic macroalgal blooms, and no growth of algae in the underlying sediment. Sediment quality is high.	Ecological communities (e.g. birds, fish, seagrass, and macroinvertebrates) are slightly affected by additional macroalgal growth arising from elevated nutrient levels. There is limited macroalgal cover (5–20%) and low biomass of opportunistic macroalgal blooms, and no growth of algae in the underlying sediment. Sediment quality is transitional.	Ecological communities (e.g. birds, fish, seagrass, and macroinvertebrates) are moderately to strongly affected by macroalgae. There is persistent, high % macroalgal cover (25–50%) and/or biomass, often with entrainment in sediment. Sediment quality is degraded.	Ecological communities (e.g. birds, fish, seagrass, and macroinvertebrates) are strongly affected by macroalgae. There is persistent, very high % macroalgal cover (> 75%) and/or biomass, with entrainment in sediment. Sediment quality is degraded with sulphidic conditions near the sediment surface.

Note: Updated TN band thresholds are based on Whitehead & Dudley 2023.

3.4 Impact of contaminant load changes on NPS-FM

To assess the impact of contaminant load changes on achieving NPS-FM bottom lines for TN, TP, and SS, we utilised a national-scale analysis of TN, TP, and SS loads in New Zealand rivers and their comparison to national bottom lines by Snelder et al. (2021). The authors define, for each contaminant, critical points (Snelder et al. 2020) along the river network that identify receiving environments not achieving NPS-FM bottom-line limits. At a critical point, the current contaminant load delivered to that point from the upstream catchment exceeds the maximum allowable load for maintaining a bottom-line state of ecological health (Snelder et al. 2020). The ratio of contaminant load over the maximum allowable load is the load compliance ratio.

We integrated the information provided on critical-point catchments and their load compliance ratio (Snelder et al. 2021) into our spatial data set for land-use scenario modelling. Based on contaminant loads calculated for our baseline land-use scenario and the compliance ratio for each critical point from Snelder et al. 2021, we calculated a maximum allowable load related to our baseline loads delivered to each critical point. For each of our land-use scenarios, we then compared our maximum allowable load to the scenario load delivered to the corresponding critical-point to determine whether the given scenario achieved the NPS-FM bottom line for the given contaminant and critical-point catchment. To indicate NPS-FM compliance of estuary catchments for a given contaminant, we simply counted the number of all critical-point catchments defined for the given contaminant across all sea-draining catchments draining into a given estuary. And for each land-use scenario, we counted the number of critical-point catchments that achieve the NPS-FM bottom line for the given contaminant in an estuary's catchments.

4 Results

4.1 General observations and processes

Contaminant loads to estuaries are controlled by environmental factors such as rainfall, soil, and slope, but are dominated by the intensity of land use. Here 'intensity' refers to the level of inputs to the land (e.g. fertiliser, herbicides, and pesticides, but also animal urine and dung). In the context of soil erosion, 'intensity' also refers to the clearance of natural woody vegetation. High-intensity land uses considered in this study are dairy, arable, and horticulture. Less-intensive land uses are sheep & beef farming and exotic forestry. (Natural vegetation is non-intensive.)

In general, the higher the land-use intensity, the more contaminants are released from the land into the environment and reach the waterways; and the greater the area of land that is used with high intensity, the more contaminants reach the waterways. This process is moderated by the environment's spatially variable characteristics (e.g. rainfall, soil, and slope). For example, the higher the rainfall, the steeper the slope, the less woody vegetation cover, the more erodible the soil, and the shorter the distance to the next water body, the more sediment ends up in waterways. Also, the lighter the soil, the higher the rainfall, and the higher the nutrient input, the higher the nutrient concentration in the groundwater. Depending on the geology (minerology) of the subsurface, the nutrient concentration in the groundwater may be attenuated before reaching the next waterway.

4.1.1 Mitigation scenarios

The potential for reducing nutrient losses from the land depends on the available mitigation options (i.e. technologies or land-management practices that help reduce the loss of N or P from the land and the amounts reaching the waterways). In the context of the mitigation options for dairy and sheep & beef farm systems considered in this study (McDowell et al. 2020; Monaghan, Manderson, Basher, Burger et al. 2021; Monaghan, Manderson, Basher, Spiekermann et al. 2021), current and future available mitigation options for dairy systems are in general more effective than mitigation options for sheep & beef. Therefore, the potential to reduce the proportion of nutrients being released into the environment is in general higher for dairy than for sheep & beef land. And because dairy generally produces significantly higher absolute losses of N and P than sheep & beef, dairy's high relative nutrient-loss reduction potential also translates into a high absolute nutrient-loss reduction potential. However, the effectiveness of mitigation options also varies considerably among different dairy and sheep & beef farm types.

So, the reduction potential for nutrient losses depends on:

- the proportion of dairy to sheep & beef land
- the proportions of different types of dairy and sheep & beef farming systems and the effectiveness of their associated mitigation options to reduce nutrient losses.

Sediment losses to waterways can be minimised by a wide variety of practices, depending on land use, erosion type, and erosion process (Drewry et al. 2022). However, in this national-scale study we focused on widely applied mitigations for preventing soil erosion in New Zealand. In hill country we focused on whole-farm plans and conversion to exotic forestry or natural vegetation, with an assumed effectiveness of 70% (Dymond et al. 2010, 2016), 80% (Vale et al. 2021), and 90% (Dymond et al. 2010, 2016), respectively. In lowlands we focused on mitigating bank erosion, surficial erosion, and sediment runoff through fencing and riparian planting, with an assumed combined effectiveness of 80% (adapted from Neverman & Smith 2022). Because slope and rainfall are significant drivers of soil erosion, by far the highest sediment yields (i.e. soil loss per unit area) are observed from hill-country and steep terrains, depending on the respective rock type. Therefore, the highest absolute sediment load reduction potentials in response to the implementation of sediment mitigation measures are observed in areas with large proportions of (soft-rock) hill country and steep terrains.

4.1.2 Land-use change scenarios

In addition to modelling the adoption of current or current & future available mitigation options by dairy and sheep & beef farms, the land-use change scenarios enable the modelling of conversion of agricultural land to exotic forestry or natural vegetation (the most benign land-use option for contaminant losses to waterways). As outlined in section 3.2.3, each scenario forces the total N load delivered to estuaries to be reduced by a set percentage. Although the implementation of mitigation measures affects farm revenue, the objective in each scenario is to maximise revenue. This means the observed patterns of land-use change (Figures 14 and A2.1–A2.4) across the modelled scenarios (Table 3) are driven by cost-effectiveness (i.e. revenue increase is traded off with N reduction). Because the scenarios are driven by the N reduction targets and the N mitigation measures do not reflect any effects of climate change, the resulting land-use patterns are identical for mid- and end of century times. However, the climate effect is reflected in the sediment response.

The following general patterns can be observed across the different land-use change scenarios. Please note that for small catchments the following generalised observations may not be applicable, because land-use trade-offs across catchments of estuaries might have occurred for estuaries in the same optimisation region (Figure 3) (see section 3.2.3).

- The proportion of dairy and sheep & beef land adopting all current (dairy) or all current & future available mitigation options (dairy and sheep & beef) increases depending on the overall land-use distribution in the estuary catchments. The lower the individual proportion of dairy or sheep & beef land, the higher the proportion of dairy or sheep & beef land adopting mitigation measures.
- Forestry might be traded off for keeping sheep & beef land or vice versa, depending on which is more profitable in a given region.
- Total horticulture and dairy land areas in catchments of estuaries remain largely unchanged in the 20%, 40%, and 60% reduction scenarios due to their high profitability.
- Arable is largely maintained with little change in the 20% and 40% reduction scenarios, but is often significantly reduced or traded off in the 60% and 80% reduction scenarios.
- Catchments of estuaries with a large proportion of agricultural land, especially those with a relatively large proportion of dairy, can achieve reduction targets of up to 60% without significant land-use change.
- Achieving the 80% N reduction target relies, in many cases, on significant land retirement (i.e. conversion to natural vegetation).

4.1.3 Impact of contaminant load changes on estuaries

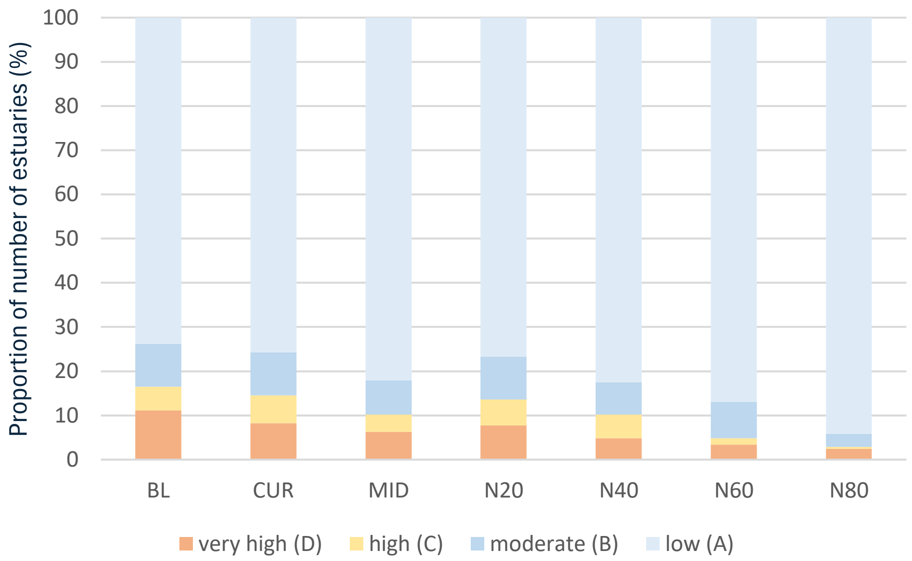


Figure 4. Proportion of New Zealand estuaries per eutrophication susceptibility band according to the ETI tool (Zeldis et al. 2017; Plew et al. 2020) for modelled land-use scenarios (cf. section 3.2 and Table A3.1).

Notes: BL: baseline; CUR: current mitigation options; MID: current and future available mitigation options; N20, N40, N60, N80: land-use change scenarios with 20%, 40%, 60%, 80% N reduction targets.

The N-driven eutrophication susceptibility of New Zealand's estuaries across modelled mitigation and land-use change scenarios is summarised in Figure 4. About a quarter of all estuaries, receiving freshwater and contaminant inputs from about 40% of the total New Zealand estuary catchments' area, show moderate to very high eutrophication susceptibility. Almost 10% of the estuaries, receiving freshwater and contaminant inputs from about 25% of the total New Zealand estuary catchments' area, show very high eutrophication susceptibility. The effect of implementing N mitigation measures for pastoral agriculture increases for higher reduction targets. Implementing all current and future available mitigation measures across all dairy and sheep & beef land (MID) in estuaries with very high eutrophication susceptibility halves the proportion of these estuaries. Combined mitigations and land-use change (N40, N60, N80) significantly reduce the proportion of estuaries that are moderate to very highly susceptible to eutrophication.

4.1.4 Impact of contaminant load changes on NPS-FM

- About 60%, 70%, and 55% of New Zealand estuary catchments contain one or more catchments that do not meet the NPS-FM bottom line standard for TN, TP, and SS (critical catchments), respectively (Table 6).
- Reducing the N load of estuary catchments by 60% would see more than 90% of critical catchments achieve the national bottom line for TN in more than 80% of estuary catchments containing critical N catchments.
- Implementing current and future available P and typical sediment mitigation measures alongside N mitigation measures targeting a 60% N reduction would see

more than 90% of critical catchments achieve the national bottom line for TP and SS in about 40% and 80% of estuary catchments containing critical P and sediment catchments, respectively.

- Implementing current and future available P mitigation measures alongside N mitigation measures targeting an 80% N reduction would result in more than 90% of critical P catchments achieve the national bottom line in more than 50% of estuary catchments containing critical P catchments.

4.2 Mitigation scenarios

This section presents the potential effect of hypothetical mitigation scenarios (Table 2) applying available current (Nc, Pc, Sc) and current and future available mitigation options across all dairy and sheep & beef land within estuary catchments at mid-century (Nm, Pm, Sm) and end of century (Se) (Figures 5 and 8). Because these scenarios assume a blanket adoption of available mitigations at the given time, they represent the maximum possible contaminant reduction that could be achieved without changing pastoral farming to forestry or retiring the land altogether (i.e. converting to natural vegetation).

4.2.1 Nutrients

Current available mitigation options for reducing N loss on sheep & beef land show overall low effectiveness (<10% potential reduction) compared to current available

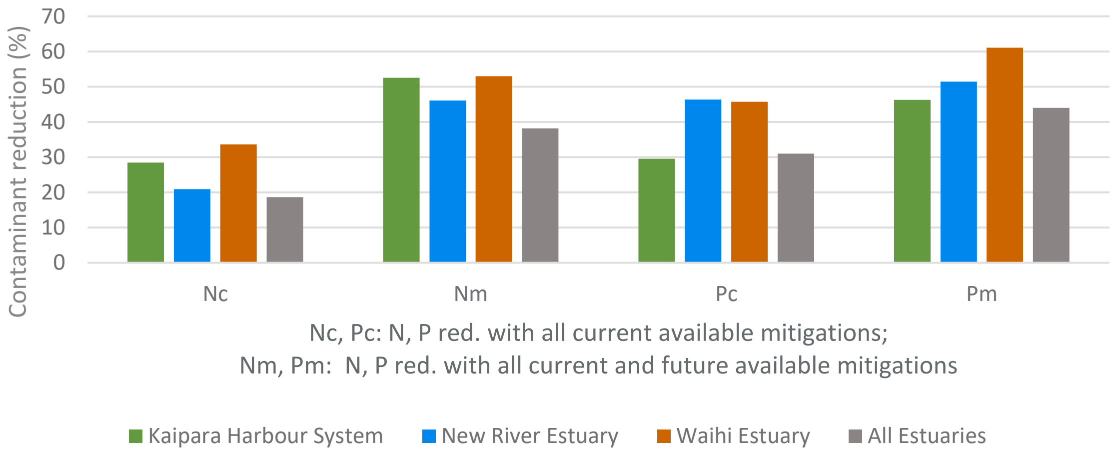


Figure 5. Potential relative reduction of contaminant loads delivered to case study and all estuaries through the implementation of all current available (c) (current scenario, Table 2) and all current and future available mitigation options (m) (mid-century scenario, Table 2) for nitrogen (N) and phosphorus (P), respectively.

N mitigation options for dairy land. Hence, relative N reduction in the current scenario is driven by the proportion of dairy relative to sheep & beef land within a given catchment. Consequently, for the case-study estuaries (Figure 5), Waihi shows the highest relative reduction potential (c. 34%, Figure 6), with 52% of agricultural or forestry land used for dairy farming. Kaipara Harbour and New River show somewhat lower relative reduction potentials of 28% and 21% (Figure 6), with 37% and 33% of agricultural or forest land used for dairy farming, respectively.

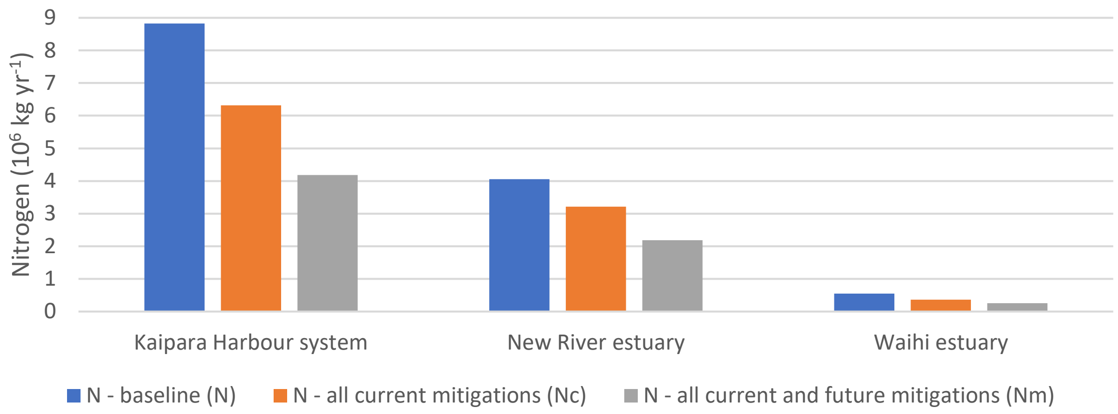
In the mid-century scenario the differences in relative reductions between case-study estuaries are smaller because future N mitigation options for sheep & beef land are more effective (c. 20% potential reduction on average). Therefore, catchments with a relatively large proportion of sheep & beef land (e.g. New River estuary, where 66% of agricultural or forest land is used for sheep & beef) reduce the effect of overall more effective (c. 60% potential reduction on average) future N mitigation options for dairy land. However, the relative contribution to contaminant losses and reduction potential varies among the individual live-stock farming types. For example, among the sheep & beef systems in the Kaipara Harbour estuary's catchments, about 40% are made up of intensive finishing sheep & beef land that contributes almost 50% of the N loss from sheep & beef land and about 20% to the total loss. At the same time, they show a relatively high N reduction potential of >50%. This results in a total relative N-loss reduction potential that matches that of the Waihi estuary in the mid-century scenario.

Since in all three case-study estuaries more than 50% of the land is used for pastoral farming and 20 to 30% for dairy farming, the absolute loss of nutrients (Figures 6 and 7) is controlled by the total size of the estuary catchments. Hence, the Kaipara Harbour system shows by far the overall highest nutrient loads across all mitigation scenarios, followed by New River estuary and Waihi estuary.

Relative reduction potentials for P in the current scenario show a slightly different pattern. Waihi and New River have an equally high reduction potential of about 46% (Figure 7), whereas the 30% reduction potential for Kaipara Harbour about matches the average reduction potential (Figure 7) for all estuary catchments. The relative difference between Kaipara Harbour on the one hand and New River and Waihi estuaries on the other can be attributed to different proportions of dairy systems that provide very effective P mitigation options. About 18% and 14% of New River and Waihi estuary catchments' agricultural and forest land is used by dairy farm systems that exhibit high effectiveness in applying farm dairy effluent to the land, which results in substantial reductions of P losses. Only 3% of the agricultural and forest land in the Kaipara Harbour system's catchments is used by dairy systems that show a similar effectiveness of farm dairy effluent application to land, while the remaining dairy systems show a significantly lower P reduction potential.

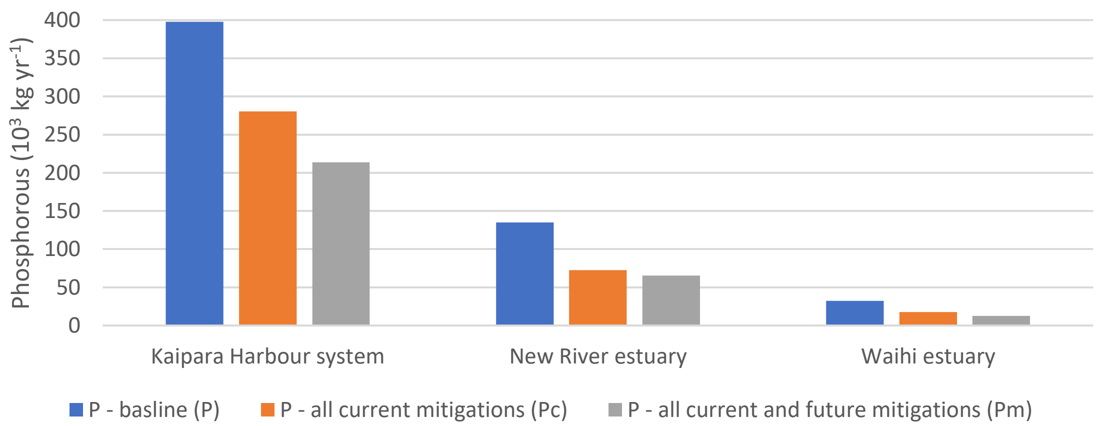
The potential relative P reductions in the mid-century scenario (Figure 5) reflect the relative difference of the combined effectiveness of all current and future available P mitigation options for the dairy farming systems in the case study estuary catchments. The slightly higher proportion of dairy farming in the Waihi estuary catchments compared to the other case study estuary catchments further adds to this trend. The smaller difference in potential P reduction between Kaipara Harbour and New River is a result of the greater overall P reduction potential on sheep & beef land in Kaipara compared to New River, even though the proportion of sheep & beef land in Kaipara is slightly smaller than in New River.

Analogous to the N losses, absolute P losses are driven by the total size of estuary catchments. As a result, total P loads are by far the highest for the Kaipara Harbour system (Figure 7), followed by New River estuary and Waihi estuary.



	N (kg yr^{-1})	Nc (kg yr^{-1})	Nm (kg yr^{-1})	Nc reduction (%)	Nm reduction (%)
Kaipara Harbour system	8,823,717	6,315,855	4,187,108	28	53
New River estuary	4,057,181	3,210,359	2,186,896	21	46
Waihi estuary	549,644	364,955	258,187	34	53
All estuaries	107,725,235	87,627,602	66,578,885	19	38

Figure 6. Nitrogen loss in case-study estuaries for baseline (N, current), all current available mitigation options (Nc, current with mitigation), and all current and future available mitigation options (Nm, mid and end-of-century). Mitigation scenarios Nc and Nm show the potential reduction relative to the baseline.



	P (kg yr^{-1})	Pc (kg yr^{-1})	Pm (kg yr^{-1})	Pc reduction (%)	Pm reduction (%)
Kaipara Harbour system	397,686	280,335	213,628	30	46
New River estuary	135,088	72,469	65,613	46	51
Waihi estuary	32,474	17,625	12,622	46	61
All estuaries	6,653,431	4,588,260	3,724,634	31	44

Figure 7. Phosphorus loss in case-study estuaries for baseline (P, baseline scenario), all current available mitigation options (Pc, current scenario), and all current and future available mitigation options (Pm, mid-century scenario). Mitigation scenarios Pc and Pm show the potential reduction relative to the baseline.

4.2.2 Sediment

The modelled blanket implementation of sediment mitigation measures for the current climate (Sc) results in moderate to high relative sediment reduction potentials (Figure 8 and Appendix 6, Table A6.1). This is not surprising given the high effectiveness (≥70%) of the modelled sediment mitigation measures in conjunction with the large proportion of pastoral farmland (without woody vegetation cover) in all case-study estuary catchments.

Since all modelled future scenarios assume a blanket implementation and use the same set of available sediment mitigation measures, they clearly show the spatially variable effect of a changing climate on (mitigated) sediment generation in New Zealand. In general, all case-study estuary catchments show a drop in their sediment reduction potential through mitigations towards the end of the century with higher greenhouse gas concentrations in the atmosphere (expressed as representative concentration pathways, RCPs) (Figures 9–12). However, the Kaipara Harbour estuary catchments show the greatest response to climate change, underlined by a c. 70% increase of the mitigated sediment load above the current baseline at the end of the century for the RCP 8.5 climate scenario (Figure 9).

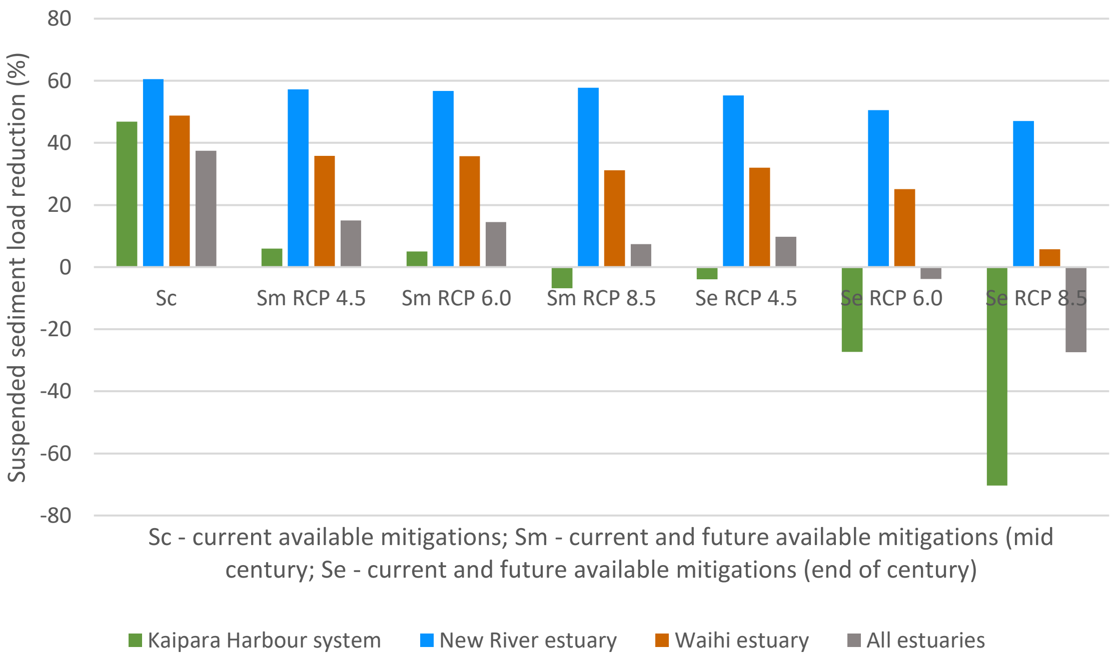
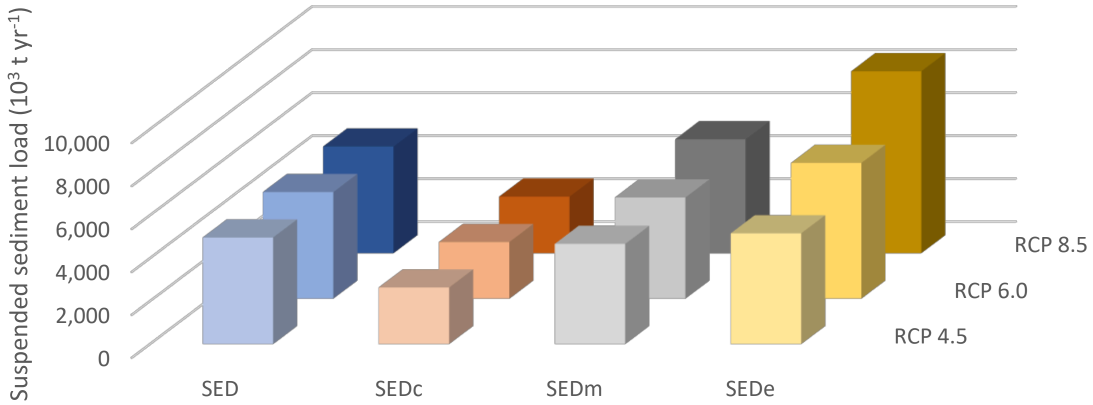


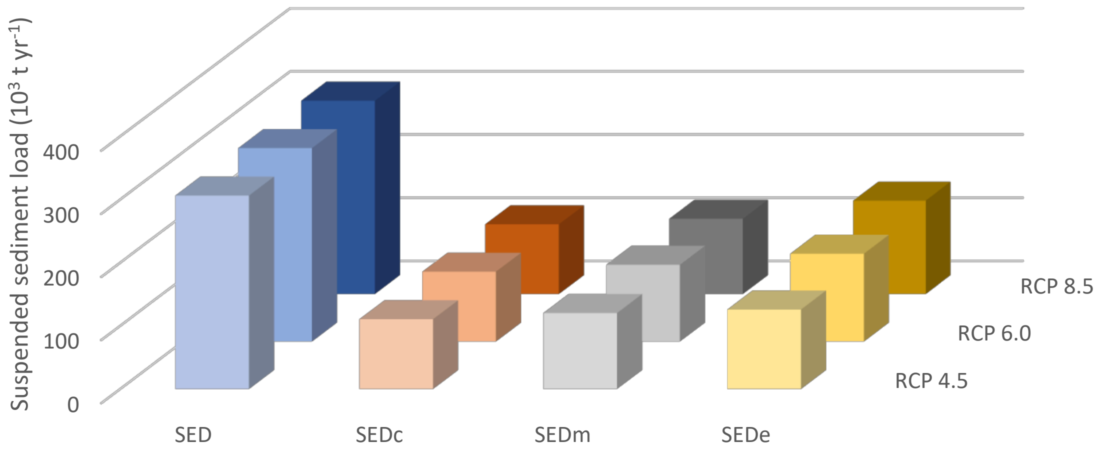
Figure 8. Potential relative reduction of suspended sediment loads delivered to case-study and all estuaries through the blanket implementation of sediment mitigation measures for current (Sc), mid-century (Sm), and end-of-century (Se) scenarios (cf. Table 2) under a changing climate.



Sediment scenarios: SED - baseline; SEDc - current available mitigations; SEDm - current and future available mitigations, mid century; SEDe - current and future available mitigations, end of century

	SED (%)	SEDc reduction (%)	SEDm reduction (%)	SEDe reduction (%)
RCP 4.5	100	47	6	-4
RCP 6.0	100	47	5	-27
RCP 8.5	100	47	-7	-70

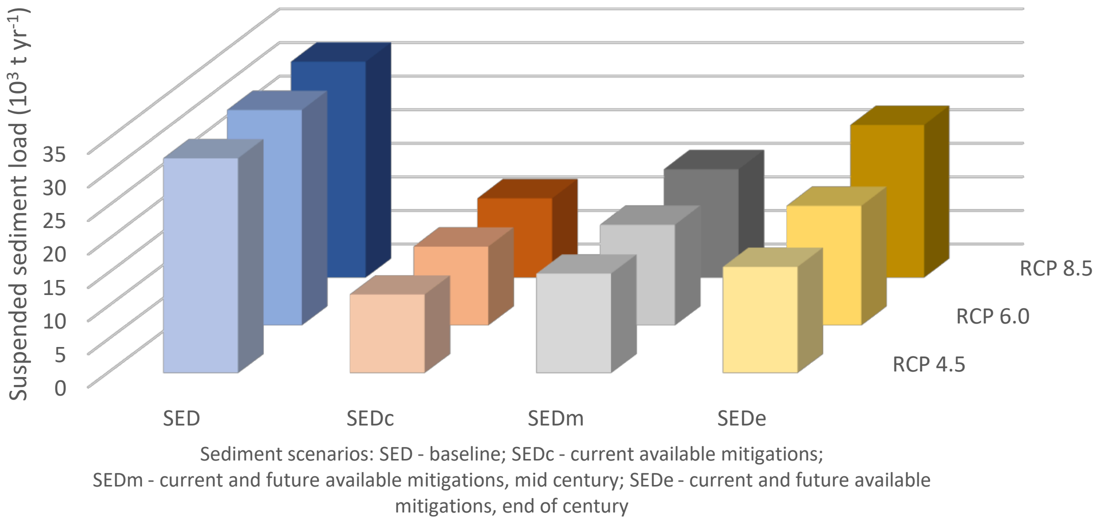
Figure 9. Impact of blanket sediment mitigation on suspended sediment loads entering the Kaipara Harbour system under different climate scenarios at mid- and end of century.



Sediment scenarios: SED - baseline; SEDc - current available mitigations; SEDm - current and future available mitigations, mid century; SEDe - current and future available mitigations, end of century

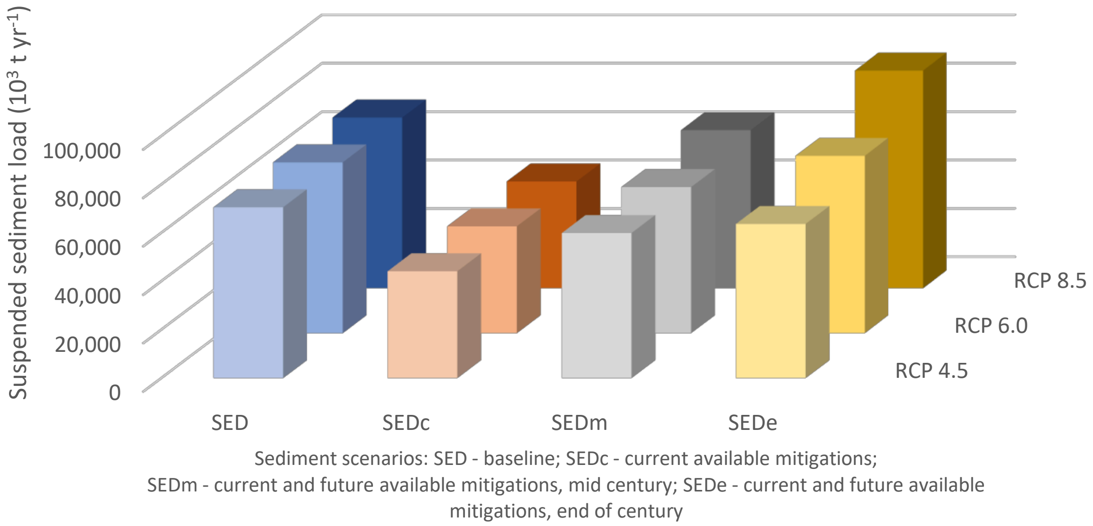
	SED (%)	SEDc reduction (%)	SEDm reduction (%)	SEDe reduction (%)
RCP 4.5	100	61	57	55
RCP 6.0	100	61	57	51
RCP 8.5	100	61	58	47

Figure 10. Impact of blanket sediment mitigation on suspended sediment loads entering New River estuary under different climate scenarios at mid- and end of century.



	SED (%)	SEDc reduction (%)	SEDm reduction (%)	SEDe reduction (%)
RCP 4.5	100	49	36	32
RCP 6.0	100	49	36	25
RCP 8.5	100	49	31	6

Figure 11. Impact of blanket sediment mitigation on suspended sediment loads entering Waihi estuary under different climate scenarios at mid- and end of century.



	SED (%)	SEDc reduction (%)	SEDm reduction (%)	SEDe reduction (%)
RCP 4.5	100	37	15	10
RCP 6.0	100	37	14	-4
RCP 8.5	100	37	7	-27

Figure 12. Impact of blanket sediment mitigation on suspended sediment loads entering New Zealand's estuaries under different climate scenarios at mid- and end of century.

4.3 Land-use change scenarios

Figure 13 shows the potential contaminant reductions that can be achieved in the case-study estuary catchments across the four land-use change scenarios (Table 3) for mid-century and RCP 4.5. Figure 14 shows the associated change of land-use distributions across the modelled scenarios.

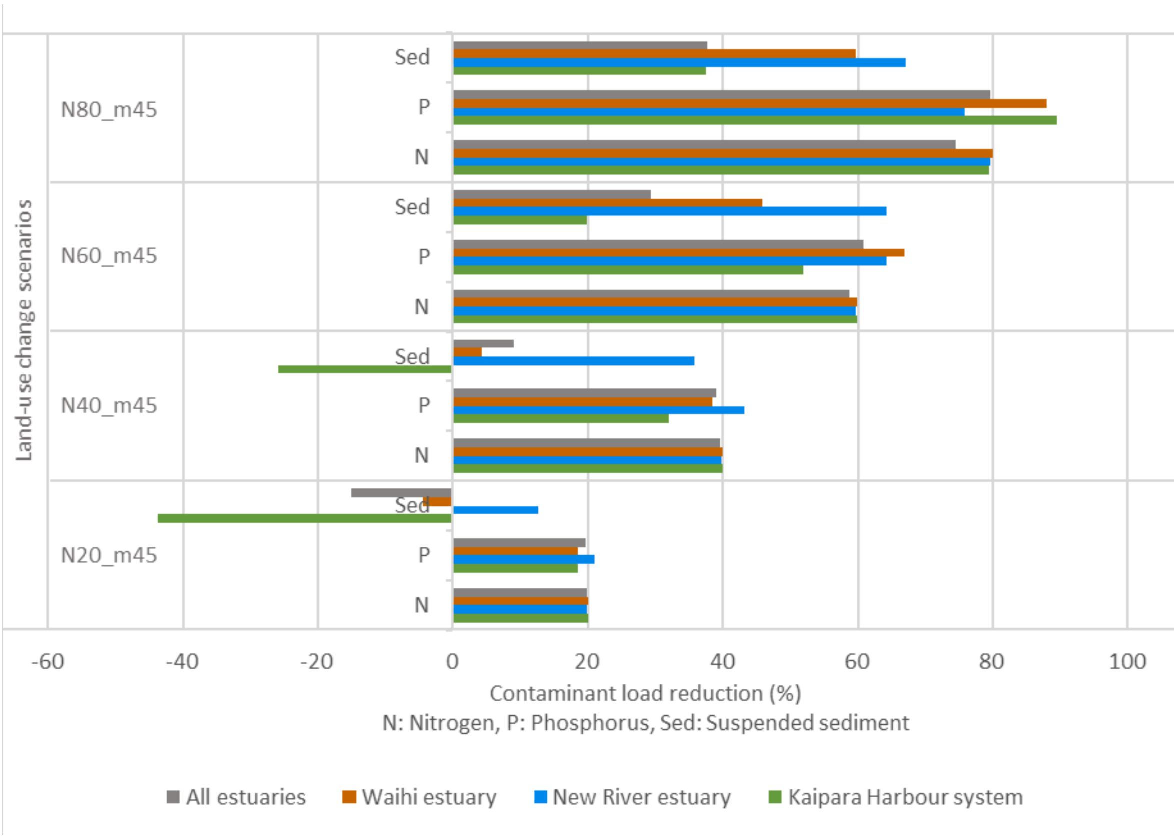


Figure 13. Contaminant (N: nitrogen, P: phosphorus, Sed: suspended sediment) load reductions for mid-century (RCP 4.5) land-use change scenarios targeting 20%, 40%, 60%, and 80% reduction of N loads in catchments draining into case-study estuaries.

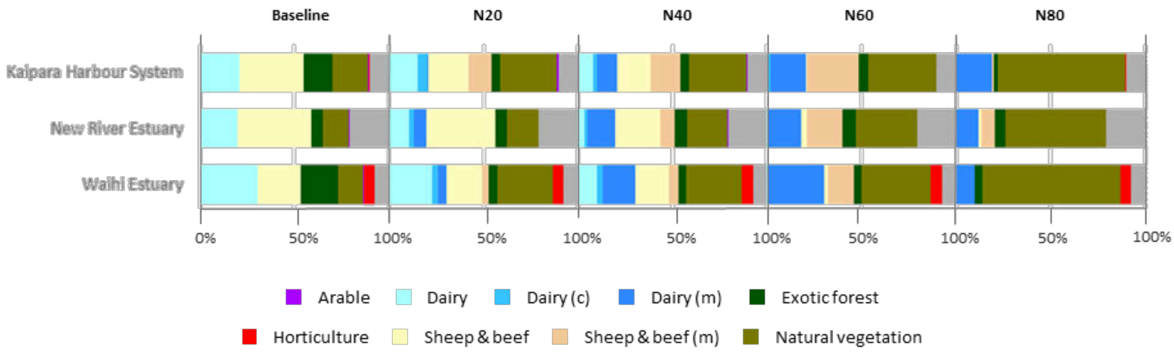


Figure 14. Effect of set contaminant reduction targets (Figure 13) on land-use proportions in the case-study estuaries when enabling adoption of all current and future available mitigation measures, plus conversion of intensive land use to exotic forest or natural vegetation while optimising for profitability.

4.3.1 Nutrients

Each of the modelled case-study catchments achieves the set N reduction targets. The associated P reductions deviate more or less from the N reductions, but also increase with higher N reduction targets. In New River and Waihi estuaries, dairy and sheep & beef land equally contribute to the absolute modelled P loss, which means the relative P reduction is driven by the proportion of dairy land adopting mitigation measures. As this proportion is slightly higher in New River than in Waihi for the 20% and 40% reduction scenarios (Figure 14), the relative reduction of P is also slightly higher in New River in those scenarios (Figure 13). In the 60% reduction scenario, all dairy and almost all sheep & beef land in New River and Waihi adopted mitigations (Figures 15 and 16). However, the slightly higher proportion of dairy land with an overall higher effectiveness of mitigation options sees Waihi with a slightly higher relative P reduction than New River. In the 80% reduction scenario in Waihi, a greater proportion of land is converted to natural vegetation than in New River, which leads to a higher relative reduction of P.

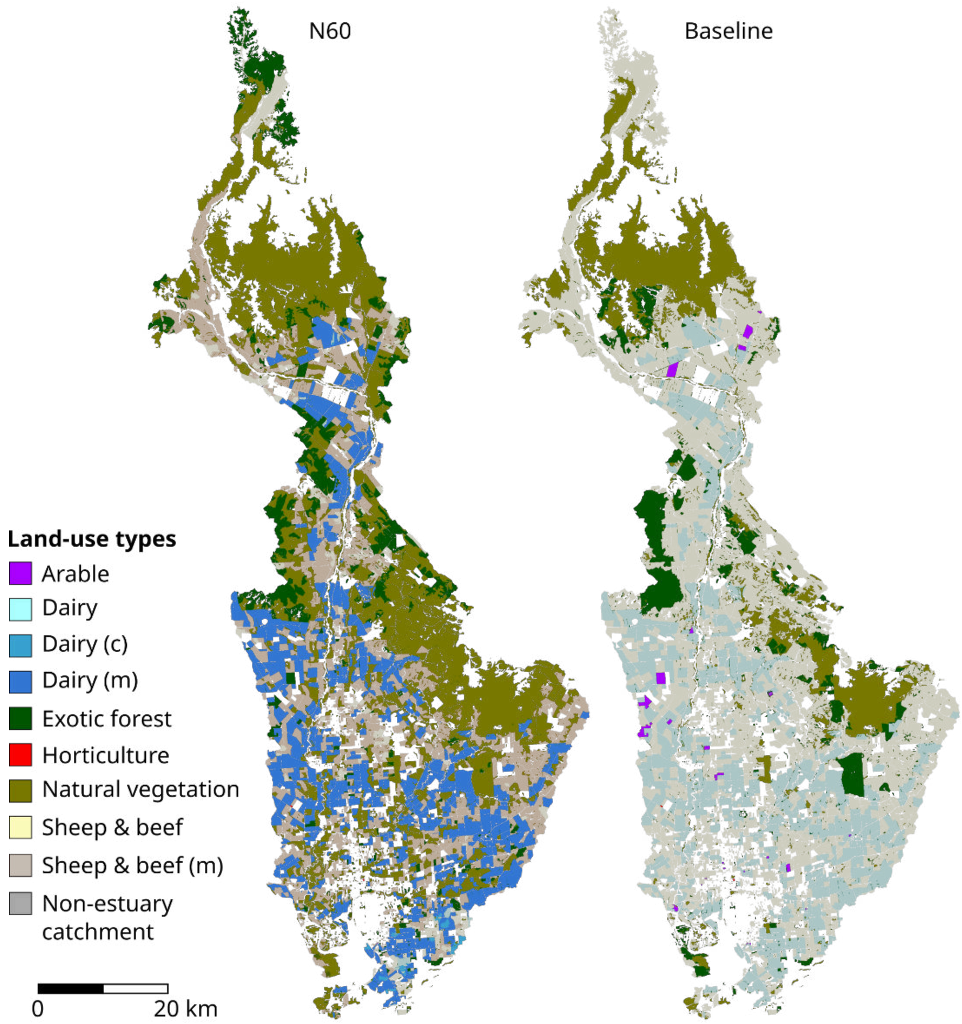


Figure 15. Comparison of baseline land use (right) and modelled land-use change in the New River estuary's catchments for the mid-century 60% nitrogen reduction target (N60, left). Land uses marked with (c) and (m) adopt all current and all current and future available mitigation options, respectively.

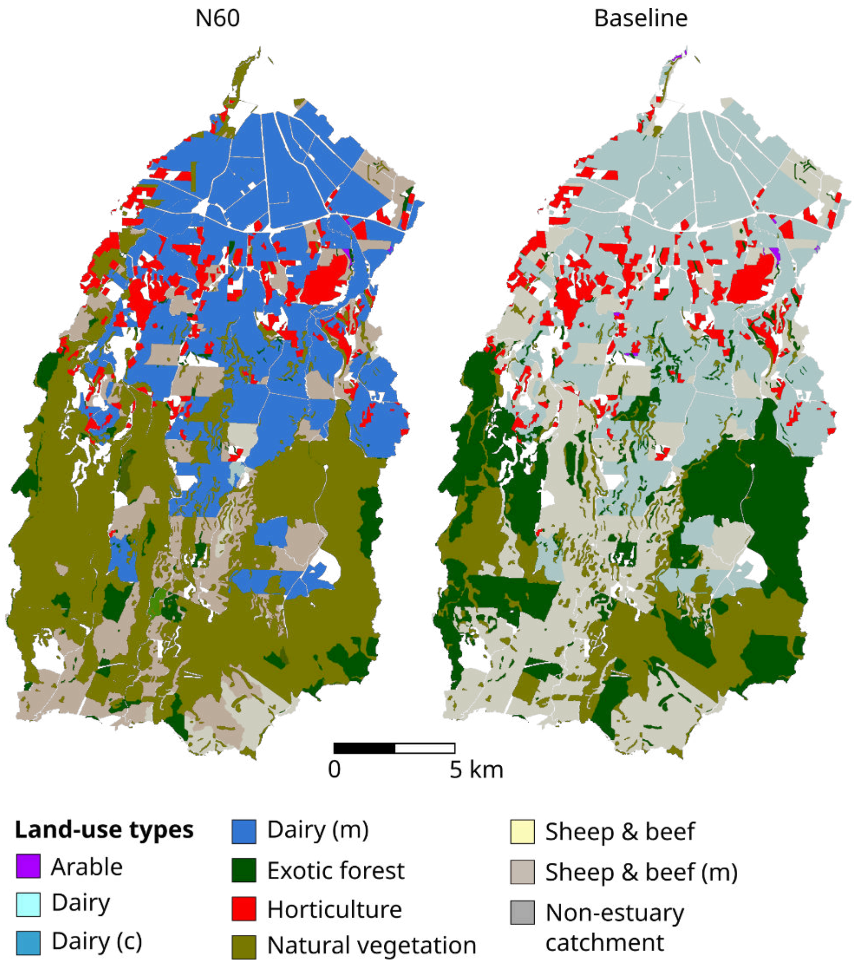


Figure 16. Comparison of baseline land use (right) and modelled land-use change in the Waihi estuary's catchments for the mid-century 60% nitrogen reduction target (N60, left). Land uses marked with (c) and (m) adopt all current and all current and future available mitigation options, respectively.

In contrast to the other two case-study estuaries, in Kaipara (Figure 17) about 72% of the total P loss is generated on sheep & beef land and only 25% on dairy land. Therefore, in the 20%, 40%, and 60% reduction scenarios the adoption of mitigation measures on equal or smaller proportions of dairy and sheep & beef land (Figure 14) leads to an overall smaller relative P reduction compared to New River and Waihi (Figure 13). However, the conversion of the largest proportion (Figure 14) of agricultural land to natural vegetation in the 80% scenarios yields the greatest relative reduction of P among the three case-study estuaries (Figure 13).

4.3.2 Sediment

The spatially variable effect of sediment generation and the impact of climate change on it becomes clearly visible in the modelled sediment reductions across the case study estuary catchments for the mid-century scenario and RCP 4.5 (Figure 13). In the Kaipara Harbour and Waihi estuary catchments around c. 70% of the total sediment is generated in soft-rock hill country, and it is in this terrain where sediment yields are predicted to increase the most with a changing climate (Neverman et al. 2023).

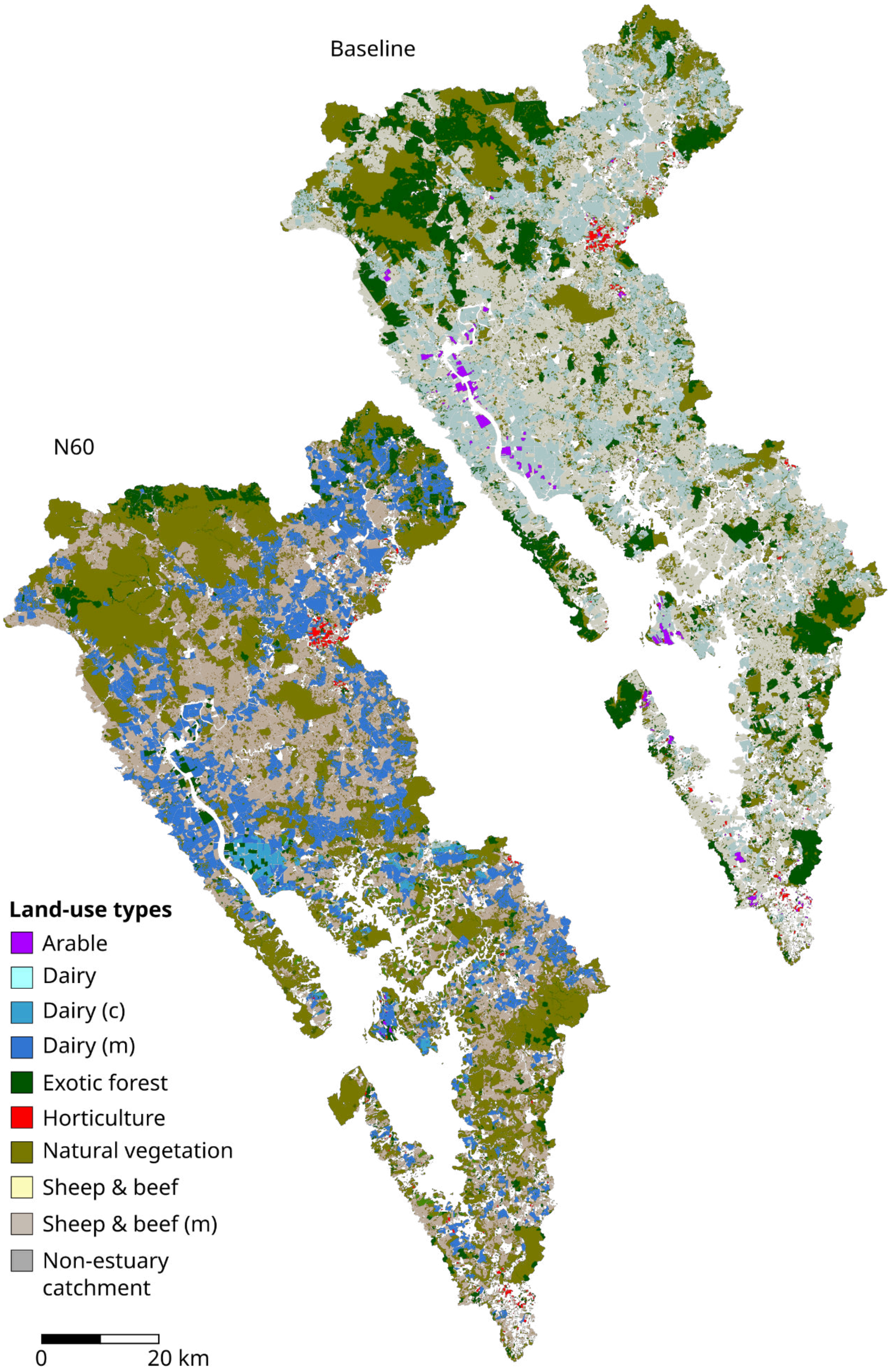


Figure 17. Comparison of baseline land use (right) and modelled land-use change in the Kaipara Harbour estuary's catchments for the mid-century 60% nitrogen reduction target (N60, left). Land uses marked with (c) and (m) adopt all current and all current and future available mitigation options, respectively.

Therefore, the small proportions of sheep & beef land being mitigated in the 20% scenario (Figure 14) result in a net increase in sediment loss in the Kaipara and in the Waihi estuary catchments compared to baseline. A small increase in the proportion of mitigated sheep & beef land and a larger increase in the proportion of mitigated dairy land in the 40% reduction scenario yields a small net reduction in sediment loss in the Waihi estuary catchment. However, while the overall proportion of mitigated dairy and sheep & beef land increases slightly in the Kaipara Harbour estuary catchments, the associated mitigation effect cannot compensate for the increase in sediment generation through climate change (Figure 13).

The relatively small impact of climate change on sediment yield in low-land areas in the South Island (Neverman et al. 2023) results in a relative reduction in sediment loss over baseline through fencing and riparian planting on a small proportion of dairy land. This proportion increases in the 40% reduction scenario, in addition to whole-farm plan implementation on sheep & beef land (Figure 14), so the relative reduction over baseline increases significantly (Figure 13) compared to the 20% reduction scenario.

Only in the 60% reduction scenario, which sees almost all pastoral farming land in the Kaipara Harbour (Figures 14 and 17) and Waihi estuary catchments (Figures 14 and 16) implementing mitigations, did the model estimate a net reduction in sediment load compared to the baseline. As all sheep & beef land, and thus soft-rock hill country, is being retired in the Kaipara Harbour and Waihi estuary catchments (Figure 14), the model registered with 37% and 60% the overall highest relative reductions in sediment load in these catchments in the 80% reduction scenario (Figure 13). With almost all pastoral farming land being mitigated and parts of it being retired (Figure 14), New River estuary catchments reduce net erosion over baseline by c. 67% (Figure 13) in the 80% reduction scenario.

Modelled absolute sediment loads for the case-study estuaries across all land-use change scenarios and under climate change for mid- and end of century show the same general pattern (Figures 18–20). Sediment loads decrease with higher N reduction targets as more pastoral farming land adopts mitigation measures or is converted to either exotic forestry or natural vegetation. Sediment loads increase towards the end of the century with higher greenhouse gas concentrations in the atmosphere. However, relative differences show between (i) different reduction scenarios for a given RCP, (ii) different RCPs for a given reduction scenario, and (iii) the baseline and a given reduction scenario for a given RCP.

Appendix 6, Tables A6.2 and A6.3, present a complete list of modelled baseline suspended sediment loads for all modelled estuary catchments and their associated reduction potentials in percent for all land-use change scenarios.

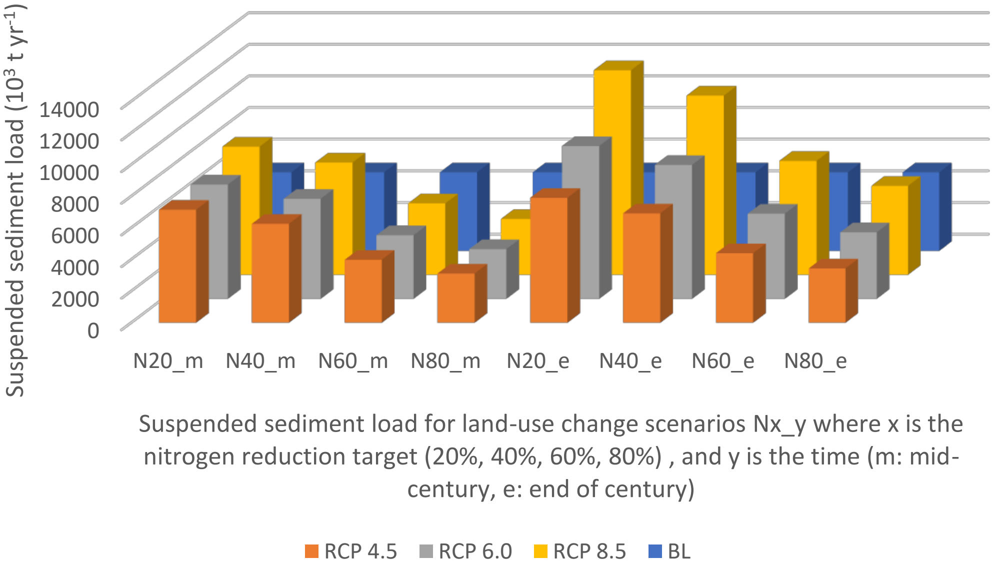


Figure 18. Absolute suspended sediment loads entering the Kaipara Harbour system for different land-use change scenarios under climate change at mid- and end of century.

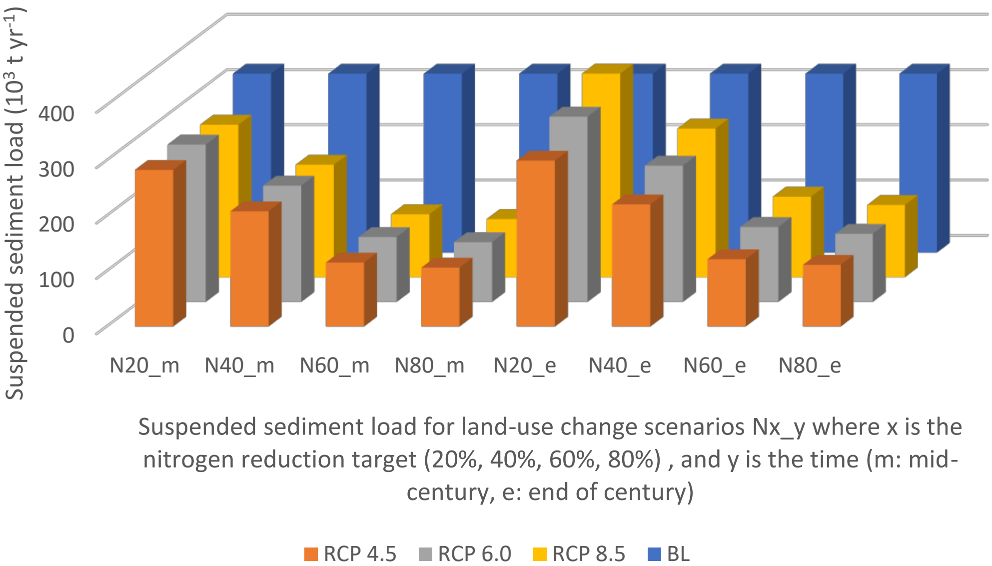


Figure 19. Absolute suspended sediment loads entering New River estuary for different land-use change scenarios under climate change at mid- and end of century.

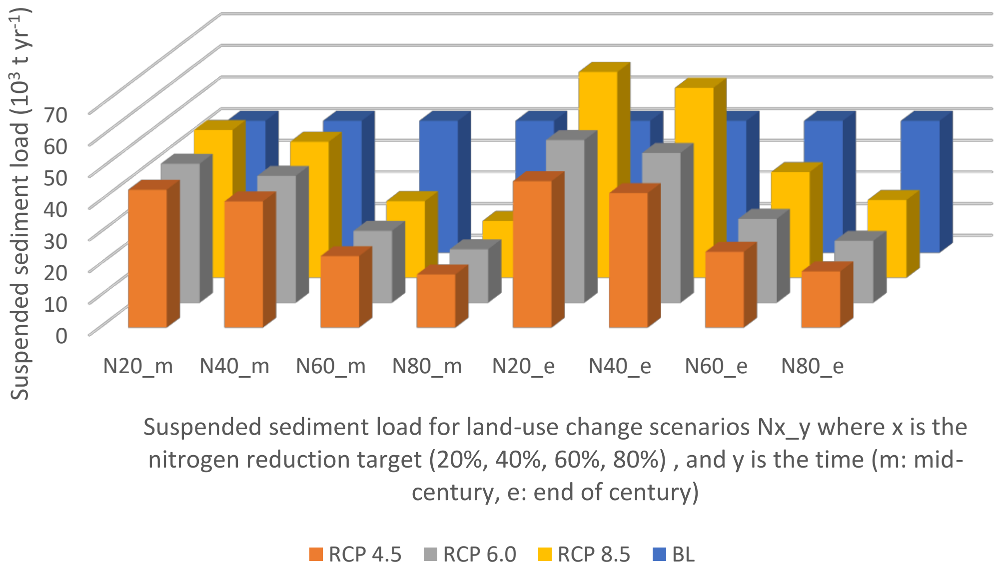


Figure 20. Absolute suspended sediment loads entering Waihi estuary for different land-use change scenarios under climate change at mid- and end of century.

4.4 Impact of contaminant load changes on estuaries

Lohrer et al. (2023) tested whether the variation of macrofaunal characteristics (response variables), i.e. abundance, taxonomic richness, H′ diversity, and *Austrovenus stutchburyi, Macomona liliana,* and *Heteromastus filiformis* abundance, at three sites in each of six estuaries in the Auckland and Waikato regions could be explained by the variation of freshwater contaminant loads and data on sediment mud, organic matter, and chlorophyll α content (predictor variables) (section 3.4). They found that:

- mud was a significant predictor variable of total abundance of macrofauna at almost all sites in Kaipara and Mahurangi Harbours
- the 6- and 12-month averages of TN preceding a monthly macrofauna sample were also significantly correlated with total macrofauna abundance at one or more sites in almost every estuary
- sediment and freshwater predictor variables were also significantly correlated with taxonomic richness in at least one case
- the 12-month average of suspended sediment preceding a monthly macrofauna sample was the most commonly significant predictor for taxonomic richness across all sampled sites and estuaries
- however, the 12-month averages of TN and TP preceding a macrofauna sample were also significant predictors of taxonomic richness at one or more sites in all estuaries.

In general, the analyses of Lohrer et al. (2023) showed that relationships between predictor variables and macrofauna characteristics were very context specific, and that the statistical models showed variable positively and negatively correlated relationships. Also, macrofauna responses to freshwater were often delayed and inconsistent, even across sites within an estuary, and occasionally the direction of the modelled relationships was contrary to published data. Therefore, specific contaminant load targets could not be derived.

To assess the potential impact of estuaries to nutrient reduction scenarios (section 3.2) we used the Estuary Trophic Index Tool (ETI, Zeldis et al. 2017; Plew et al. 2020) (section 3.3). Table 5 shows the change in estimated eutrophication susceptibility for the case-study estuaries across the modelled land-use scenarios.

The results (Table 5) indicate that the Kaipara Harbour system is not susceptible to eutrophication in any of the modelled scenarios of nutrient loads entering the estuary. In contrast, New River and Waihi estuaries are at high risk of eutrophication in the baseline scenario. The implementation of all current and future available mitigation measures could reduce the estuary eutrophication susceptibility to moderate. Minimal eutrophication susceptibility in both estuaries could only be achieved through the implementation of mitigations and land-use change indicated in the N60_m45 and N80_m45 scenarios.

Table 5. Impact of baseline (BL) nutrient load and nutrient load changes for mitigation (CUR: current, MID: mid-century, cf. Table 2) and land-use-change scenarios (N20: N20_m45, N40: N40_m45, N60: N60_m45, N80: N80_m45, cf. Table 3) on eutrophication susceptibility of case-study estuaries

	BL	Mitigation		Land-use change			
Estuary Name		**CUR**	**MID**	**N20**	**N40**	**N60**	**N80**
Kaipara Harbour system	A	A	A	A	A	A	A
New River estuary	C	B	B	B	B	A	A
Waihi estuary	C	B	B	C	B	A	A

4.5 Impact of contaminant load changes on NPS-FM

Table 6 summarises the modelled effect of contaminant reduction for the land-use change scenarios on achieving NPS-FM bottom lines for critical catchments within estuary sea-draining catchments. For all three contaminants, at least about 80% of critical catchments in at least two of the three case-study estuaries achieve NPS-FM bottom lines in the land-use change scenario targeting 60% N reduction.

In the Kaipara Harbour and Waihi estuary catchments, the 60% N reduction target results in c. 90% of critical catchments achieving the bottom line for TN, whereas c. 60% of critical catchments in the New River estuary catchments achieve the TN bottom line for the same scenario. About 80% and 90% of critical P catchments in the New River and Waihi estuary catchments respectively achieve the NPS-FM bottom line for TP in the 60% N reduction scenario. Only around 40% of critical P catchments achieve the NPS-FM TP standard for the same scenario in the Kaipara Harbour.

Circa 90% of critical catchments achieve the NPS-FM bottom line standard for suspended sediment in the Kaipara Harbour and New River estuary catchments in the land-use change scenario targeting 60% N reduction. There are no critical sediment catchments in the Waihi estuary catchments.

Table 6. Impact of nitrogen reduction targets on case-study estuary catchments meeting NPS-FM bottom lines

	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
Estuary name	**BL**	**20**	**40**	**60**	**80**	**BL**	**20**	**40**	**60**	**80**	**BL**	**20**	**40**	**60**	**80**
Kaipara Harbour	233	124	162	215	230	1510	285	482	657	1085	700	330	636	694	694
New River	424	128	172	240	368	945	319	522	732	880	637	217	584	617	620
Waihi	15	3	9	14	15	87	13	37	75	84					

[a] The number of catchments that fail the NPS-FM bottom line (baseline scenarios, BL)

[b] The number of catchments that meet the NPS-FM bottom line for the given land-use change scenario

BL: baseline scenarios

20: land-use change scenario with 20% nitrogen reduction target

40: land-use change scenario with 40% nitrogen reduction target

60: land-use change scenario with 60% nitrogen reduction target

80: land-use change scenario with 80% nitrogen reduction target

Notes: The table shows the number of estuary sub-catchments currently not meeting the NPS-FM bottom line for nitrogen, phosphorous, and sediment (No. fail BL), and the sub-catchments that do meet the NPS-FM bottom line for the given contaminant in the modelled land-use change scenarios (cf. Table 3) that target 20%, 40%, 60%, and 80% N reduction (columns 20, 40, 60, 80). The sediment data refer to RCP 4.5, and the colours show the percentage of catchments achieving NPS-FM bottom lines (red: <25%, yellow: 25% ≤ X < 50%, blue: 50% ≤ X < 75%, light green: 75% ≤ X < 100%, dark green: 100%)

5 Discussion

We explored potential contaminant reductions across catchments of New Zealand estuaries that could be achieved by (i) implementing realistic current and future available mitigation measures for pastoral farming (section 4.2), and (ii) additional land-use change (section 4.3). For each scenario we characterised the associated potential benefits for estuary ecological health, the implications for estuary catchment land use and management, and the impact on achieving NPS-FM bottom lines.

The national-scale land-use scenario modelling draws on many different input data sets and makes simplifying assumptions, and many of the input data sets draw on yet other input data sets that make their own simplifying assumptions. Consequently, the results we present here are associated with uncertainty. Details of the uncertainties and underlying assumptions of the input data sets and studies used in this analysis can be obtained from the respective source publications. Here we focus on the assumptions and uncertainties introduced by the methods we used 'on top of' the input data sets.

Key inputs to our scenario modelling are mitigation measures to reduce contaminant losses from pastoral agriculture and to reduce soil erosion from land without woody vegetation cover. When any of the mitigation measures are selected in a given scenario, we assume they are implemented and maintained such that they achieve their full contaminant reduction potential as stated in the respective source publication.

To limit the total number of land-use scenarios, in each scenario (sections 4.2 and 4.3) we modelled the impact of mitigations for different contaminants in 'parallel' (i.e. we assumed that mitigation measures for N, P, and sediment were implemented at the same time, thus tracking the potential impact of mitigations for each contaminant in each scenario. However, for all land-use change scenarios (section 4.3), the selection of whether current or future available contaminant mitigation measures or land-use change is implemented, was driven only by the constraint to achieve a given N reduction target while maximising cost-effectiveness regarding N mitigation. Hence, the results should rather be interpreted contaminant by contaminant, and modelled cost-effectiveness as a rough guide reflecting broad land-use competitiveness.

Consequently, we do not report catchment- or land-use based gross-margin summaries, because these would require a more comprehensive economic modelling approach, which is out of scope of this study. Furthermore, different parameterisations or assumptions (e.g. a different y-intercept of the implemented N abatement curve for dairy land, or the consideration of different carbon or biodiversity credits for exotic and natural forests, respectively) could have significantly altered land-use competitiveness, and hence the potential land-use pattern for a given contaminant reduction target. However, with respect to the mitigation measures considered, the overall achievability of given contaminant reduction targets would not have changed.

Notwithstanding the limits outlined above, Figures 15–17 show maps of modelled land-use change for the 60% N reduction scenario (N60) in the case-study estuary catchments. The maps reflect the general observations outlined in section 4.1.2. (e.g. most of the pastoral farming land shows adoption of all current and future available mitigation measures, and almost all arable land and noticeable portions of sheep & beef land are traded off for exotic forestry or natural vegetation). However, even without considering any of the described limits of the implemented cost-effectiveness representation above, the presented land-use patterns do not mean the given result could not be met with a different spatial pattern. For example, if two or more land-use options showed the same specific SDU-based land-use performance and would hence produce the same result, the optimiser would just pick one of the options according to its internal algorithm, while both options would have been viable. However, the smaller the region of feasible solutions (e.g. due to tight constraints), the less likely are 'alternative' solutions that show the same performance.

We would like to emphasise that the presented land-use scenarios were not designed with the aim of being implemented or to represent an action plan to improve estuary ecological health or catchment freshwater quality. They were designed with the objectives (i) to ascertain whether it is possible to achieve set contaminant reduction targets through the implementation of realistic mitigation measures and/or land-use change, and (ii) to assess the associated potential benefits and implications for estuary ecological health and catchment land use (management), respectively. They provide an overview of trade-offs between potential benefits and land-use implications to inform policy development and/or the prioritisation of potential reduction targets for further exploration of their socio-economic and cultural feasibility.

6 Conclusions

- Adoption of feasible mitigation options in combination with targeted moderate land-use change will significantly improve the ecological health of estuaries and rivers.
- Increased effort put into implementing sediment mitigation measures is required to keep up with climate-driven exacerbation of sediment generation, especially in soft-rock hill country.
- For estuaries that are susceptible to eutrophication or whose catchments exceed NPS-FM bottom lines for one or more contaminants, a 60% contaminant reduction could sustain a considerably improved ecological health of estuaries and rivers.

7 Acknowledgements

We acknowledge Ton Snelder (Land Water People) for providing a cleaned Land, Air, Water Aotearoa data set for time distribution modelling of contaminant loads and river flow (cf. Appendix 7); Sandy Elliot and Annette Semadeni-Davies for advise on CLUES modelling results; Anne-Maree Schwarz for managing the 'Ki uta ki tai' programme and for linking the Sustainable Seas and OLW projects; Drew Lohrer for advice on estuarine ecological health; and Susie McKeague and Anne-Maree Schwarz for their guidance and patience regarding the completion of this study.

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Appendix 1 – National scale: catchments of estuaries

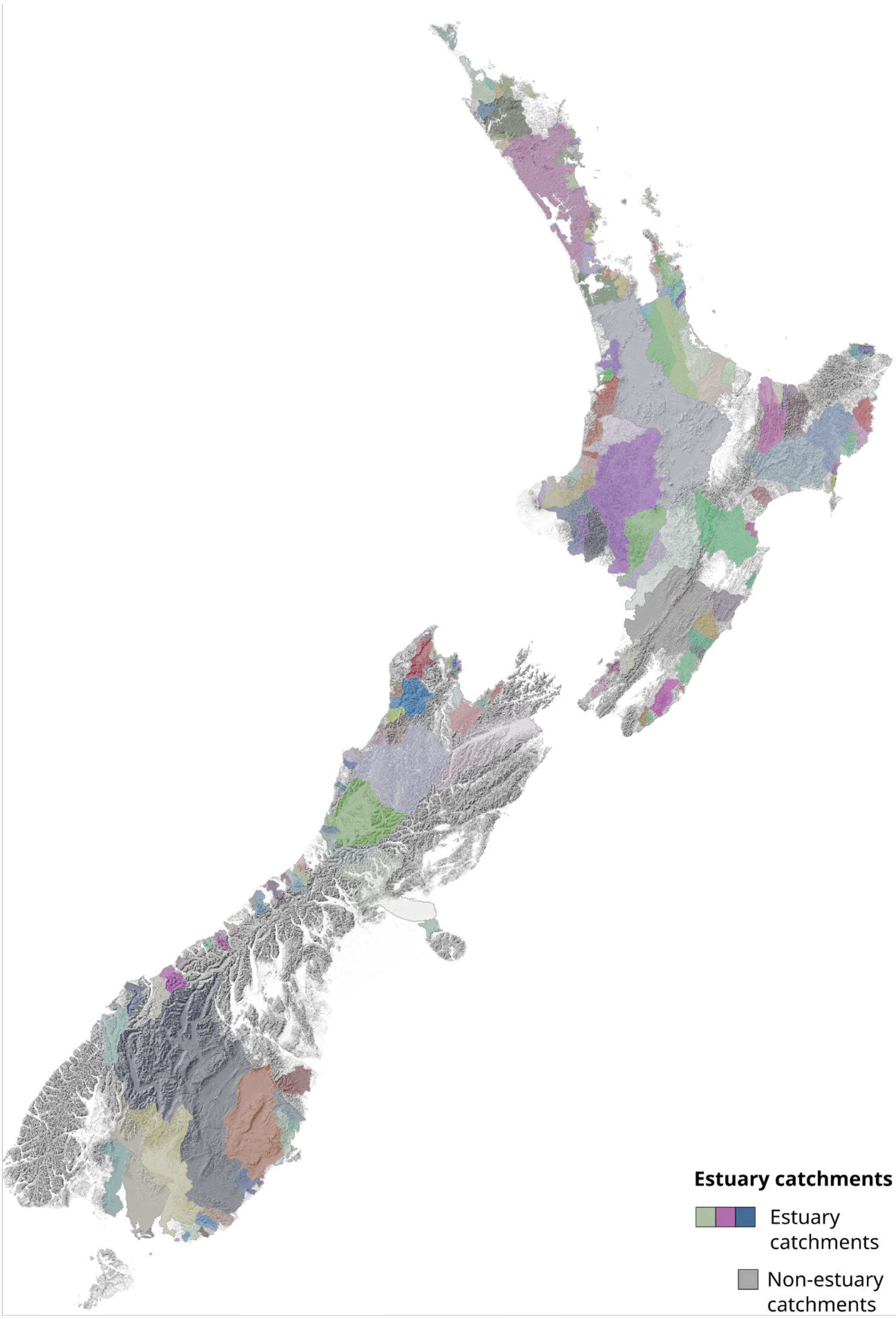

Figure A1.1. Catchments of estuaries. Please note that all catchments draining to the same estuary are displayed in the same colour.

Appendix 2 – National scale: land-use distributions for mitigation and land-use change scenarios

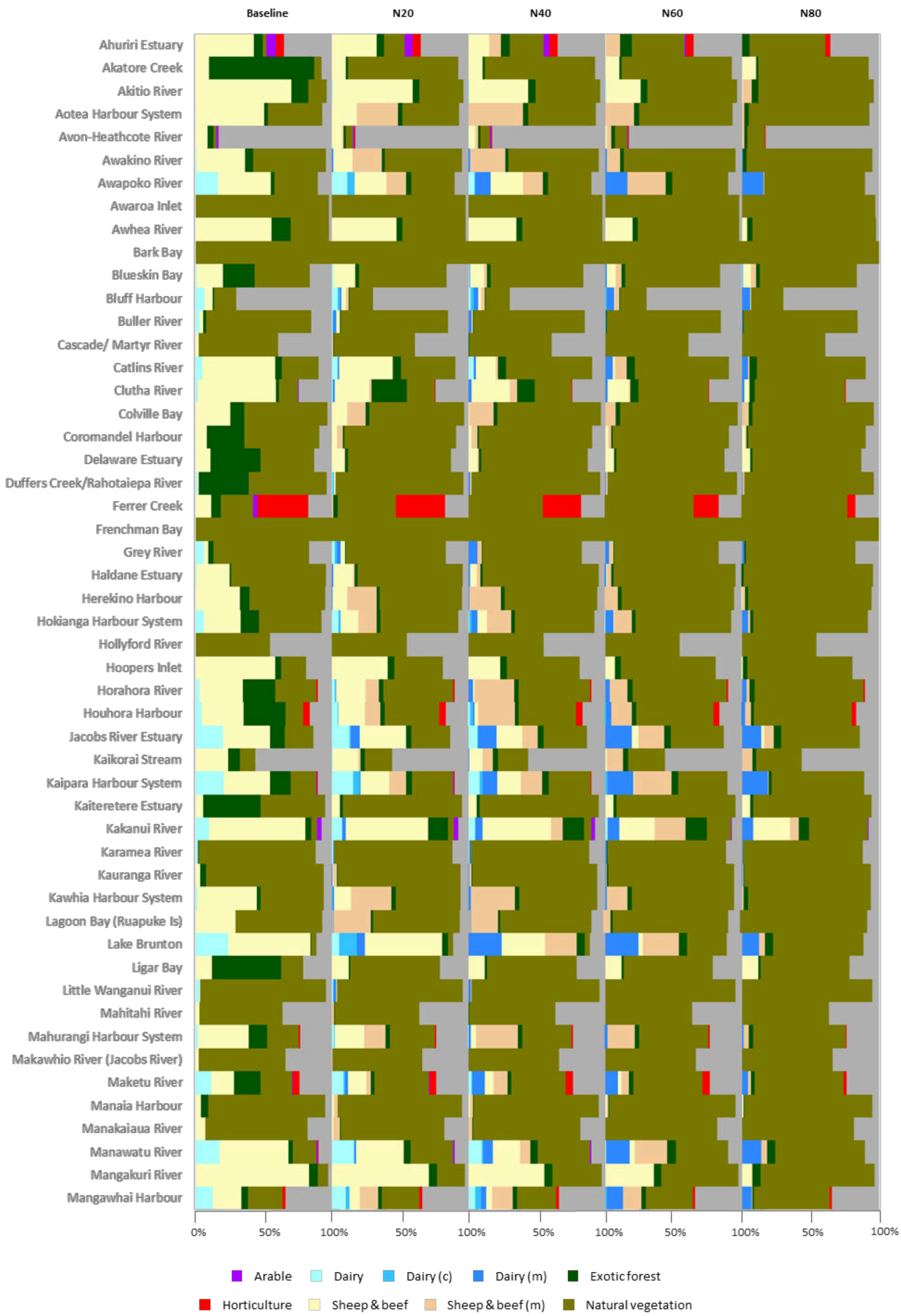

Figure A2.1. Land-use distributions for baseline (first column) and 20% to 80% (second to fifth columns) nitrogen reduction scenarios for estuary catchments in alphabetical order: Ahuriri Estuary to Mangawhai Harbour. Please note that land-use proportions smaller than 5% are hardly visible in the figure.

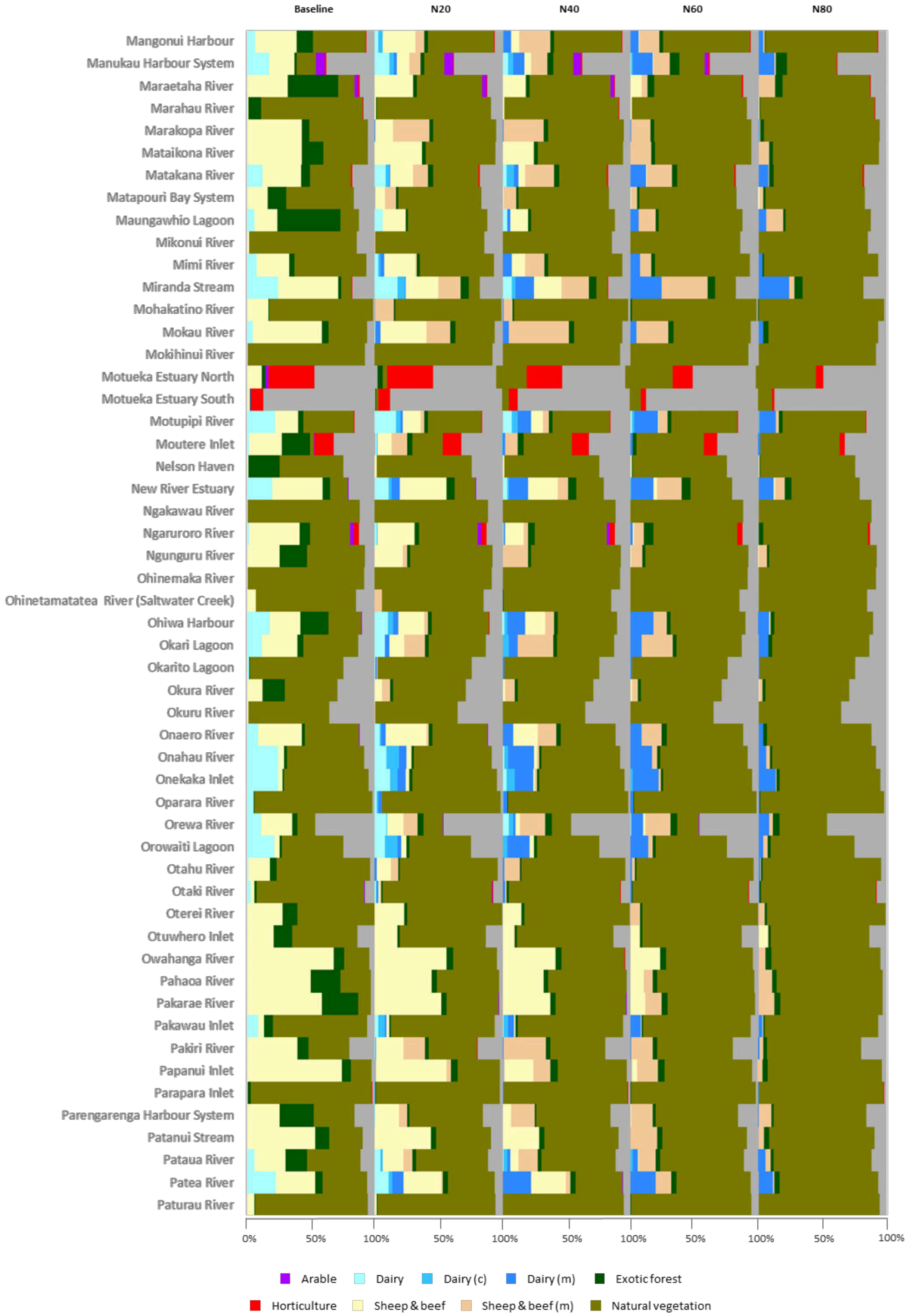

Figure A2.2. Land-use distributions for baseline (first column) and 20% to 80% (second to fifth columns) nitrogen reduction scenarios for estuary catchments in alphabetical order: Mangonui Harbour to Paturau River.

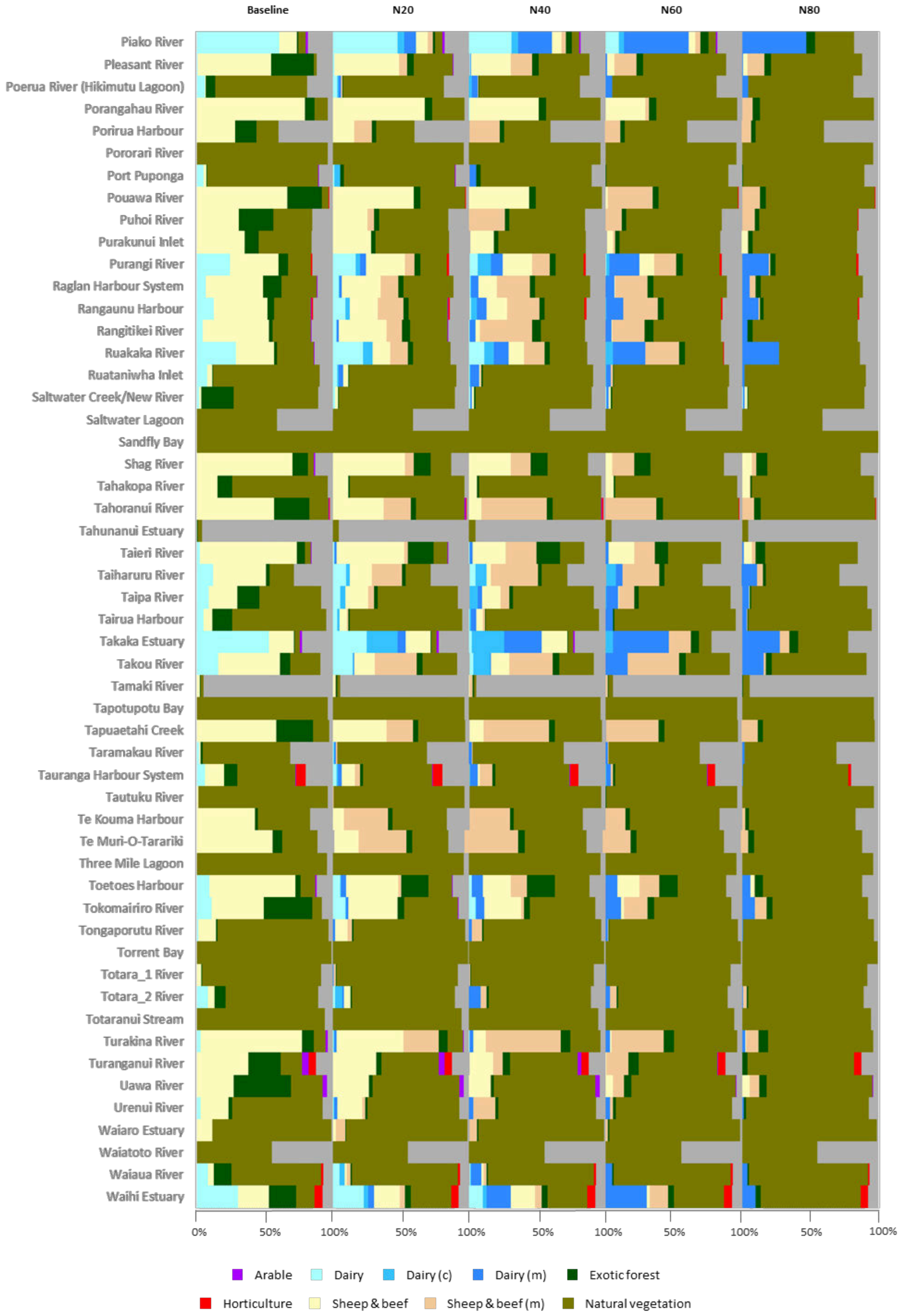

Figure A2.3. Land-use distributions for baseline (first column) and 20% to 80% (second to fifth columns) nitrogen reduction scenarios for estuary catchments in alphabetical order: Piako River to Waihi Estuary.

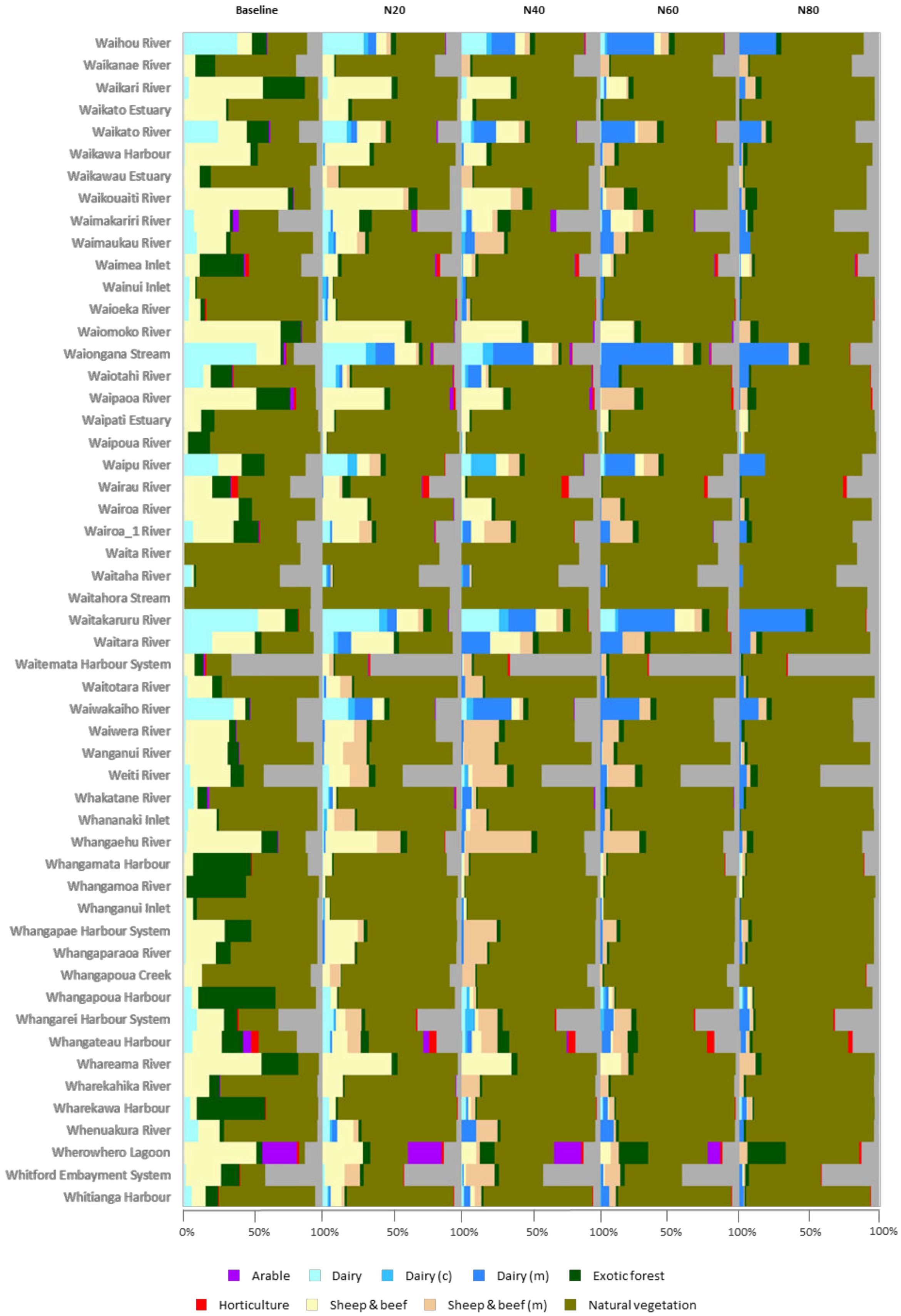

Figure A2.4. Land-use distributions for baseline (first column) and 20% to 80% (second to fifth columns) nitrogen reduction scenarios for estuary catchments in alphabetical order: Waihou River to Whitianga Harbour.

Appendix 3 – National scale: impact of mitigation and land-use change scenarios on eutrophication susceptibility of estuaries

Table A3.1. Impact of nitrogen reduction scenarios on estuary eutrophication susceptibility

	BL	Mitigation		Land-use change			
Estuary name		**CUR**	**MID**	**N20**	**N40**	**N60**	**N80**
Ahuriri Estuary	D	D	D	D	D	D	D
Akatore Creek	D	D	D	C	C	C	C
Akitio River	A	A	A	A	A	A	A
Aotea Harbour System	A	A	A	A	A	A	A
Avon-Heathcote River	A	A	A	A	A	A	A
Awakino River	A	A	A	A	A	A	A
Awapoko River	D	C	B	C	C	B	A
Awaroa Inlet	A	A	A	A	A	A	A
Bark Bay	A	A	A	A	A	A	A
Blueskin Bay	A	A	A	A	A	A	A
Bluff Harbour	A	A	A	A	A	A	A
Buller River	A	A	A	A	A	A	A
Cascade/ Martyr River	A	A	A	A	A	A	A
Catlins River	B	A	A	A	A	A	A
Clutha River	A	A	A	A	A	A	A
Colville Bay	A	A	A	A	A	A	A
Coromandel Harbour	A	A	A	A	A	A	A
Delaware Estuary	A	A	A	A	A	A	A
Duffers Creek/Rahotaiepa River	A	A	A	A	A	A	A
Ferrer Creek	B	B	B	B	A	A	A
Frenchman Bay	A	A	A	A	A	A	A
Grey River	A	A	A	A	A	A	A
Haldane Estuary	A	A	A	A	A	A	A
Herekino Harbour	A	A	A	A	A	A	A
Hokianga Harbour System	A	A	A	A	A	A	A
Hollyford River	A	A	A	A	A	A	A
Hoopers Inlet	A	A	A	A	A	A	A
Horahora River	B	B	A	B	A	A	A
Houhora Harbour	A	A	A	A	A	A	A
Jacobs River Estuary	C	C	B	C	B	B	A
Kaikorai Stream	C	C	B	B	B	B	A
Kaipara Harbour System	A	A	A	A	A	A	A
Kaiteretere Estuary	A	A	A	A	A	A	A
Kakanui River	A	A	A	A	A	A	A
Karamea River	A	A	A	A	A	A	A
Kauranga River	A	A	A	A	A	A	A
Kawhia Harbour System	A	A	A	A	A	A	A
Lake Brunton	D	D	D	D	D	C	B
Ligar Bay	A	A	A	A	A	A	A
Little Wanganui River	A	A	A	A	A	A	A

Estuary name	BL	Mitigation		Land-use change			
		CUR	MID	N20	N40	N60	N80
Mahitahi River	A	A	A	A	A	A	A
Mahurangi Harbour System	A	A	A	A	A	A	A
Makawhio River (Jacobs River)	A	A	A	A	A	A	A
Maketu River	B	B	A	B	A	A	A
Manaia Harbour	A	A	A	A	A	A	A
Manakaiaua River	A	A	A	A	A	A	A
Manawatu River	A	A	A	A	A	A	A
Mangakuri River	A	A	A	A	A	A	A
Mangawhai Harbour	A	A	A	A	A	A	A
Mangonui Harbour	A	A	A	A	A	A	A
Manukau Harbour System	A	A	A	A	A	A	A
Maraetaha River	A	A	A	A	A	A	A
Marahau River	A	A	A	A	A	A	A
Marakopa River	B	B	A	A	A	A	A
Mataikona River	A	A	A	A	A	A	A
Matakana River	A	A	A	A	A	A	A
Matapouri Bay System	A	A	A	A	A	A	A
Maungawhio Lagoon	B	B	A	B	A	A	A
Mikonui River	A	A	A	A	A	A	A
Mimi River	B	B	A	B	A	A	A
Miranda Stream	D	D	C	D	C	B	A
Mohakatino River	A	A	A	A	A	A	A
Mokau River	A	A	A	A	A	A	A
Mokihinui River	A	A	A	A	A	A	A
Motueka Estuary North	A	A	A	A	A	A	A
Motueka Estuary South	A	A	A	A	A	A	A
Motupipi River	B	A	A	A	A	A	A
Moutere Inlet	C	C	B	B	B	A	A
Nelson Haven	A	A	A	A	A	A	A
New River Estuary	C	B	B	B	B	A	A
Ngakawau River	A	A	A	A	A	A	A
Ngunguru River	A	A	A	A	A	A	A
Ohinemaka River	A	A	A	A	A	A	A
Ohinetamatatea River (Saltwater Creek)	A	A	A	A	A	A	A
Ohiwa Harbour	A	A	A	A	A	A	A
Okari Lagoon	A	A	A	A	A	A	A
Okarito Lagoon	A	A	A	A	A	A	A
Okura River	A	A	A	A	A	A	A
Okuru River	A	A	A	A	A	A	A
Onaero River	A	A	A	A	A	A	A
Onahau River	B	B	A	B	A	A	A
Onekaka Inlet	B	A	A	B	A	A	A
Oparara River	A	A	A	A	A	A	A
Orewa River	A	A	A	A	A	A	A

Estuary name	BL	Mitigation		Land-use change			
		CUR	MID	N20	N40	N60	N80
Orowaiti Lagoon	A	A	A	A	A	A	A
Otahu River	A	A	A	A	A	A	A
Otaki River	A	A	A	A	A	A	A
Oterei River	A	A	A	A	A	A	A
Otuwhero Inlet	A	A	A	A	A	A	A
Owahanga River	A	A	A	A	A	A	A
Pahaoa River	A	A	A	A	A	A	A
Pakarae River	A	A	A	A	A	A	A
Pakawau Inlet	A	A	A	A	A	A	A
Pakiri River	B	B	B	B	A	A	A
Papanui Inlet	A	A	A	A	A	A	A
Parapara Inlet	A	A	A	A	A	A	A
Parengarenga Harbour System	A	A	A	A	A	A	A
Patanui Stream	D	D	D	D	C	B	A
Pataua River	A	A	A	A	A	A	A
Patea River	A	A	A	A	A	A	A
Paturau River	A	A	A	A	A	A	A
Piako River	D	D	D	D	D	D	B
Pleasant River	C	C	C	C	B	B	A
Poerua River (Hikimutu Lagoon)	A	A	A	A	A	A	A
Porangahau River	D	D	D	D	C	B	A
Pororari River	A	A	A	A	A	A	A
Port Puponga	A	A	A	A	A	A	A
Pouawa River	D	D	C	C	C	B	A
Puhoi River	A	A	A	A	A	A	A
Purakunui Inlet	A	A	A	A	A	A	A
Purangi River	B	B	A	B	B	A	A
Raglan Harbour System	A	A	A	A	A	A	A
Rangaunu Harbour	A	A	A	A	A	A	A
Rangitikei River	A	A	A	A	A	A	A
Ruakaka River	D	C	B	D	C	B	A
Ruataniwha Inlet	A	A	A	A	A	A	A
Saltwater Creek/New River	A	A	A	A	A	A	A
Saltwater Lagoon	A	A	A	A	A	A	A
Sandfly Bay	A	A	A	A	A	A	A
Shag River	B	B	B	B	A	A	A
Tahakopa River	A	A	A	A	A	A	A
Tahoranui River	C	C	B	B	B	A	A
Tahunanui Estuary	A	A	A	A	A	A	A
Taieri River	D	D	D	D	D	B	B
Taiharuru River	A	A	A	A	A	A	A
Taipa River	B	B	A	B	A	A	A
Tairua Harbour	A	A	A	A	A	A	A
Takaka Estuary	A	A	A	A	A	A	A
Takou River	D	C	B	C	B	B	A

Estuary name	BL	Mitigation		Land-use change			
		CUR	MID	N20	N40	N60	N80
Tamaki River	A	A	A	A	A	A	A
Tapotupotu Bay	A	A	A	A	A	A	A
Tapuaetahi Creek	B	B	A	B	A	A	A
Taramakau River	A	A	A	A	A	A	A
Tauranga Harbour System	A	A	A	A	A	A	A
Tautuku River	A	A	A	A	A	A	A
Te Kouma Harbour	A	A	A	A	A	A	A
Te Muri-O-Tarariki	A	A	A	A	A	A	A
Three Mile Lagoon	A	A	A	A	A	A	A
Toetoes Harbour	D	C	C	C	C	B	A
Tokomairiro River	D	D	D	D	D	D	D
Tongaporutu River	A	A	A	A	A	A	A
Torrent Bay	A	A	A	A	A	A	A
Totara_1 River	A	A	A	A	A	A	A
Totara_2 River	A	A	A	A	A	A	A
Totaranui Stream	A	A	A	A	A	A	A
Turakina River	D	D	D	D	D	C	B
Turanganui River	A	A	A	A	A	A	A
Uawa River	B	B	B	B	B	A	A
Urenui River	A	A	A	A	A	A	A
Waiaro Estuary	A	A	A	A	A	A	A
Waiatoto River	A	A	A	A	A	A	A
Waiaua River	B	B	A	B	A	A	A
Waihi Estuary	C	B	B	C	B	A	A
Waihou River	C	B	A	C	B	B	A
Waikanae River	A	A	A	A	A	A	A
Waikari River	A	A	A	A	A	A	A
Waikato Estuary	A	A	A	A	A	A	A
Waikato River	D	C	B	C	B	B	A
Waikawa Harbour	A	A	A	A	A	A	A
Waikawau Estuary	A	A	A	A	A	A	A
Waikouaiti River	D	D	D	D	C	B	B
Waimakariri River	B	B	A	B	B	A	A
Waimaukau River	C	B	B	B	B	A	A
Waimea Inlet	A	A	A	A	A	A	A
Wainui Inlet	A	A	A	A	A	A	A
Waioeka River	A	A	A	A	A	A	A
Waiomoko River	A	A	A	A	A	A	A
Waiongana Stream	A	A	A	A	A	A	A
Waiotahi River	B	A	A	A	A	A	A
Waipaoa River	A	A	A	A	A	A	A
Waipati Estuary	A	A	A	A	A	A	A
Waipoua River	A	A	A	A	A	A	A
Waipu River	D	C	B	C	C	B	A
Wairau River	D	D	D	D	D	D	D

Estuary name	BL	Mitigation		Land-use change			
		CUR	MID	N20	N40	N60	N80
Wairoa River	D	D	D	D	D	D	D
Wairoa River	A	A	A	A	A	A	A
Wairoa_1 River	B	B	A	A	A	A	A
Waita River	A	A	A	A	A	A	A
Waitaha River	A	A	A	A	A	A	A
Waitahora Stream	C	C	C	A	A	A	A
Waitakaruru River	D	D	C	D	D	D	B
Waitara River	A	A	A	A	A	A	A
Waitemata Harbour System	A	A	A	A	A	A	A
Waitotara River	A	A	A	A	A	A	A
Waiwakaiho River	D	D	C	D	C	B	A
Waiwera River	A	A	A	A	A	A	A
Wanganui River	A	A	A	A	A	A	A
Weiti River	A	A	A	A	A	A	A
Whakatane River	D	D	D	D	D	D	D
Whananaki Inlet	A	A	A	A	A	A	A
Whangaehu River	A	A	A	A	A	A	A
Whangamata Harbour	A	A	A	A	A	A	A
Whangamoa River	A	A	A	A	A	A	A
Whanganui Inlet	A	A	A	A	A	A	A
Whangapae Harbour System	A	A	A	A	A	A	A
Whangaparaoa River	A	A	A	A	A	A	A
Whangapoua Creek	A	A	A	A	A	A	A
Whangapoua Harbour	A	A	A	A	A	A	A
Whangarei Harbour System	A	A	A	A	A	A	A
Whangateau Harbour	A	A	A	A	A	A	A
Wharekahika River	A	A	A	A	A	A	A
Wharekawa Harbour	A	A	A	A	A	A	A
Whenuakura River	A	A	A	A	A	A	A
Wherowhero Lagoon	C	C	C	C	B	A	A
Whitford Embayment System	A	A	A	A	A	A	A
Whitianga Harbour	A	A	A	A	A	A	A

Appendix 4 – National scale: impact of land-use change scenarios on achieving NPS-FM national bottom lines for total nitrogen, total phosphorus, and suspended sediment

Table A4.1. Impact of nitrogen reduction targets on estuary catchments meeting NPS-FM bottom lines. The table shows the number of estuary sub-catchments currently not meeting the NPS-FM bottom line for nitrogen, phosphorous, and sediment (No. fail BL), and the sub-catchments that do meet the NPS-FM bottom line for the given contaminant in the modelled land-use change scenarios (cf. Table 3) that target 20%, 40%, 60%, and 80% reduction of nitrogen (columns 20, 40, 60, 80). The sediment data refer to RCP 4.5, and the colours show the percentage of catchments achieving NPS-FM bottom lines (red: <25%, yellow: 25% ≤ X < 50%, blue: 50% ≤ X < 75%, light green: 75% ≤ X < 100%, dark green: 100%)

	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
Estuary name	BL	20	40	60	80	BL	20	40	60	80	BL	20	40	60	80
Ahuriri	7	4	5	7	7	28	3	3	3	4					
Akatore Creek	3	2	2	2	2	4	0	0	0	0	23	14	23	23	23
Akitio River	69	14	27	49	64	198	11	38	83	164	34	6	20	25	33
Aotea Harbour System	6	3	6	6	6	9	7	9	9	9	47	31	45	46	47
Avon-Heathcote River	35	16	19	26	35	27	11	13	18	18					
Awakino River	2	2	2	2	2	31	8	31	31	31	41	23	39	39	40
Awapoko River	2	2	2	2	2	55	16	29	47	54					
Awaroa Inlet															
Awhea River	12	4	8	12	12	51	8	14	25	31	4	3	3	3	4
Bark Bay															
Blueskin Bay	15	4	10	14	15	40	4	6	11	12					
Bluff Harbour	8	3	7	8	8	6	2	3	5	5	72	25	72	72	72
Buller River	5	2	5	5	5	10	8	8	9	9	316	119	248	249	249
Cascade/Martyr River						2	2	2	2	2	2	2	2	2	2
Catlins River	61	13	22	38	58	86	19	35	59	81	38	17	38	38	38
Clutha River	1316	530	880	1183	1265	1792	792	1317	1704	1746	1560	994	1455	1506	1538
Colville Bay	2	2	2	2	2	1	0	1	1	1					
Coromandel Harbour	2	2	2	2	2	10	5	8	8	8					

Estuary name	Nitrogen No. fail[a] BL	Nitrogen No. meeting targets[b] 20	40	60	80	Phosphorous No. fail BL	Phosphorous No. meeting targets 20	40	60	80	Sediment No. fail BL	Sediment No. meeting targets 20	40	60	80
Delaware															
Duffers Creek/Rahotaiepa River															
Ferrer Creek						4	2	2	3	3					
Frenchman Bay															
Grey River	16	6	15	15	15	3	0	1	1	1	625	260	560	560	567
Haldane	12	3	9	10	10						10	4	10	10	10
Herekino Harbour						9	9	9	9	9	8	8	8	8	8
Hokianga Harbour System	46	34	42	45	45	199	108	153	182	187	37	22	34	34	34
Hollyford River						9	9	9	9	9	22	22	22	22	22
Hoopers Inlet															
Horahora River	2	2	2	2	2	12	6	11	12	12	1	0	1	1	1
Houhora Harbour	7	2	4	5	6	115	2	4	26	55	20	16	19	19	19
Jacobs River	135	42	48	84	119	271	96	153	218	245	235	92	194	213	216
Kaikorai Stream	21	12	14	14	16	43	14	20	27	31					
Kaipara Harbour System	233	124	162	215	230	1510	285	482	657	1085	700	330	636	694	694
Kaiteretere															
Kakanui River	83	14	25	57	72	144	19	56	136	144	33	8	16	30	30
Karamea River						5	4	4	5	5	7	0	5	5	5
Kauranga River	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1
Kawhia Harbour System	13	11	13	13	13	13	7	10	13	13	124	39	105	108	113
Lagoon Bay(Ruapuke Is)											1	1	1	1	1
Lake Brunton	2	2	2	2	2	2	2	2	2	2	14	2	14	14	14
Ligar Bay															
Little Wanganui River											8	1	5	5	5
Mahitahi River											2	1	2	2	2
Mahurangi Harbour System						30	5	18	21	27					

Estuary name	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
	BL	20	40	60	80	BL	20	40	60	80	BL	20	40	60	80
Makawhio River (Jacobs River)											1	0	1	1	1
Maketu River	65	29	59	60	65	161	40	113	131	138	8	5	8	8	8
Manaia Harbour						1	0	0	0	0					
Manakaiaua River															
Manawatu River	198	78	104	155	181	675	88	105	187	299	13	11	12	13	13
Mangakuri River	1	0	1	1	1	21	0	4	9	19	5	0	1	1	4
Mangawhai Harbour	2	2	2	2	2	52	22	28	40	49	1	0	1	1	1
Mangonui Harbour	5	4	5	5	5	11	7	11	11	11	7	6	7	7	7
Manukau HarbourSystem	75	29	39	52	66	375	75	93	129	255	155	81	153	154	154
Maraetaha River	3	1	1	3	3	8	1	4	4	5					
Marahau River															
Marakopa River	10	7	10	10	10	4	2	4	4	4	26	5	20	21	21
Mataikona River	2	1	1	2	2						26	7	14	14	14
Matakana River	3	2	3	3	3	1	1	1	1	1					
Matapouri Bay System						2	0	1	2	2					
Maungawhio Lagoon						15	2	8	14	14					
Mikonui River															
Mimi River	10	5	8	10	10	8	4	6	8	8	17	9	16	17	17
Miranda Stream	4	1	2	3	4	8	2	4	8	8	4	0	3	4	4
Mohakatino River						2	2	2	2	2	3	1	3	3	3
Mokau River	256	128	219	240	254	560	190	465	498	544	24	10	23	24	24
Mokihinui River						1	1	1	1	1	4	2	4	4	4
Motueka North															
Motueka South						2	2	2	2	2					
Motupipi River	7	0	5	6	7										
Moutere Inlet	18	8	14	16	16	51	5	6	7	9					

	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
Estuary name	**BL**	**20**	**40**	**60**	**80**	**BL**	**20**	**40**	**60**	**80**	**BL**	**20**	**40**	**60**	**80**
Nelson Haven	6	4	4	4	4	13	2	3	3	3					
New River	424	128	172	240	368	945	319	522	732	880	637	217	584	617	620
Ngakawau River											2	0	1	1	1
Ngaruroro River	203	93	142	183	202	494	71	137	200	259	25	15	24	25	25
Ngunguru River						21	9	21	21	21					
Ohinemaka River															
Ohinetamatatea River															
Ohiwa Harbour	10	3	7	9	9	104	15	55	85	97					
Okari Lagoon											34	17	33	33	34
Okarito Lagoon											1	1	1	1	1
Okura River						5	0	0	0	0					
Okuru River	2	2	2	2	2	2	0	0	0	0	30	6	30	30	30
Onaero River	21	7	11	19	20	36	8	21	35	35	19	8	19	19	19
Onahau River															
Onekaka Inlet															
Oparara River	3	1	3	3	3						3	1	3	3	3
Orewa River						2	0	1	2	2					
Orowaiti Lagoon											14	3	13	13	13
Otahu River	5	1	5	5	5	2	1	2	2	2					
Otaki River	7	5	6	7	7	25	4	11	13	13	36	19	36	36	36
Oterei River	3	0	1	3	3	20	2	6	6	8	2	1	1	1	1
Otuwhero Inlet															
Owahanga River	63	12	31	50	62	217	10	42	106	184	14	3	8	10	12
Pahaoa River	24	11	17	20	23	4	1	2	2	3	60	30	43	48	54
Pakarae River						40	3	13	33	39					
Pakawau Inlet															

Estuary name	Nitrogen No. fail[a] BL	Nitrogen No. meeting targets[b] 20	40	60	80	Phosphorous No. fail BL	Phosphorous No. meeting targets 20	40	60	80	Sediment No. fail BL	Sediment No. meeting targets 20	40	60	80
Pakiri River	2	2	2	2	2	4	1	3	3	3					
Papanui Inlet															
Parapara Inlet															
Parengarenga Harbour System	5	5	5	5	5	133	12	13	23	36	28	27	28	28	28
Patanui Stream	4	2	2	2	4	19	3	6	9	11	2	1	2	2	2
Pataua River	2	2	2	2	2	23	10	19	23	23	1	1	1	1	1
Patea River	21	10	15	17	18	61	6	25	33	41	4	3	4	4	4
Paturau River						1	1	1	1	1					
Piako River	11	5	5	6	9	24	10	10	10	11	224	136	201	219	223
Pleasant River	7	1	2	4	5	48	2	29	40	43					
Poerua River (Hikimutu Lagoon)											2	1	2	2	2
Porangahau River	98	24	47	67	89	535	40	120	235	427	15	6	13	13	13
Porirua Harbour	13	6	7	9	10	43	6	10	10	10	27	22	27	27	27
Pororari River											1	0	0	0	0
Port Puponga															
Pouawa River	2	1	2	2	2	29	4	12	28	29					
Puhoi River															
Purakunui Inlet	2	0	2	2	2	5	0	3	4	5					
Purangi River	5	2	4	4	5	9	2	7	9	9					
Raglan Harbour System	30	11	20	29	29	105	39	81	98	101	159	45	147	152	156
Rangaunu Harbour	6	4	6	6	6	193	32	56	80	129	23	17	23	23	23
Rangitikei River	302	123	248	268	298	232	33	46	47	72	77	47	69	73	74
Ruakaka River	4	4	4	4	4	27	11	14	24	27					
Ruataniwha Inlet	11	3	11	11	11	9	3	9	9	9	4	0	4	4	4
Saltwater Creek/New River											18	7	18	18	18
Saltwater Lagoon															

Estuary name	Nitrogen No. fail[a] BL	Nitrogen No. meeting targets[b] 20	40	60	80	Phosphorous No. fail BL	Phosphorous No. meeting targets 20	40	60	80	Sediment No. fail BL	Sediment No. meeting targets 20	40	60	80
Sandfly Bay															
Shag River	3	3	3	3	3	77	22	59	74	75	33	15	33	33	33
Tahakopa River	2	1	1	1	1						71	20	71	71	71
Tahoranui River	1	1	1	1	1	5	4	4	5	5					
Tahunanui						2	0	0	0	0					
Taieri River	21	4	12	18	20	379	87	182	247	339	493	245	423	427	466
Taiharuru River	1	1	1	1	1	13	8	12	13	13					
Taipa River	3	0	2	3	3	23	10	15	22	23	2	2	2	2	2
Tairua Harbour	14	5	9	14	14	18	3	11	16	16					
Takaka						4	3	4	4	4					
Takou River	17	13	17	17	17	16	10	12	13	16	1	1	1	1	1
Tamaki River	8	5	5	6	6	79	49	49	50	57					
Tapotupotu Bay						16	16	16	16	16					
Tapuaetahi Creek						12	5	7	10	12					
Taramakau River						1	1	1	1	1	11	2	10	10	10
Tauranga Harbour System	76	44	67	75	76	203	93	152	170	172	33	24	32	32	33
Tautuku River											3	2	3	3	3
Te Kouma Harbour															
Te Muri-O-Tarariki															
Three Mile Lagoon															
Toetoes Harbour	12	6	6	9	12	1175	353	611	920	1139	313	142	288	310	312
Tokomairiro River	2	1	1	1	2	194	35	74	135	165	34	24	34	34	34
Tongaporutu River	1	1	1	1	1	6	2	5	6	6	5	1	5	5	5
Torrent Bay															
Totara_1 River	1	1	1	1	1						26	10	17	17	17
Totara_2 River															

	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
Estuary name	BL	20	40	60	80	BL	20	40	60	80	BL	20	40	60	80
Totaranui Stream															
Turakina River	12	5	5	5	8	127	9	11	14	22	37	29	37	37	37
Turanganui River	3	1	1	2	3	111	26	48	91	92					
Uawa River						107	14	51	83	84	2	2	2	2	2
Urenui River	3	2	3	3	3						10	5	10	10	10
Waiaro															
Waiatoto River						2	2	2	2	2	8	4	8	8	8
Waiaua River						18	5	9	12	13	1	1	1	1	1
Waihi	15	3	9	14	15	87	13	37	75	84					
Waihou River	34	8	23	33	34	150	24	32	45	86	111	34	81	106	111
Waikanae River	2	1	2	2	2	16	3	4	4	4	32	14	32	32	32
Waikari River	14	2	7	10	14	55	8	20	36	49					
Waikato															
Waikato River	640	219	329	517	620	639	75	107	209	439	193	38	174	187	192
Waikawa Harbour	27	8	20	26	26						55	19	54	55	55
Waikawau															
Waikouaiti River	4	1	1	3	4	100	20	28	56	84	25	10	25	25	25
Waimakariri River	133	50	73	107	128	158	31	56	129	151	4	1	4	4	4
Waimaukau River	2	1	1	1	1						9	4	9	9	9
Waimea Inlet	24	8	10	11	12	99	6	8	8	9	6	4	6	6	6
Wainui Inlet															
Waioeka River	2	2	2	2	2	66	34	62	64	64	33	22	29	29	29
Waiomoko River						19	4	6	14	19					
Waiongana Stream	27	2	11	25	25	42	7	23	36	40	35	35	35	35	35
Waiotahi River	4	1	4	4	4	50	11	35	48	48	1	0	1	1	1
Waipaoa River	260	73	150	242	250	601	41	197	247	414	5	5	5	5	5

Estuary name	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
	BL	20	40	60	80	BL	20	40	60	80	BL	20	40	60	80
Waipati											9	6	9	9	9
Waipoua River											9	9	9	9	9
Waipu River	8	6	7	7	8	129	53	78	96	129					
Wairau River	34	6	12	22	23	289	38	69	76	77	8	7	8	8	8
Wairoa River	5	1	3	5	5	317	45	129	271	274	17	13	17	17	17
Wairoa_1 River	14	10	13	14	14	24	5	7	9	17	39	20	39	39	39
Waita River						1	0	0	0	0	10	3	10	10	10
Waitaha River						1	0	1	1	1	3	1	3	3	3
Waitahora Stream						2	2	2	2	2					
Waitakaruru River	4	1	1	1	4	21	2	3	3	7	29	9	27	28	29
Waitara River	90	33	67	84	90	158	32	103	154	154	33	9	33	33	33
Waitemata Harbour System	64	38	39	43	44	191	53	71	92	100	57	33	57	57	57
Waitotara River	43	18	24	38	38	173	12	26	42	42	28	11	28	28	28
Waiwakaiho River	6	4	5	6	6	10	4	7	7	7	13	6	13	13	13
Waiwera River						2	1	2	2	2					
Wanganui River	70	21	38	44	45	412	52	85	113	131	36	21	36	36	36
Weiti River	4	4	4	4	4	4	1	3	4	4					
Whakatane River	10	4	4	4	5	307	82	192	255	257					
Whananaki Inlet	2	2	2	2	2	13	8	9	13	13					
Whangaehu River	38	13	24	28	33	200	14	23	53	98	18	14	18	18	18
Whangamata Harbour	2	1	2	2	2	14	0	2	2	2					
Whangamoa River															
Whanganui Inlet						2	0	0	0	0					
Whangapae Harbour System						4	2	4	4	4	11	2	11	11	11
Whangaparaoa River	1	1	1	1	1						3	0	3	3	3
Whangapoua Creek	2	2	2	2	2						5	0	5	5	5

	Nitrogen					Phosphorous					Sediment				
	No. fail[a]	No. meeting targets[b]				No. fail	No. meeting targets				No. fail	No. meeting targets			
Estuary name	BL	20	40	60	80	BL	20	40	60	80	BL	20	40	60	80
Whangapoua Harbour	1	0	1	1	1	8	0	0	2	2	2	2	2	2	2
Whangarei Harbour System	14	14	14	14	14	93	37	65	81	91	5	4	5	5	5
Whangateau Harbour	2	2	2	2	2	1	1	1	1	1					
Whareama River	70	16	37	58	64	240	28	69	132	164	31	19	23	27	27
Wharekahika River						2	1	1	1	1					
Wharekawa Harbour	4	2	3	3	3	7	0	4	6	6					
Whenuakura River	43	15	20	38	42	107	15	47	66	68	6	6	6	6	6
Wherowhero Lagoon	2	1	2	2	2	19	3	7	9	9					
Whitford Embayment System	4	1	3	3	3	47	0	1	1	16					
Whitianga Harbour	13	4	9	13	13	19	8	10	17	18					

a The number of catchments that fail the NPS-FM bottom line (baseline scenarios, BL)

b The number of catchments that meet the NPS-FM bottom line for the given land-use change scenario

BL: baseline scenarios

20: land-use change scenario with 20% nitrogen reduction target

40: land-use change scenario with 40% nitrogen reduction target

60: land-use change scenario with 60% nitrogen reduction target

80: land-use change scenario with 80% nitrogen reduction target

Appendix 5 – National scale: modelled nutrient losses for baseline and reduction potential for mitigation and land-use change scenarios

Table A5.1. Baseline losses (kg yr^{-1}) for nitrogen (N) and phosphorous (P), and relative reduction potential (%) for modelled mitigation scenarios (Table 2)

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Ahuriri Estuary	13,807	102,499	9,483	1	15	19	27
Akatore Creek	6,964	22,520	733	0	3	1	1
Akitio River	58,971	534,208	66,669	3	19	24	35
Aotea Harbour System	16,195	117,914	9,236	6	26	27	44
Avon-Heathcote River	21,487	21,212	1,237	1	17	11	24
Awakino River	38,338	256,006	17,282	6	24	24	40
Awapoko River	9,551	145,354	9,699	28	53	27	44
Awaroa Inlet	6,647	11,312	650	0	0	0	0
Awhea River	15,192	110,614	13,611	2	17	22	31
Bark Bay	693	1,224	69	0	0	0	0
Blueskin Bay	9,277	23,336	1,065	5	13	12	12
Bluff Harbour	7,595	20,358	906	21	60	63	68
Buller River	642,672	2,232,987	89,060	14	28	28	35
Cascade/ Martyr River	43,874	67,894	3,396	1	11	5	12
Catlins River	41,861	198,297	6,366	15	30	26	30
Clutha River	2,111,189	6,523,135	337,069	10	21	17	19
Colville Bay	4,202	18,483	1,233	6	21	28	44
Coromandel Harbour	6,950	23,822	1,461	1	10	13	23
Delaware Estuary	8,025	28,256	1,088	1	6	5	8
Duffers Creek	6,575	27,561	742	6	12	12	13
Ferrer Creek	1,432	16,814	410	0	1	2	3
Frenchman Bay	130	215	13	0	0	0	0
Grey River	394,744	2,014,377	53,773	19	38	35	41
Haldane Estuary	6,768	22,951	879	4	15	8	8
Herekino Harbour	8,806	64,162	4,450	3	22	18	33
Hokianga Harbour	154,029	1,448,376	79,788	17	39	25	40
Hollyford River	113,487	114,340	5,278	0	0	0	0
Hoopers Inlet	928	3,403	121	0	11	4	4
Horahora River	8,574	82,499	4,192	11	30	22	36
Houhora Harbour	11,633	133,013	14,672	6	35	17	30
Jacobs River Estuary	156,859	1,411,452	49,813	27	49	44	48

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Kaikorai Stream	5,473	9,336	450	4	18	7	9
Kaipara Harbour	574,888	8,823,717	397,686	28	53	30	46
Kaiteretere Estuary	380	1,342	50	1	10	6	15
Kakanui River	89,673	731,515	43,440	34	52	33	44
Karamea River	130,762	355,579	14,876	12	23	23	24
Kauranga River	13,295	31,625	2,140	7	14	13	21
Kawhia Harbour	45,316	344,122	23,278	6	24	25	41
Lagoon Bay	70	290	12	2	16	7	7
Lake Brunton	1,466	15,544	390	17	42	42	42
Ligar Bay	406	1,569	54	0	5	6	8
Little Wanganui River	20,991	71,947	2,693	14	26	26	27
Mahitahi River	20,152	34,370	1,679	1	11	5	13
Mahurangi Harbour	9,955	75,938	10,958	8	35	18	33
Makawhio Rive	17,083	27,806	1,380	1	9	4	10
Maketu River	122,905	823,921	45,979	16	35	30	44
Manaia Harbour	5,914	13,433	829	1	7	9	15
Manakaiaua River	5,923	15,185	745	1	17	7	19
Manawatu River	587,648	6,799,098	516,532	17	42	34	48
Mangakuri River	10,486	87,658	13,561	3	19	23	33
Mangawhai Harbour	6,571	68,520	5,495	28	53	30	45
Mangonui Harbour	25,644	269,492	11,857	18	37	27	44
Manukau Harbour	81,853	898,267	76,942	27	48	32	47
Maraetaha River	7,834	53,323	4,811	2	11	24	40
Marahau River	2,740	5,539	266	0	1	1	1
Marakopa River	36,450	265,558	19,715	4	24	23	39
Mataikona River	19,120	115,369	15,223	3	18	26	45
Matakana River	4,855	48,635	5,151	27	50	26	43
Matapouri Bay	1,406	6,597	316	2	14	17	30
Maungawhio Lagoon	7,379	52,671	3,665	21	34	33	54
Mikonui River	15,742	30,557	1,536	0	6	3	7
Mimi River	13,213	94,658	5,599	26	42	35	55
Miranda Stream	1,437	17,238	1,983	23	52	31	50
Mohakatino River	12,654	46,097	2,933	4	14	15	34
Mokau River	144,606	1,494,640	137,708	7	31	23	38
Mokihinui River	75,155	150,227	7,096	3	6	3	3
Motueka Estuary North	112	1,265	29	0	5	5	14

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Motueka Estuary South	161	421	9	0	2	3	6
Motupipi River	4,073	67,504	2,555	40	59	74	80
Moutere Inlet	18,560	130,706	5,190	4	16	14	29
Nelson Haven	10,630	23,123	855	0	1	1	1
New River Estuary	398,538	4,057,181	135,088	21	46	46	51
Ngakawau River	19,699	33,118	1,739	0	0	0	0
Ngaruroro River	336,907	2,170,802	209,468	4	17	22	34
Ngunguru River	7,988	53,812	2,601	2	18	16	30
Ohinemaka River	7,104	12,286	651	0	0	0	0
Ohinetamatatea River	9,487	24,291	1,195	1	16	7	18
Ohiwa Harbour	16,065	162,403	8,776	21	42	44	58
Okari Lagoon	7,556	76,536	2,613	15	48	39	57
Okarito Lagoon	30,256	58,172	2,350	9	24	15	16
Okura River	2,098	7,162	980	1	23	14	27
Okuru River	51,459	73,831	3,718	0	6	2	6
Onaero River	8,840	74,131	4,448	26	43	32	56
Onahau River	2,168	34,825	697	24	45	61	72
Onekaka Inlet	1,735	21,380	525	26	56	70	73
Oparara River	14,439	64,167	1,912	17	32	29	29
Orewa River	2,546	21,485	3,148	29	58	27	40
Orowaiti Lagoon	4,740	62,772	1,074	24	44	67	71
Otahu River	7,158	31,532	2,389	10	25	19	32
Otaki River	35,770	116,531	4,985	11	21	17	22
Oterei River	6,533	29,178	3,553	3	16	24	39
Otuwhero Inlet	5,795	18,284	994	1	7	6	7
Owahanga River	40,820	358,095	46,168	3	19	25	39
Pahaoa River	65,064	418,940	56,524	3	17	25	40
Pakarae River	24,440	201,804	24,804	3	18	26	42
Pakawau Inlet	942	5,865	157	19	41	26	36
Pakiri River	3,406	20,912	2,240	5	26	22	38
Papanui Inlet	1,006	4,570	171	2	14	4	4
Parapara Inlet	4,340	10,202	453	4	9	4	6
Parengarenga Harbour	19,594	142,380	19,514	1	33	15	28
Patanui Stream	3,497	26,179	2,677	2	22	19	29
Pataua River	5,043	45,733	2,798	20	40	24	41
Patea River	104,939	1,355,553	51,373	22	44	53	68

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Paturau River	9,093	18,953	1,074	0	3	3	3
Piako River	148,201	3,174,395	180,902	43	66	60	76
Pleasant River	12,904	53,582	3,899	5	25	13	24
Poerua River	25,830	115,323	3,535	18	43	38	42
Porangahau River	85,488	740,744	100,334	2	20	22	31
Porirua Harbour	17,199	68,651	4,608	2	15	16	43
Pororari River	10,405	19,017	1,000	0	0	0	0
Port Puponga	519	1,843	84	19	34	37	42
Pouawa River	4,252	34,729	5,135	4	19	28	48
Puhoi River	5,302	30,419	2,246	2	18	19	35
Purakunui Inlet	762	2,270	97	0	9	4	4
Purangi River	1,955	30,702	2,296	38	59	39	56
Raglan Harbour	50,527	462,638	36,740	19	39	29	47
Rangaunu Harbour	55,150	748,007	51,308	21	48	23	40
Rangitikei River	392,967	2,498,434	205,639	10	31	22	45
Ruakaka River	8,993	148,819	8,426	35	62	34	53
Ruataniwha Inlet	71,502	424,232	13,253	20	39	44	48
Saltwater Creek	14,608	53,011	1,657	8	18	15	18
Saltwater Lagoon	2,033	2,077	118	0	0	0	0
Sandfly Bay	2,143	3,700	214	0	0	0	0
Shag River	54,234	219,389	21,289	2	22	12	23
Tahakopa River	31,145	88,758	3,531	0	6	2	2
Tahoranui River	2,697	37,605	5,218	1	39	15	29
Tahunanui Estuary	327	29	1	0	0	0	0
Taieri River	570,636	2,244,550	122,636	12	27	17	21
Taiharuru River	1,300	18,803	2,293	25	57	21	36
Taipa River	12,618	128,450	5,840	27	45	36	51
Tairua Harbour	27,957	139,378	6,622	26	39	23	36
Takaka Estuary	489	15,239	330	32	53	67	83
Takou River	7,213	126,366	9,986	26	55	21	37
Tamaki River	8,675	3,753	734	2	31	16	30
Tapotupotu Bay	1,341	2,586	105	0	0	0	0
Tapuaetahi Creek	1,185	16,725	2,747	1	40	15	29
Taramakau River	100,526	246,539	9,401	12	31	23	26
Tauranga Harbour	122,190	937,516	52,563	15	31	27	39
Tautuku River	6,235	10,917	612	0	1	0	0

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Te Kouma Harbour	426	2,986	218	3	21	21	38
Te Muri-O-Tarariki	121	1,073	78	3	21	22	39
Three Mile Lagoon	2,587	4,271	205	0	0	0	0
Toetoes Harbour	542,993	3,620,626	158,300	18	36	31	32
Tokomairiro River	39,618	253,510	9,224	14	36	35	39
Tongaporutu River	27,216	102,183	6,575	14	28	22	35
Torrent Bay	1,510	2,608	150	0	0	0	0
Totara_1 River	10,885	25,773	1,250	3	14	7	14
Totara_2 River	13,538	93,813	2,299	18	36	38	44
Totaranui Stream	880	1,444	90	1	2	8	8
Turakina River	96,135	764,476	72,740	7	25	22	48
Turanganui River	32,358	227,558	24,892	3	13	26	46
Uawa River	55,868	372,236	30,341	2	12	23	38
Urenui River	13,357	66,154	4,399	17	32	29	47
Waiaro Estuary	1,150	3,049	209	5	16	21	32
Waiatoto River	54,116	59,817	3,043	0	1	1	1
Waiaua River	10,882	59,497	3,691	18	36	36	44
Waihi Estuary	33,806	549,644	32,474	34	53	46	61
Waihou River	198,285	3,140,087	165,705	41	62	56	72
Waikanae River	15,343	42,145	2,309	1	10	9	22
Waikari River	32,695	281,906	29,832	9	25	27	37
Waikato Estuary	314	1,111	69	1	9	7	7
Waikato River	1,447,372	15,420,681	861,635	27	51	48	60
Waikawa Harbour	23,799	114,750	3,850	4	18	13	13
Waikawau Estuary	2,765	7,974	527	3	13	18	29
Waikouaiti River	42,569	184,543	13,605	5	23	12	23
Waimakariri River	359,218	2,196,491	77,319	36	50	23	37
Waimaukau River	13,311	108,880	7,124	18	41	39	57
Waimea Inlet	91,584	390,962	14,827	4	12	11	18
Wainui Inlet	4,096	14,900	1,621	10	30	73	73
Waioeka River	120,375	495,491	34,995	11	24	30	42
Waiomoko River	7,196	61,018	8,294	3	18	25	38
Waiongana Stream	16,573	428,169	11,980	38	60	62	79
Waiotahi River	14,664	103,656	5,837	25	43	53	59
Waipaoa River	218,269	1,858,150	213,106	3	16	27	47
Waipati Estuary	7,269	19,156	800	0	4	1	1

Estuary name	Area (ha)	N loss (kg yr^{-1})	P loss (kg yr^{-1})	N reduction (%)		P reduction (%)	
				Current	Mid-century	Current	Mid-century
Waipoua River	11,228	37,783	1,047	3	11	8	13
Waipu River	22,099	359,530	14,885	41	62	39	59
Wairau River	412,020	1,533,392	72,542	3	10	9	12
Wairoa River	367,366	2,345,681	263,658	4	18	26	42
Wairoa_1 River	27,316	205,854	22,823	13	38	24	38
Waita River	13,130	21,203	1,109	0	1	0	1
Waitaha River	33,735	141,188	4,226	19	44	39	44
Waitahora Stream	614	1,125	49	0	0	0	0
Waitakaruru River	16,591	367,656	22,299	49	70	52	73
Waitara River	113,935	1,670,691	56,634	21	43	41	61
Waitemata Harbour	39,109	92,651	12,902	4	25	15	28
Waitotara River	116,188	488,286	31,984	10	23	23	40
Waiwakaiho River	13,635	277,411	5,487	27	48	58	73
Waiwera River	3,592	21,011	1,849	8	27	21	37
Wanganui River	713,591	4,119,639	330,874	5	23	22	38
Weiti River	2,782	17,661	3,607	9	45	18	33
Whakatane River	178,141	897,954	41,349	20	35	35	43
Whananaki Inlet	5,366	35,314	1,697	16	31	24	41
Whangaehu River	199,144	1,591,061	182,686	6	28	20	39
Whangamata Harbour	4,874	20,642	1,016	7	15	15	25
Whangamoa River	9,459	32,665	1,019	0	2	2	3
Whanganui Inlet	6,912	20,837	884	8	16	11	11
Whangapae Harbour	29,201	225,006	8,762	8	24	22	38
Whangaparaoa River	18,139	90,322	9,818	12	26	30	54
Whangapoua Creek	2,431	8,608	1,611	1	30	14	26
Whangapoua Harbour	10,121	64,593	2,584	24	35	24	37
Whangarei Harbour	26,766	252,328	18,391	26	50	25	42
Whangateau Harbour	3,734	36,477	2,290	16	29	26	41
Whareama River	53,248	404,737	50,714	3	18	25	39
Wharekahika River	16,156	65,837	6,754	3	14	25	45
Wharekawa Harbour	9,002	53,665	3,028	20	32	24	36
Whenuakura River	46,645	282,421	15,697	18	39	41	53
Wherowhero Lagoon	2,473	30,678	2,426	1	9	21	32
Whitford Embayment	5,333	25,789	3,317	6	31	19	34
Whitianga Harbour	42,445	239,503	13,436	27	42	24	38

Table A5.2. Potential relative nitrogen and phosphorus reduction (%) for modelled land-use change scenarios (N20, N40, N60, N80) targeting a 20%, 40%, 60%, and 80% nitrogen loss reduction in individual sea-draining estuary catchments

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
Ahuriri Estuary	20	40	60	80	21	46	75	88
Akatore Creek	52	52	52	52	0	0	0	0
Akitio River	20	40	60	80	14	33	55	88
Aotea Harbour System	20	40	59	76	31	54	67	80
Avon-Heathcote River	16	34	56	73	10	31	55	69
Awakino River	20	40	60	71	26	50	65	79
Awapoko River	20	40	60	80	23	33	49	93
Awaroa Inlet	0	0	0	0	0	0	0	0
Awhea River	20	40	60	76	13	32	56	82
Bark Bay	0	0	0	0	0	0	0	0
Blueskin Bay	26	37	43	45	3	10	16	18
Bluff Harbour	19	38	57	74	27	51	67	78
Buller River	20	40	53	53	17	38	41	41
Cascade/ Martyr River	18	24	25	26	17	21	22	22
Catlins River	18	40	60	72	13	26	49	59
Clutha River	19	39	59	67	31	32	50	59
Colville Bay	21	39	54	57	27	50	60	62
Coromandel Harbour	31	37	42	46	15	23	31	36
Delaware Estuary	38	42	44	45	6	13	16	17
Duffers Creek	37	47	51	51	8	13	13	13
Ferrer Creek	18	36	57	80	22	34	47	63
Frenchman Bay	0	0	0	0	0	0	0	0
Grey River	20	40	60	68	20	41	38	44
Haldane Estuary	19	35	42	50	13	22	25	26
Herekino Harbour	20	39	59	69	25	42	57	77
Hokianga Harbour	20	40	59	74	22	35	50	85
Hollyford River	100	100	100	100	100	100	100	100
Hoopers Inlet	20	40	59	66	13	25	38	42
Horahora River	20	40	60	71	19	38	51	76
Houhora Harbour	20	40	59	72	10	29	61	85
Jacobs River Estuary	20	40	60	80	15	34	58	73
Kaikorai Stream	17	33	51	62	6	18	34	43
Kaipara Harbour	20	40	60	80	19	32	52	89
Kaiteretere Estuary	33	33	33	33	0	0	0	0

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
Kakanui River	20	40	60	79	11	25	54	68
Karamea River	20	26	32	37	9	19	23	23
Kauranga River	19	25	27	27	20	28	34	34
Kawhia Harbour	20	40	60	76	31	53	69	80
Lagoon Bay	20	39	54	60	13	38	44	46
Lake Brunton	20	40	60	80	30	43	72	85
Ligar Bay	45	45	45	45	2	2	2	2
Little Wanganui River	19	37	49	49	12	27	26	26
Mahitahi River	19	26	27	27	18	23	23	23
Mahurangi Harbour	20	40	60	76	15	32	56	83
Makawhio Rive	18	21	22	22	16	18	18	18
Maketu River	20	40	60	79	21	44	80	85
Manaia Harbour	11	16	20	23	9	14	18	22
Manakaiaua River	18	30	39	39	19	28	35	35
Manawatu River	20	40	60	80	26	46	71	87
Mangakuri River	20	40	60	80	13	30	51	82
Mangawhai Harbour	20	40	60	78	22	35	53	90
Mangonui Harbour	20	40	58	77	20	41	56	82
Manukau Harbour	20	40	59	79	23	40	57	91
Maraetaha River	20	40	60	63	3	30	53	71
Marahau River	16	16	16	16	1	1	1	1
Marakopa River	19	40	60	75	28	50	65	79
Mataikona River	20	40	60	69	10	33	75	81
Matakana River	20	40	60	79	19	34	52	88
Matapouri Bay	18	39	49	53	16	42	53	56
Maungawhio Lagoon	20	40	60	60	0	20	63	63
Mikonui River	13	14	15	15	11	12	12	12
Mimi River	20	40	60	75	14	43	70	78
Miranda Stream	20	40	60	80	22	34	55	90
Mohakatino River	19	36	51	53	38	48	58	57
Mokau River	20	39	59	80	21	42	55	90
Mokihinui River	12	12	12	12	3	3	3	3
Motueka Estuary North	20	36	60	80	32	41	57	72
Motueka Estuary South	19	37	60	80	18	31	50	67
Motupipi River	20	40	60	79	16	68	84	86
Moutere Inlet	20	39	59	78	20	48	62	70
Nelson Haven	38	38	38	38	1	2	2	2

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
New River Estuary	20	40	60	80	21	43	64	76
Ngakawau River	1	1	1	1	0	0	0	0
Ngaruroro River	19	39	59	78	22	50	76	85
Ngunguru River	17	39	56	61	12	36	46	49
Ohinemaka River	0	0	0	0	0	0	0	0
Ohinetamatatea River	20	36	37	37	21	32	32	32
Ohiwa Harbour	20	40	60	77	18	43	71	82
Okari Lagoon	20	40	60	80	24	56	58	77
Okarito Lagoon	20	29	29	29	15	16	16	16
Okura River	27	40	50	57	14	27	46	65
Okuru River	12	13	13	14	10	11	11	11
Onaero River	20	40	60	78	16	41	70	82
Onahau River	20	40	60	80	37	65	71	71
Onekaka Inlet	20	40	60	80	31	64	74	72
Oparara River	20	40	51	56	20	27	27	26
Orewa River	20	40	60	80	16	32	45	89
Orowaiti Lagoon	20	40	60	80	43	66	69	64
Otahu River	20	39	57	59	17	39	61	67
Otaki River	19	38	44	44	11	26	33	33
Oterei River	20	40	60	64	12	33	73	76
Otuwhero Inlet	21	36	38	38	9	28	32	32
Owahanga River	20	40	60	80	15	33	55	88
Pahaoa River	20	40	60	71	9	29	61	81
Pakarae River	20	40	60	74	9	29	61	82
Pakawau Inlet	20	35	50	64	23	36	43	42
Pakiri River	18	38	60	76	20	42	63	82
Papanui Inlet	17	37	54	68	10	24	34	41
Parapara Inlet	13	16	20	21	5	7	7	7
Parengarenga Harbour	23	40	56	66	9	24	50	71
Patanui Stream	20	40	60	79	17	45	69	85
Pataua River	20	40	56	69	18	35	48	80
Patea River	20	40	60	80	24	47	79	84
Paturau River	13	17	17	17	15	21	21	21
Piako River	20	40	60	80	21	44	68	93
Pleasant River	20	40	60	68	7	28	57	63
Poerua River	20	40	60	60	19	41	43	43
Porangahau River	20	40	60	80	15	34	58	88

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
Porirua Harbour	17	37	58	64	20	51	64	69
Pororari River	0	0	0	0	0	0	0	0
Port Puponga	20	40	58	58	34	46	45	45
Pouawa River	20	40	60	76	9	27	72	85
Puhoi River	16	38	60	64	8	41	62	66
Purakunui Inlet	21	35	49	51	6	14	25	29
Purangi River	20	40	60	79	16	36	57	90
Raglan Harbour	20	40	60	76	18	39	60	80
Rangaunu Harbour	20	40	60	79	22	34	50	92
Rangitikei River	20	40	60	80	15	48	62	84
Ruakaka River	20	40	60	80	21	35	53	92
Ruataniwha Inlet	20	40	60	70	22	48	50	52
Saltwater Creek	23	32	32	32	0	8	8	8
Saltwater Lagoon	0	0	0	0	0	0	0	0
Sandfly Bay	0	0	0	0	0	0	0	0
Shag River	20	38	58	74	15	37	64	72
Tahakopa River	20	30	30	30	4	9	9	9
Tahoranui River	20	40	60	79	11	26	54	88
Tahunanui Estuary	35	35	35	35	0	0	0	0
Taieri River	19	39	59	74	23	34	42	59
Taiharuru River	20	40	60	80	17	29	53	89
Taipa River	21	40	60	76	19	39	58	83
Tairua Harbour	22	41	58	61	11	23	57	59
Takaka Estuary	20	40	60	80	35	65	84	87
Takou River	20	40	60	80	22	29	41	92
Tamaki River	20	39	58	78	22	36	54	93
Tapotupotu Bay	100	100	100	100	100	100	100	100
Tapuaetahi Creek	20	40	60	78	9	24	51	82
Taramakau River	20	40	42	43	21	26	28	28
Tauranga Harbour	20	39	59	76	21	43	71	79
Tautuku River	4	5	5	5	1	2	2	2
Te Kouma Harbour	20	39	59	75	33	52	68	81
Te Muri-O-Tarariki	20	40	60	76	30	53	69	82
Three Mile Lagoon	0	0	0	0	0	0	0	0
Toetoes Harbour	19	39	60	79	24	40	55	69
Tokomairiro River	20	40	59	71	5	26	51	59
Tongaporutu River	20	38	51	54	15	43	59	60

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
Torrent Bay	0	0	0	0	0	0	0	0
Totara_1 River	19	24	25	26	17	21	21	21
Totara_2 River	20	40	60	72	27	44	42	43
Totaranui Stream	2	3	3	3	8	8	8	8
Turakina River	19	39	59	78	19	49	65	82
Turanganui River	18	37	57	71	11	35	71	86
Uawa River	20	40	58	59	2	31	53	54
Urenui River	20	40	60	66	15	52	67	72
Waiaro Estuary	19	29	37	41	29	39	44	46
Waiatoto River	3	3	3	3	2	3	3	3
Waiaua River	20	40	57	61	26	45	71	72
Waihi Estuary	20	40	60	80	19	38	67	88
Waihou River	20	40	60	80	20	40	64	89
Waikanae River	17	32	34	34	1	27	27	27
Waikari River	20	40	60	75	11	34	61	84
Waikato Estuary	19	34	47	48	23	41	55	56
Waikato River	20	40	60	80	20	39	66	90
Waikawa Harbour	20	40	55	62	13	29	37	41
Waikawau Estuary	19	34	46	47	21	37	48	49
Waikouaiti River	18	39	60	73	14	30	58	69
Waimakariri River	20	40	60	80	14	28	43	68
Waimaukau River	20	40	60	73	19	55	67	87
Waimea Inlet	26	35	40	44	6	19	21	23
Wainui Inlet	19	36	44	51	69	76	76	76
Waioeka River	19	40	52	54	22	58	66	66
Waiomoko River	20	40	60	80	13	32	56	87
Waiongana Stream	20	40	60	80	25	50	76	83
Waiotahi River	20	40	60	69	21	46	78	77
Waipaoa River	20	40	60	74	11	32	73	86
Waipati Estuary	20	25	25	25	4	6	6	6
Waipoua River	20	23	23	23	4	7	7	7
Waipu River	20	40	60	80	20	36	54	90
Wairau River	20	40	56	56	18	43	51	51
Wairoa River	20	40	60	72	15	36	75	85
Wairoa_1 River	20	40	60	79	17	33	55	91
Waita River	2	2	2	2	2	2	2	2
Waitaha River	20	40	59	65	23	44	44	46

Estuary name	Nitrogen reduction (%)				Phosphorus reduction (%)			
	N20	N40	N60	N80	N20	N40	N60	N80
Waitahora Stream	100	100	100	100	100	100	100	100
Waitakaruru River	20	40	60	80	18	37	58	91
Waitara River	20	40	60	80	16	42	71	78
Waitemata Harbour	20	38	56	68	16	32	57	84
Waitotara River	18	39	56	56	20	48	63	63
Waiwakaiho River	20	40	60	80	28	57	73	73
Waiwera River	19	39	60	75	20	44	60	84
Wanganui River	20	40	60	67	23	45	61	73
Weiti River	21	40	60	78	15	30	49	89
Whakatane River	20	40	60	62	19	39	57	59
Whananaki Inlet	20	39	59	69	27	46	67	74
Whangaehu River	20	40	60	79	18	42	56	86
Whangamata Harbour	36	44	46	46	4	19	22	22
Whangamoa River	44	44	44	44	0	0	0	0
Whanganui Inlet	12	22	31	38	12	20	24	25
Whangapae Harbour	20	39	58	66	15	44	60	70
Whangaparaoa River	19	40	60	61	7	60	77	77
Whangapoua Creek	20	39	54	60	17	41	76	86
Whangapoua Harbour	29	40	49	51	6	18	26	31
Whangarei Harbour	20	40	58	74	22	35	49	84
Whangateau Harbour	21	40	57	74	20	35	63	82
Whareama River	20	40	60	73	9	29	57	82
Wharekahika River	17	35	50	54	12	56	68	72
Wharekawa Harbour	27	42	50	51	1	20	28	30
Whenuakura River	20	40	58	70	17	52	70	72
Wherowhero Lagoon	19	40	60	80	33	59	68	87
Whitford Embayment	22	39	58	74	19	35	57	85
Whitianga Harbour	20	39	54	65	14	31	48	67

Appendix 6 – National scale: modelled suspended sediment loads for baseline and reduction potential for mitigation and land-use change scenarios

Table A6.1. Baseline suspended sediment load (t yr^{-1}) and reduction potential (%) for mitigation scenarios (cf. Table 2) assuming the implementation of current available (Current) and current and future available mitigation measures at mid-century and end of century times under a changing climate

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%)						
			Current	Mid-century by RCP			End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Ahuriri Estuary	13,807	11,497	59	42	43	37	38	29	11
Akatore Creek	6,964	2,875	21	-6	-5	-13	-14	-29	-60
Akitio River	58,971	724,206	56	37	38	32	32	21	3
Aotea Harbour System	16,195	45,065	50	40	41	37	39	35	26
Avon-Heathcote River	21,487	1,884	40	33	32	34	34	26	19
Awakino River	38,338	473,913	50	25	27	17	20	8	-18
Awapoko River	9,551	391,335	67	35	35	26	28	11	-20
Awaroa Inlet	6,647	9,481	0	-8	-25	1	-7	-18	-16
Awhea River	15,192	455,282	35	-1	2	-12	-10	-31	-66
Bark Bay	693	1,060	0	-12	-27	-1	-10	-22	-20
Blueskin Bay	9,277	3,755	25	15	14	11	9	4	-14
Bluff Harbour	7,595	4,223	13	-3	-5	2	-6	-26	-25
Buller River	642,672	1,650,685	11	-22	-21	-33	-30	-48	-81
Cascade/ Martyr River	43,874	817,798	3	-9	-18	-19	-15	-30	-47
Catlins River	41,861	16,029	63	63	64	65	63	61	57
Clutha River	2,111,189	518,000	49	45	44	43	43	37	31
Colville Bay	4,202	7,590	32	29	29	27	29	28	29
Coromandel Harbour	6,950	5,957	13	8	8	5	8	3	3
Delaware Estuary	8,025	5,868	13	2	-9	8	4	-9	-11
Duffers Creek/ Rahotaiepa River	6,575	20,521	6	10	10	8	10	-1	-11
Ferrer Creek	1,432	2,278	36	31	23	36	32	26	26
Frenchman Bay	130	197	0	-11	-26	-1	-10	-22	-20
Grey River	394,744	1,142,741	15	-6	-5	-12	-8	-21	-42
Haldane Estuary	6,768	3,059	49	49	45	49	48	41	35
Herekino Harbour	8,806	66,025	48	3	3	-10	-8	-32	-77
Hokianga Harbour System	154,029	3,158,317	43	-7	-8	-21	-18	-46	-96
Hollyford River	113,487	62,331	0	-14	-22	-20	-15	-34	-52

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Current	Reduction potential (%) Mid-century by RCP 4.5	6.0	8.5	End of century by RCP 4.5	6.0	8.5
Hoopers Inlet	928	249	52	53	53	53	50	48	47
Horahora River	8,574	46,845	34	0	-2	-12	-9	-28	-66
Houhora Harbour	11,633	1,771	46	51	50	52	50	48	47
Jacobs River Estuary	156,859	111,273	62	61	60	63	59	54	48
Kaikorai Stream	5,473	1,445	37	41	39	39	36	34	26
Kaipara Harbour System	574,888	4,966,085	47	6	5	-7	-4	-27	-70
Kaiteretere Estuary	380	815	6	-1	-14	6	-1	-10	-9
Kakanui River	89,673	184,537	61	46	46	43	42	34	22
Karamea River	130,762	620,999	2	-14	-17	-22	-18	-30	-44
Kauranga River	13,295	3,028	9	2	2	1	0	-3	-4
Kawhia Harbour System	45,316	159,447	47	36	38	33	35	31	20
Lagoon Bay (Ruapuke Is)	70	0	0	0	0	0	0	0	0
Lake Brunton	1,466	155	76	79	74	79	77	72	70
Ligar Bay	406	453	11	-6	-13	-4	-5	-17	-42
Little Wanganui River	20,991	96,681	3	-43	-42	-58	-54	-81	-123
Mahitahi River	20,152	617,091	1	-15	-19	-22	-19	-32	-54
Mahurangi Harbour System	9,955	6,969	44	46	47	44	48	47	43
Makawhio River (Jacobs River)	17,083	373,903	1	-15	-23	-20	-19	-29	-50
Maketu River	122,905	58,099	42	31	31	28	29	22	6
Manaia Harbour	5,914	3,242	9	4	4	2	4	-2	1
Manakaiaua River	5,923	72,152	7	-9	-16	-16	-16	-26	-44
Manawatu River	587,648	3,015,562	57	40	41	35	37	25	9
Mangakuri River	10,486	390,606	54	37	37	31	32	22	4
Mangawhai Harbour	6,571	2,755	41	42	42	40	42	37	39
Mangonui Harbour	25,644	945,018	47	-6	-6	-21	-18	-46	-97
Manukau Harbour System	81,853	30,439	59	58	57	55	57	55	47
Maraetaha River	7,834	130,281	43	30	30	25	26	20	6
Marahau River	2,740	5,244	2	-4	-21	3	-3	-16	-14
Marakopa River	36,450	301,511	50	29	30	22	24	13	-9
Mataikona River	19,120	533,522	44	14	14	5	8	-11	-42
Matakana River	4,855	4,926	37	24	24	18	20	13	-6
Matapouri Bay System	1,406	2,396	18	25	21	21	24	26	31
Maungawhio Lagoon	7,379	21,207	28	21	23	20	21	17	10
Mikonui River	15,742	398,549	1	-17	-26	-27	-24	-34	-54
Mimi River	13,213	130,593	33	6	7	-2	-1	-17	-45

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Current	Reduction potential (%) Mid-century by RCP			Reduction potential (%) End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Miranda Stream	1,437	2,893	59	47	47	43	44	36	23
Mohakatino River	12,654	51,747	34	-2	0	-13	-11	-31	-71
Mokau River	144,606	2,156,913	57	30	32	22	24	9	-19
Mokihinui River	75,155	712,000	0	-47	-46	-64	-60	-87	-131
Motueka Estuary North	112	89	72	65	66	68	68	65	56
Motueka Estuary South	161	30	75	71	72	75	72	71	64
Motupipi River	4,073	8,770	52	43	36	43	44	36	21
Moutere Inlet	18,560	25,804	46	37	35	35	35	25	15
Nelson Haven	10,630	3,610	3	-12	-23	-9	-11	-28	-32
New River Estuary	398,538	323,513	61	57	57	58	55	51	47
Ngakawau River	19,699	155,693	0	-40	-39	-52	-49	-70	-112
Ngaruroro River	336,907	653,956	31	23	23	18	21	12	2
Ngunguru River	7,988	46,099	13	-35	-38	-53	-47	-75	-130
Ohinemaka River	7,104	71,743	0	-23	-24	-31	-28	-44	-70
Ohinetamatatea River (Saltwater Creek)	9,487	96,656	9	-8	-16	-17	-13	-25	-43
Ohiwa Harbour	16,065	20,275	42	32	34	29	30	26	16
Okari Lagoon	7,556	28,321	41	36	34	31	35	31	20
Okarito Lagoon	30,256	53,181	1	-12	-12	-17	-17	-26	-46
Okura River	2,098	5,621	18	-24	-24	-35	-35	-56	-102
Okuru River	51,459	1,390,733	0	-10	-18	-20	-13	-29	-49
Onaero River	8,840	87,958	31	9	10	2	4	-10	-33
Onahau River	2,168	3,984	50	48	42	51	49	47	38
Onekaka Inlet	1,735	23,500	25	3	0	-3	-3	-17	-35
Oparara River	14,439	88,038	4	-38	-36	-51	-46	-71	-108
Orewa River	2,546	1,036	51	51	50	48	52	49	45
Orowaiti Lagoon	4,740	12,595	40	23	23	18	21	12	-6
Otahu River	7,158	4,978	31	15	14	9	9	0	-17
Otaki River	35,770	214,195	1	3	-2	-2	1	-3	1
Oterei River	6,533	53,709	47	18	20	9	11	-5	-34
Otuwhero Inlet	5,795	7,646	18	12	0	18	15	4	2
Owahanga River	40,820	649,949	56	35	35	28	30	16	-5
Pahaoa River	65,064	384,221	40	10	12	1	3	-14	-43
Pakarae River	24,440	1,093,051	54	37	37	32	33	24	7
Pakawau Inlet	942	1,142	40	30	26	30	28	20	12
Pakiri River	3,406	6,144	39	15	14	6	9	-5	-31

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Current	Reduction potential (%) Mid-century by RCP			End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Papanui Inlet	1,006	302	61	57	58	57	55	51	51
Parapara Inlet	4,340	12,699	2	-18	-24	-21	-24	-37	-50
Parengarenga Harbour System	19,594	216,665	36	-29	-27	-45	-43	-78	-136
Patanui Stream	3,497	22,833	25	-20	-19	-34	-30	-52	-102
Pataua River	5,043	13,493	41	28	26	22	24	15	0
Patea River	104,939	99,642	43	27	28	22	24	12	-5
Paturau River	9,093	21,657	11	6	-3	11	5	-1	2
Piako River	148,201	96,775	70	72	71	71	72	69	67
Pleasant River	12,904	13,151	57	37	37	30	33	22	1
Poerua River (Hikimutu Lagoon)	25,830	269,227	7	-6	-11	-11	-8	-18	-34
Porangahau River	85,488	1,093,890	60	45	46	40	41	32	18
Porirua Harbour	17,199	26,263	37	35	34	35	32	32	30
Pororari River	10,405	70,136	0	-42	-42	-56	-51	-77	-115
Port Puponga	519	202	15	27	21	31	32	23	18
Pouawa River	4,252	73,648	55	41	42	37	38	32	18
Puhoi River	5,302	6,719	28	14	16	8	14	9	-8
Purakunui Inlet	762	319	38	25	25	21	19	14	-5
Purangi River	1,955	1,875	51	45	45	43	44	40	34
Raglan Harbour System	50,527	212,373	53	41	42	38	39	33	21
Rangaunu Harbour	55,150	138,259	49	10	10	-1	2	-19	-58
Rangitikei River	392,967	971,742	43	32	32	27	30	21	9
Ruakaka River	8,993	11,004	50	51	51	52	52	53	54
Ruataniwha Inlet	71,502	941,125	26	14	11	10	10	1	-8
Saltwater Creek/New River	14,608	57,627	5	-28	-27	-40	-34	-55	-91
Saltwater Lagoon	2,033	1,912	0	-6	-7	-11	-12	-21	-39
Sandfly Bay	2,143	3,211	0	-8	-25	1	-8	-20	-17
Shag River	54,234	62,807	59	43	43	38	38	27	14
Tahakopa River	31,145	11,565	31	29	28	29	28	24	16
Tahoranui River	2,697	2,789	47	46	48	43	43	46	36
Tahunanui Estuary	327	39	0	-31	-35	-39	-36	-61	-86
Taieri River	570,636	231,338	55	50	51	50	49	43	39
Taiharuru River	1,300	637	59	56	58	60	59	57	56
Taipa River	12,618	272,992	35	-28	-28	-46	-41	-75	-136
Tairua Harbour	27,957	16,092	26	17	16	14	14	8	3

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Current	Reduction potential (%) Mid-century by RCP			End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Takaka Estuary	489	1,568	75	72	70	72	73	70	63
Takou River	7,213	6,847	59	56	57	53	53	54	45
Tamaki River	8,675	580	47	37	35	32	34	27	10
Tapotupotu Bay	1,341	136	0	11	13	6	13	15	15
Tapuaetahi Creek	1,185	2,091	51	55	58	53	53	60	55
Taramakau River	100,526	1,095,956	4	-5	-9	-10	-8	-16	-31
Tauranga Harbour System	122,190	80,629	39	23	23	18	19	8	-11
Tautuku River	6,235	1,054	6	7	4	7	2	-3	-13
Te Kouma Harbour	426	456	44	31	31	27	28	19	8
Te Muri-O-Tarariki	121	120	45	47	48	46	52	51	51
Three Mile Lagoon	2,587	8,059	0	-14	-12	-19	-19	-25	-42
Toetoes Harbour	542,993	713,135	37	29	29	28	29	23	19
Tokomairiro River	39,618	34,177	38	22	22	17	16	5	-17
Tongaporutu River	27,216	106,492	17	-22	-20	-35	-32	-55	-98
Torrent Bay	1,510	2,398	0	-9	-25	0	-9	-21	-19
Totara_1 River	10,885	32,575	7	-20	-21	-30	-26	-41	-73
Totara_2 River	13,538	95,262	16	4	2	-3	-3	-13	-28
Totaranui Stream	880	1,157	0	-12	-15	-1	-9	-14	-18
Turakina River	96,135	608,382	63	45	46	39	41	31	14
Turanganui River	32,358	509,424	50	35	36	31	32	24	8
Uawa River	55,868	2,231,505	28	7	7	1	2	-9	-30
Urenui River	13,357	220,457	25	-2	-1	-11	-9	-26	-53
Waiaro Estuary	1,150	1,896	17	12	13	9	14	12	16
Waiatoto River	54,116	1,541,670	0	-11	-20	-24	-15	-33	-52
Waiaua River	10,882	26,714	8	11	14	10	8	6	12
Waihi Estuary	33,806	41,662	49	36	36	31	32	25	6
Waihou River	198,285	160,282	59	53	53	50	51	45	36
Waikanae River	15,343	21,837	9	9	7	5	7	4	3
Waikari River	32,695	113,158	55	45	45	42	43	37	26
Waikato Estuary	314	6,899	32	9	7	2	2	-11	-29
Waikato River	1,447,372	1,327,632	59	48	48	44	45	38	25
Waikawa Harbour	23,799	22,956	55	53	52	52	53	48	42
Waikawau Estuary	2,765	1,327	17	15	17	14	17	18	15
Waikouaiti River	42,569	40,993	61	54	55	53	53	50	41
Waimakariri River	359,218	526,111	16	8	6	8	8	4	-2

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Current	Reduction potential (%)					
				Mid-century by RCP			End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Waimaukau River	13,311	131,840	35	-21	-22	-38	-34	-67	-123
Waimea Inlet	91,584	120,828	21	4	1	2	2	-10	-23
Wainui Inlet	4,096	6,880	22	15	5	22	17	10	9
Waioeka River	120,375	459,389	21	17	19	14	17	14	12
Waiomoko River	7,196	339,115	52	35	34	29	30	21	2
Waiongana Stream	16,573	12,085	70	81	81	80	82	81	80
Waiotahi River	14,664	27,727	13	9	16	6	9	10	10
Waipaoa River	218,269	6,101,242	31	11	11	4	6	-5	-27
Waipati Estuary	7,269	2,507	26	22	19	21	20	13	7
Waipoua River	11,228	2,118	8	11	11	11	11	7	17
Waipu River	22,099	28,446	37	32	33	31	32	28	24
Wairau River	412,020	472,220	14	11	10	13	13	10	5
Wairoa River	367,366	4,216,247	53	40	40	36	37	31	16
Wairoa_1 River	27,316	32,379	41	36	37	31	36	35	28
Waita River	13,130	113,690	0	-19	-25	-29	-26	-42	-67
Waitaha River	33,735	835,409	4	-12	-22	-22	-17	-25	-44
Waitahora Stream	614	53	0	3	3	-2	5	8	11
Waitakaruru River	16,591	15,547	57	58	57	56	58	58	57
Waitara River	113,935	1,115,060	46	28	29	22	23	12	-7
Waitemata Harbour System	39,109	6,492	33	34	32	29	34	31	24
Waitotara River	116,188	481,654	38	16	18	10	12	-2	-24
Waiwakaiho River	13,635	15,710	48	46	46	44	48	44	40
Waiwera River	3,592	4,128	33	16	17	10	14	5	-16
Wanganui River	713,591	4,101,427	49	24	26	17	18	4	-22
Weiti River	2,782	12,663	49	22	22	14	15	0	-29
Whakatane River	178,141	263,721	9	7	8	0	7	5	5
Whananaki Inlet	5,366	9,846	28	33	31	31	33	36	39
Whangaehu River	199,144	984,946	60	43	44	38	40	30	13
Whangamata Harbour	4,874	2,631	15	4	2	-1	0	-5	-16
Whangamoa River	9,459	7,462	2	-11	-11	-4	-8	-19	-28
Whanganui Inlet	6,912	8,863	23	16	8	20	15	7	8
Whangapae Harbour System	29,201	641,588	42	-10	-10	-25	-22	-49	-101
Whangaparaoa River	18,139	1,983,015	43	28	28	23	24	16	2
Whangapoua Creek	2,431	887	22	7	7	1	5	-3	-17
Whangapoua Harbour	10,121	5,719	19	17	17	15	17	17	12

Estuary name	Area (ha)	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%)						
			Current	Mid-century by RCP			End of century by RCP		
				4.5	6.0	8.5	4.5	6.0	8.5
Whangarei Harbour System	26,766	177,831	35	-11	-13	-26	-22	-48	-100
Whangateau Harbour	3,734	3,923	29	9	8	1	4	-8	-32
Whareama River	53,248	1,179,217	47	13	14	3	6	-13	-48
Wharekahika River	16,156	585,786	40	23	23	17	18	9	-6
Wharekawa Harbour	9,002	4,767	14	7	4	3	3	0	-7
Whenuakura River	46,645	138,622	33	12	13	6	8	-6	-27
Wherowhero Lagoon	2,473	15,095	61	52	52	49	50	45	36
Whitford Embayment System	5,333	10,354	42	20	21	14	15	4	-21
Whitianga Harbour	42,445	24,038	32	26	27	25	25	22	19

Table A6.2. Baseline suspended sediment load (t yr^{-1}) and reduction potential (%) for land-use change scenarios (cf. Table 3) (N20, N40) targeting a 20% and 40% N reduction at mid-century and end of century times under a changing climate (RCPs 4.5, 6.0, 8.5)

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Ahuriri Estuary	11,497	-18	-18	-30	-28	-46	-82	9	10	0	2	-12	-40
Akatore Creek	2,875	8	10	2	1	-12	-39	8	10	2	1	-12	-39
Akitio River	724,206	-26	-26	-38	-37	-60	-98	-4	-3	-13	-12	-31	-62
Aotea Harbour System	45,065	18	20	14	17	12	-2	43	44	40	43	39	30
Avon-Heathcote River	1,884	13	11	12	12	1	-10	32	30	32	32	23	15
Awakino River	473,913	-9	-7	-22	-18	-37	-78	38	39	31	34	24	3
Awapoko River	391,335	-39	-38	-58	-52	-89	-156	-4	-3	-18	-13	-41	-91
Awaroa Inlet	9,481	-8	-25	1	-7	-18	-16	-8	-25	1	-7	-18	-16
Awhea River	455,282	-27	-23	-40	-38	-65	-108	-7	-4	-18	-17	-39	-76
Bark Bay	1,060	-12	-27	-1	-10	-22	-20	-12	-27	-1	-10	-22	-20
Blueskin Bay	3,755	6	4	1	-1	-7	-28	15	14	11	9	4	-16
Bluff Harbour	4,223	-8	-10	-3	-12	-33	-32	-5	-7	0	-8	-29	-27
Buller River	1,650,685	-27	-26	-39	-36	-55	-89	-18	-17	-29	-26	-44	-75
Cascade/ Martyr River	817,798	-9	-18	-19	-14	-30	-47	-9	-18	-18	-14	-30	-47
Catlins River	16,029	31	32	35	31	28	19	54	55	57	54	52	46
Clutha River	518,000	45	45	43	43	37	29	51	51	50	50	45	40
Colville Bay	7,590	28	29	26	29	28	29	40	40	38	40	40	41
Coromandel Harbour	5,957	20	21	18	21	16	16	23	24	21	24	19	19
Delaware Estuary	5,868	17	9	22	19	9	6	22	14	27	24	13	11
Duffers Creek/ Rahotaiepa River	20,521	34	34	32	34	26	19	36	36	34	36	28	21
Ferrer Creek	2,278	20	12	26	22	15	12	30	22	35	31	25	23
Frenchman Bay	197	-11	-26	-1	-10	-22	-20	-11	-26	-1	-10	-22	-20

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Grey River	1,142,741	-10	-9	-17	-12	-25	-47	-2	-2	-9	-5	-17	-38
Haldane Estuary	3,059	26	20	25	24	14	4	49	45	49	48	41	34
Herekino Harbour	66,025	-13	-13	-28	-26	-53	-105	20	20	9	10	-9	-46
Hokianga Harbour System	3,158,317	-28	-30	-46	-42	-75	-136	-9	-11	-24	-21	-49	-102
Hollyford River	62,331	100	100	100	100	100	100	100	100	100	100	100	100
Hoopers Inlet	249	23	24	23	19	16	13	44	44	44	41	38	36
Horahora River	46,845	-2	-3	-14	-10	-29	-67	23	22	14	17	2	-26
Houhora Harbour	1,771	34	33	36	33	29	29	56	54	56	55	53	52
Jacobs River Estuary	111,273	14	9	18	7	-7	-24	37	34	40	32	23	11
Kaikorai Stream	1,445	27	24	24	19	17	7	41	39	39	35	34	25
Kaipara Harbour System	4,966,085	-44	-45	-63	-59	-94	-160	-26	-27	-43	-39	-70	-128
Kaiteretere Estuary	815	21	10	26	21	13	14	21	10	26	21	13	14
Kakanui River	184,537	-36	-38	-47	-47	-72	-105	-27	-28	-37	-37	-60	-91
Karamea River	620,999	-15	-18	-22	-18	-31	-45	-14	-17	-22	-18	-30	-44
Kauranga River	3,028	3	2	1	1	-3	-4	7	7	6	5	2	2
Kawhia Harbour System	159,447	26	28	22	25	19	7	41	43	38	41	37	27
Lagoon Bay (Ruapuke Is)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake Brunton	155	31	18	31	25	9	5	53	44	53	50	39	35
Ligar Bay	453	20	14	20	20	11	-8	20	14	20	20	11	-8
Little Wanganui River	96,681	-44	-43	-59	-55	-82	-125	-43	-42	-57	-54	-81	-123
Mahitahi River	617,091	-15	-19	-22	-19	-32	-53	-15	-19	-22	-19	-31	-53
Mahurangi Harbour System	6,969	31	31	28	33	31	26	48	48	46	50	48	44
Makawhio River (Jacobs River)	373,903	-14	-23	-20	-19	-29	-50	-14	-23	-20	-19	-29	-50
Maketu River	58,099	15	15	12	13	4	-15	41	41	39	40	33	20

Estuary name	Baseline suspended sediment load (t yr-1)	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Manaia Harbour	3,242	9	9	7	9	3	6	11	11	9	11	5	8
Manakaiaua River	72,152	-10	-17	-18	-17	-28	-46	-8	-15	-16	-15	-26	-44
Manawatu River	3,015,562	-4	-3	-14	-10	-31	-61	22	22	14	17	2	-20
Mangakuri River	390,606	-24	-22	-35	-32	-52	-88	6	7	-3	-1	-16	-43
Mangawhai Harbour	2,755	24	24	22	24	18	19	34	34	33	34	29	30
Mangonui Harbour	945,018	-89	-89	-116	-110	-160	-252	5	4	-9	-6	-31	-78
Manukau Harbour System	30,439	24	20	19	22	17	4	41	38	37	39	36	26
Maraetaha River	130,281	-8	-8	-16	-14	-25	-49	-1	-1	-8	-7	-17	-39
Marahau River	5,244	2	-14	9	3	-9	-7	2	-14	9	3	-9	-7
Marakopa River	301,511	10	11	1	3	-10	-39	38	39	32	34	25	6
Mataikona River	533,522	-31	-30	-45	-40	-70	-117	-10	-10	-22	-18	-43	-83
Matakana River	4,926	6	5	-1	2	-6	-26	23	23	17	20	13	-5
Matapouri Bay System	2,396	28	24	24	27	29	34	37	33	33	35	37	41
Maungawhio Lagoon	21,207	9	11	5	7	0	-14	17	19	14	16	10	-3
Mikonui River	398,549	-17	-26	-27	-24	-34	-54	-17	-26	-27	-24	-34	-54
Mimi River	130,593	-34	-32	-46	-43	-66	-106	-13	-11	-22	-20	-40	-73
Miranda Stream	2,893	-2	-4	-9	-8	-22	-47	6	5	-1	0	-13	-38
Mohakatino River	51,747	0	2	-11	-9	-29	-68	6	8	-4	-2	-21	-58
Mokau River	2,156,913	-24	-21	-38	-35	-61	-111	37	38	30	31	18	-7
Mokihinui River	712,000	-47	-45	-64	-60	-87	-131	-47	-45	-64	-60	-87	-131
Motueka Estuary North	89	12	14	19	19	12	-11	28	29	33	34	28	9
Motueka Estuary South	30	12	16	22	15	12	-10	32	35	40	35	32	15
Motupipi River	8,770	-5	-15	-4	-2	-16	-51	14	6	14	16	5	-22
Moutere Inlet	25,804	20	18	17	17	5	-8	53	51	52	51	45	38

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Nelson Haven	3,610	15	6	17	15	2	-1	15	7	17	16	3	0
New River Estuary	323,513	13	12	15	7	-3	-14	36	35	37	32	24	17
Ngakawau River	155,693	-39	-39	-52	-49	-69	-111	-39	-39	-52	-49	-69	-111
Ngaruroro River	653,956	6	6	0	3	-8	-23	26	26	21	24	16	6
Ngunguru River	46,099	-18	-21	-33	-28	-50	-94	-5	-7	-19	-14	-36	-78
Ohinemaka River	71,743	-23	-24	-31	-28	-44	-70	-23	-24	-31	-28	-44	-70
Ohinetamatatea River (Saltwater Creek)	96,656	-8	-16	-16	-13	-25	-43	-7	-15	-15	-12	-24	-42
Ohiwa Harbour	20,275	3	4	-2	-1	-9	-25	21	22	16	18	11	-2
Okari Lagoon	28,321	13	11	7	13	8	-6	38	36	33	37	33	22
Okarito Lagoon	53,181	-12	-11	-16	-16	-25	-45	-11	-11	-16	-16	-25	-44
Okura River	5,621	4	4	-5	-4	-21	-56	10	10	2	2	-13	-46
Okuru River	1,390,733	-10	-18	-20	-13	-29	-49	-10	-18	-20	-13	-29	-49
Onaero River	87,958	-29	-27	-39	-36	-56	-88	-3	-1	-11	-8	-24	-49
Onahau River	3,984	27	18	31	28	25	11	43	36	46	44	41	32
Onekaka Inlet	23,500	-11	-15	-17	-18	-33	-54	-2	-5	-8	-8	-22	-41
Oparara River	88,038	-39	-37	-52	-46	-72	-109	-38	-36	-51	-45	-71	-108
Orewa River	1,036	23	21	18	25	20	12	42	40	38	43	39	34
Orowaiti Lagoon	12,595	6	5	0	4	-6	-26	19	18	14	17	8	-11
Otahu River	4,978	-6	-7	-14	-13	-26	-50	22	22	17	18	9	-7
Otaki River	214,195	3	-2	-2	1	-4	1	4	-1	-1	1	-3	1
Oterei River	53,709	-26	-22	-39	-37	-62	-106	-8	-5	-19	-17	-39	-76
Otuwhero Inlet	7,646	10	-2	16	13	2	-1	21	10	26	23	13	12
Owahanga River	649,949	-31	-30	-44	-41	-68	-111	-2	-2	-13	-10	-32	-65
Pahaoa River	384,221	-21	-20	-34	-31	-54	-93	-5	-4	-16	-14	-34	-67

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Pakarae River	1,093,051	-21	-22	-33	-30	-48	-83	6	5	-3	-1	-15	-42
Pakawau Inlet	1,142	20	16	20	18	8	-1	24	20	24	22	13	4
Pakiri River	6,144	-12	-12	-23	-20	-38	-73	23	23	15	17	5	-19
Papanui Inlet	302	15	15	14	9	2	3	48	48	47	44	40	40
Parapara Inlet	12,699	-7	-12	-9	-12	-23	-34	-7	-12	-9	-12	-23	-34
Parengarenga Harbour System	216,665	-62	-59	-83	-79	-124	-197	-25	-23	-42	-39	-74	-130
Patanui Stream	22,833	-45	-45	-62	-58	-85	-144	-22	-22	-37	-33	-56	-106
Pataua River	13,493	3	1	-5	-3	-15	-40	15	14	8	10	-2	-24
Patea River	99,642	-19	-18	-28	-25	-43	-71	-9	-8	-17	-14	-31	-57
Paturau River	21,657	6	-4	11	5	-1	2	9	-1	14	8	2	5
Piako River	96,775	22	20	19	23	15	9	34	33	32	35	28	23
Pleasant River	13,151	-28	-28	-43	-37	-59	-102	-5	-4	-17	-13	-30	-66
Poerua River (Hikimutu Lagoon)	269,227	-7	-12	-12	-9	-19	-35	-4	-9	-9	-6	-16	-32
Porangahau River	1,093,890	-20	-20	-31	-29	-49	-80	6	7	-2	-1	-16	-40
Porirua Harbour	26,263	26	24	25	22	22	20	51	50	51	49	49	47
Pororari River	70,136	-42	-42	-56	-51	-77	-115	-42	-42	-56	-51	-77	-115
Port Puponga	202	25	19	30	30	21	16	27	21	31	32	23	18
Pouawa River	73,648	-14	-15	-23	-21	-35	-65	13	13	6	8	-2	-25
Puhoi River	6,719	2	5	-5	3	-3	-22	29	31	24	29	25	10
Purakunui Inlet	319	-14	-14	-21	-23	-33	-66	1	1	-5	-6	-15	-44
Purangi River	1,875	3	3	0	1	-5	-16	20	20	17	18	13	4
Raglan Harbour System	212,373	4	6	-2	0	-12	-33	35	36	31	33	25	12
Rangaunu Harbour	138,259	-58	-58	-78	-72	-109	-179	-22	-22	-38	-33	-62	-115
Rangitikei River	971,742	-20	-18	-29	-25	-44	-73	32	33	27	30	21	8

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Ruakaka River	11,004	18	18	21	21	21	22	31	31	33	32	33	35
Ruataniwha Inlet	941,125	-5	-8	-10	-10	-21	-34	14	11	10	10	2	-8
Saltwater Creek/ New River	57,627	-7	-7	-17	-12	-29	-60	-5	-4	-14	-9	-27	-56
Saltwater Lagoon	1,912	-6	-7	-11	-12	-21	-39	-6	-7	-11	-12	-21	-39
Sandfly Bay	3,211	-8	-25	1	-8	-20	-17	-8	-25	1	-8	-20	-17
Shag River	62,807	-19	-20	-31	-31	-56	-86	15	15	6	7	-11	-33
Tahakopa River	11,565	15	13	15	12	8	-2	28	27	28	26	22	14
Tahoranui River	2,789	39	42	37	37	38	24	56	58	54	54	56	48
Tahunanui Estuary	39	-19	-22	-27	-24	-47	-70	-19	-22	-27	-24	-47	-70
Taieri River	231,338	22	24	22	20	6	1	47	49	48	46	39	36
Taiharuru River	637	24	29	34	30	27	23	48	51	54	52	49	48
Taipa River	272,992	-60	-60	-82	-76	-118	-195	-32	-32	-50	-45	-80	-143
Tairua Harbour	16,092	6	5	3	2	-5	-13	13	12	10	9	3	-5
Takaka Estuary	1,568	19	13	21	21	13	-7	45	40	45	47	40	26
Takou River	6,847	31	34	27	27	29	15	42	44	38	38	40	27
Tamaki River	580	-2	-5	-11	-8	-20	-49	21	19	14	16	7	-15
Tapotupotu Bay	136	100	100	100	100	100	100	100	100	100	100	100	100
Tapuaetahi Creek	2,091	35	38	31	32	41	35	61	64	59	60	65	61
Taramakau River	1,095,956	-5	-9	-10	-8	-15	-31	-4	-9	-9	-7	-15	-30
Tauranga Harbour System	80,629	-5	-5	-12	-11	-26	-52	22	22	17	18	6	-13
Tautuku River	1,054	8	4	7	3	-2	-12	9	5	8	4	-1	-11
Te Kouma Harbour	456	22	22	17	18	8	-4	38	38	34	35	27	18
Te Muri-O-Tarariki	120	44	45	43	49	48	47	55	56	54	59	59	58
Three Mile Lagoon	8,059	-14	-12	-19	-19	-25	-42	-14	-12	-19	-19	-25	-42

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Toetoes Harbour	713,135	32	32	31	30	23	17	49	49	49	48	44	39
Tokomairiro River	34,177	11	11	4	3	-8	-29	23	24	18	17	8	-11
Tongaporutu River	106,492	-41	-39	-55	-52	-79	-127	-19	-17	-31	-28	-51	-92
Torrent Bay	2,398	-9	-25	0	-9	-21	-19	-9	-25	0	-9	-21	-19
Totara_1 River	32,575	-20	-21	-29	-25	-41	-72	-19	-20	-29	-25	-40	-71
Totara_2 River	95,262	1	0	-6	-5	-16	-31	7	6	0	1	-9	-24
Totaranui Stream	1,157	-12	-15	-1	-9	-14	-18	-12	-15	-1	-9	-14	-18
Turakina River	608,382	-22	-18	-33	-29	-53	-91	39	41	33	35	24	5
Turanganui River	509,424	0	0	-8	-6	-18	-44	32	32	27	28	20	3
Uawa River	2,231,505	-3	-3	-11	-9	-21	-45	27	26	21	22	13	-4
Urenui River	220,457	-33	-31	-44	-41	-63	-100	0	2	-8	-6	-23	-50
Waiaro Estuary	1,896	10	11	7	12	10	14	15	15	11	17	14	18
Waiatoto River	1,541,670	-11	-20	-24	-15	-33	-52	-11	-20	-24	-15	-33	-52
Waiaua River	26,714	18	20	17	15	13	19	20	23	19	17	16	21
Waihi Estuary	41,662	-4	-5	-12	-11	-23	-56	4	4	-3	-2	-14	-44
Waihou River	160,282	11	10	6	8	-4	-21	29	29	25	27	17	4
Waikanae River	21,837	12	10	8	10	6	6	21	19	18	19	16	16
Waikari River	113,158	-10	-9	-17	-15	-27	-51	12	13	6	7	-1	-21
Waikato Estuary	6,899	-11	-14	-19	-20	-36	-58	5	3	-2	-2	-15	-34
Waikato River	1,327,632	-16	-15	-26	-23	-40	-72	-7	-6	-15	-13	-28	-58
Waikawa Harbour	22,956	20	17	18	19	11	0	45	43	44	44	39	31
Waikawau Estuary	1,327	20	21	19	22	22	21	26	27	25	28	28	26
Waikouaiti River	40,993	2	3	-2	-1	-11	-31	27	28	24	24	17	1
Waimakariri River	526,111	-1	-2	-1	0	-5	-13	2	1	2	3	-2	-9

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Waimaukau River	131,840	-63	-65	-85	-81	-124	-200	-19	-20	-35	-32	-63	-118
Waimea Inlet	120,828	-1	-4	-4	-4	-17	-32	6	4	4	4	-8	-22
Wainui Inlet	6,880	3	-9	11	5	-3	-4	21	12	28	23	16	15
Waioeka River	459,389	8	10	4	8	4	1	24	26	21	24	21	21
Waiomoko River	339,115	-23	-24	-34	-33	-49	-85	-2	-3	-12	-10	-24	-54
Waiongana Stream	12,085	62	62	60	63	62	59	68	68	67	69	68	66
Waiotahi River	27,727	11	17	7	10	10	9	15	22	12	15	15	15
Waipaoa River	6,101,242	8	9	1	3	-8	-31	23	23	17	18	9	-10
Waipati Estuary	2,507	13	9	12	11	3	-4	18	15	18	17	10	3
Waipoua River	2,118	12	11	11	11	8	18	13	13	13	13	9	20
Waipu River	28,446	14	15	14	14	9	2	24	25	23	24	20	14
Wairau River	472,220	14	13	16	16	12	7	26	25	28	28	25	22
Wairoa River	4,216,247	-5	-5	-13	-11	-23	-49	19	19	13	15	6	-14
Wairoa_1 River	32,379	15	16	9	15	15	5	32	33	27	32	31	23
Waita River	113,690	-19	-24	-29	-26	-42	-67	-19	-24	-29	-26	-42	-67
Waitaha River	835,409	-14	-23	-24	-18	-27	-46	-12	-22	-22	-17	-25	-44
Waitahora Stream	53	100	100	100	100	100	100	100	100	100	100	100	100
Waitakaruru River	15,547	16	13	12	16	15	12	22	20	19	23	22	19
Waitara River	1,115,060	-32	-30	-43	-40	-61	-96	-9	-7	-18	-16	-33	-62
Waitemata Harbour System	6,492	18	16	13	18	13	3	35	33	31	35	32	25
Waitotara River	481,654	-12	-10	-20	-18	-37	-66	25	26	20	21	8	-11
Waiwakaiho River	15,710	25	25	22	27	23	16	38	39	36	40	36	31
Waiwera River	4,128	0	1	-8	-2	-12	-35	22	23	16	20	11	-8
Wanganui River	4,101,427	-9	-6	-19	-17	-38	-76	31	33	24	26	13	-11

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential by RCP (%) – N20						Reduction potential by RCP (%) – N40					
		Mid-century			End of century			Mid-century			End of century		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Weiti River	12,663	-15	-14	-26	-25	-46	-89	22	22	14	15	1	-29
Whakatane River	263,721	2	3	-5	2	-1	-1	7	8	0	7	5	5
Whananaki Inlet	9,846	28	25	25	28	30	34	33	31	31	33	35	39
Whangaehu River	984,946	-29	-26	-41	-37	-61	-100	48	49	44	45	36	20
Whangamata Harbour	2,631	15	14	10	11	5	-7	31	30	27	28	24	16
Whangamoa River	7,462	19	18	23	20	13	6	19	18	23	20	13	6
Whanganui Inlet	8,863	3	-6	6	2	-8	-9	12	3	15	11	2	2
Whangapae Harbour System	641,588	-63	-63	-85	-81	-122	-199	10	10	-2	0	-22	-64
Whangaparaoa River	1,983,015	-12	-12	-20	-19	-31	-53	46	46	42	43	37	27
Whangapoua Creek	887	-7	-7	-14	-10	-20	-36	8	8	2	5	-2	-16
Whangapoua Harbour	5,719	29	30	28	30	28	24	37	38	36	38	36	32
Whangarei Harbour System	177,831	-41	-44	-60	-55	-88	-155	-25	-27	-42	-37	-66	-126
Whangateau Harbour	3,923	9	9	1	5	-6	-27	18	17	11	13	4	-16
Whareama River	1,179,217	-40	-38	-56	-51	-82	-138	-15	-14	-28	-24	-50	-96
Wharekahika River	585,786	-5	-4	-12	-11	-23	-44	34	34	29	30	22	9
Wharekawa Harbour	4,767	19	15	15	14	11	4	28	25	24	24	21	15
Whenuakura River	138,622	-23	-22	-32	-29	-49	-78	14	16	9	10	-3	-24
Wherowhero Lagoon	15,095	13	14	8	10	1	-16	47	47	44	45	40	29
Whitford Embayment System	10,354	-1	0	-10	-9	-23	-55	31	31	25	26	16	-6
Whitianga Harbour	24,038	8	9	7	7	2	-3	25	25	24	24	20	17

Table A6.3. Baseline suspended sediment load (t yr^{-1}) and reduction potential (%) for land-use change scenarios (cf. Table 3) (N60, N80) targeting a 60% and 80% N reduction at mid-century and end of century times under a changing climate (RCPs 4.5, 6.0, 8.5)

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Ahuriri Estuary	11,497	64	65	61	62	56	47	67	67	64	64	59	50
Akatore Creek	2,875	8	10	2	1	-12	-39	8	10	2	1	-12	-39
Akitio River	724,206	22	22	15	16	1	-22	64	64	60	61	54	44
Aotea Harbour System	45,065	50	51	48	50	46	39	57	58	55	57	54	48
Avon-Heathcote River	1,884	52	52	53	53	48	43	58	57	58	58	54	49
Awakino River	473,913	51	52	45	48	40	24	56	57	52	54	48	34
Awapoko River	391,335	38	39	30	33	16	-14	54	54	47	49	37	15
Awaroa Inlet	9,481	-8	-25	1	-7	-18	-16	-8	-25	1	-7	-18	-16
Awhea River	455,282	9	11	-1	0	-19	-50	24	26	16	17	1	-25
Bark Bay	1,060	-12	-27	-1	-10	-22	-20	-12	-27	-1	-10	-22	-20
Blueskin Bay	3,755	23	22	19	18	13	-4	27	26	23	22	18	1
Bluff Harbour	4,223	-2	-4	3	-6	-26	-24	-2	-3	4	-5	-25	-23
Buller River	1,650,685	-17	-16	-27	-24	-42	-73	-17	-16	-27	-24	-42	-73
Cascade/ Martyr River	817,798	-9	-18	-18	-14	-30	-47	-9	-18	-18	-14	-30	-47
Catlins River	16,029	72	73	74	73	71	68	76	77	78	77	75	72
Clutha River	518,000	73	73	72	72	69	66	79	79	78	78	76	73
Colville Bay	7,590	45	45	44	46	45	46	46	46	45	47	46	47
Coromandel Harbour	5,957	24	24	22	24	20	20	25	25	23	25	20	21
Delaware Estuary	5,868	23	15	28	25	15	13	23	15	28	25	15	13
Duffers Creek/ Rahotaiepa River	20,521	36	36	34	36	29	21	36	36	34	36	29	21
Ferrer Creek	2,278	37	30	42	38	32	31	45	38	49	45	41	40
Frenchman Bay	197	-11	-26	-1	-10	-22	-20	-11	-26	-1	-10	-22	-20

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Grey River	1,142,741	-1	-1	-8	-4	-16	-37	0	0	-7	-3	-15	-35
Haldane Estuary	3,059	59	56	59	58	53	48	62	59	62	61	56	51
Herekino Harbour	66,025	31	31	22	23	7	-25	39	39	30	32	17	-11
Hokianga Harbour System	3,158,317	14	13	2	5	-18	-59	26	25	16	18	-1	-36
Hollyford River	62,331	100	100	100	100	100	100	100	100	100	100	100	100
Hoopers Inlet	249	62	62	62	60	58	57	69	70	69	68	66	66
Horahora River	46,845	29	28	20	23	9	-18	33	32	25	27	14	-11
Houhora Harbour	1,771	63	62	64	63	61	60	66	65	66	66	64	64
Jacobs River Estuary	111,273	61	59	63	59	53	47	68	66	69	66	61	57
Kaikorai Stream	1,445	55	53	53	50	49	42	58	56	56	54	52	46
Kaipara Harbour System	4,966,085	20	19	9	11	-8	-45	37	37	29	31	15	-13
Kaiteretere Estuary	815	21	10	26	21	13	14	21	10	26	21	13	14
Kakanui River	184,537	37	36	33	32	22	8	55	54	53	52	47	38
Karamea River	620,999	-14	-17	-22	-18	-30	-44	-14	-17	-21	-18	-30	-44
Kauranga River	3,028	7	7	6	6	3	2	7	7	6	6	3	2
Kawhia Harbour System	159,447	49	51	47	49	45	37	53	55	51	53	50	42
Lagoon Bay (Ruapuke Is)	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake Brunton	155	79	75	79	78	73	72	85	83	85	84	81	80
Ligar Bay	453	20	14	20	20	11	-8	20	14	20	20	11	-8
Little Wanganui River	96,681	-42	-41	-57	-53	-80	-123	-42	-41	-57	-53	-80	-123
Mahitahi River	617,091	-15	-19	-22	-19	-31	-53	-15	-19	-22	-19	-31	-53
Mahurangi Harbour System	6,969	56	56	54	57	56	52	59	59	57	60	59	56
Makawhio River (Jacobs River)	373,903	-14	-23	-20	-19	-29	-50	-14	-23	-20	-19	-29	-50
Maketu River	58,099	49	49	47	48	43	32	54	54	51	52	47	37

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Manaia Harbour	3,242	11	11	9	11	6	8	12	12	10	12	7	9
Manakaiaua River	72,152	-8	-15	-15	-15	-25	-43	-8	-15	-15	-15	-25	-43
Manawatu River	3,015,562	50	50	45	47	37	24	64	64	61	62	55	47
Mangakuri River	390,606	35	36	30	31	20	2	66	66	63	63	58	48
Mangawhai Harbour	2,755	45	45	43	45	41	42	50	50	48	50	46	47
Mangonui Harbour	945,018	31	31	21	23	5	-28	31	31	21	24	6	-28
Manukau Harbour System	30,439	57	55	54	56	54	47	66	65	64	65	64	58
Maraetaha River	130,281	55	55	52	52	48	39	60	60	58	58	55	46
Marahau River	5,244	2	-14	9	3	-9	-7	2	-14	9	3	-9	-7
Marakopa River	301,511	45	46	40	42	33	16	51	52	46	47	40	25
Mataikona River	533,522	36	36	29	32	17	-6	42	42	36	38	25	4
Matakana River	4,926	33	32	27	30	23	7	39	39	34	36	30	15
Matapouri Bay System	2,396	38	35	35	37	39	43	39	36	35	38	39	44
Maungawhio Lagoon	21,207	45	47	44	45	41	35	45	47	44	45	42	35
Mikonui River	398,549	-17	-26	-27	-24	-34	-54	-17	-26	-27	-24	-34	-54
Mimi River	130,593	15	17	8	9	-5	-30	21	22	14	15	1	-22
Miranda Stream	2,893	49	49	46	46	39	26	56	56	53	54	47	36
Mohakatino River	51,747	13	14	3	5	-13	-46	13	15	4	6	-12	-46
Mokau River	2,156,913	48	49	42	43	32	11	59	60	54	56	47	31
Mokihinui River	712,000	-47	-45	-64	-60	-87	-131	-47	-45	-64	-60	-87	-131
Motueka Estuary North	89	51	52	55	55	51	38	71	71	73	73	71	63
Motueka Estuary South	30	55	56	60	56	54	43	74	75	77	75	74	67
Motupipi River	8,770	44	38	45	45	38	23	49	44	50	50	44	30
Moutere Inlet	25,804	58	57	57	57	51	45	64	63	63	63	58	52

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Nelson Haven	3,610	15	7	17	16	3	0	15	7	17	16	3	0
New River Estuary	323,513	64	64	65	62	58	55	67	67	68	66	62	60
Ngakawau River	155,693	-39	-39	-52	-49	-69	-111	-39	-39	-52	-49	-69	-111
Ngaruroro River	653,956	40	40	37	39	33	27	43	43	40	42	37	31
Ngunguru River	46,099	-4	-6	-18	-13	-35	-77	-4	-6	-17	-13	-34	-77
Ohinemaka River	71,743	-23	-24	-31	-28	-44	-70	-23	-24	-31	-28	-44	-70
Ohinetamatatea River (Saltwater Creek)	96,656	-7	-15	-15	-12	-24	-42	-7	-15	-15	-12	-24	-42
Ohiwa Harbour	20,275	45	46	42	43	39	31	51	53	49	50	47	40
Okari Lagoon	28,321	39	38	35	39	35	24	44	43	40	43	39	29
Okarito Lagoon	53,181	-11	-11	-16	-16	-25	-44	-11	-11	-16	-16	-25	-44
Okura River	5,621	10	11	2	3	-13	-46	10	11	2	3	-13	-46
Okuru River	1,390,733	-10	-18	-20	-13	-29	-49	-10	-18	-20	-13	-29	-49
Onaero River	87,958	18	19	11	13	0	-20	20	21	14	15	3	-17
Onahau River	3,984	52	46	54	53	50	42	55	50	58	56	54	47
Onekaka Inlet	23,500	5	2	0	-1	-14	-32	8	6	3	3	-10	-27
Oparara River	88,038	-38	-36	-51	-45	-71	-108	-38	-36	-51	-45	-71	-108
Orewa River	1,036	52	50	48	53	50	46	59	58	57	60	58	54
Orowaiti Lagoon	12,595	26	26	21	24	15	-2	30	29	25	27	19	2
Otahu River	4,978	33	32	28	29	21	8	34	34	30	30	23	10
Otaki River	214,195	4	-1	-1	1	-3	2	4	-1	-1	1	-3	2
Oterei River	53,709	39	40	32	33	21	0	40	42	34	34	23	2
Otuwhero Inlet	7,646	24	12	29	26	16	15	24	12	29	26	16	15
Owahanga River	649,949	28	28	21	22	8	-16	63	63	59	60	52	40
Pahaoa River	384,221	24	25	16	18	4	-20	41	42	35	37	26	7

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Pakarae River	1,093,051	40	40	35	36	27	11	63	63	60	61	56	45
Pakawau Inlet	1,142	34	30	34	33	24	18	38	34	38	37	29	23
Pakiri River	6,144	29	29	22	24	13	-9	37	37	31	33	23	4
Papanui Inlet	302	69	69	69	67	64	64	76	76	76	74	72	72
Parapara Inlet	12,699	-7	-12	-8	-11	-23	-33	-7	-12	-8	-11	-23	-33
Parengarenga Harbour System	216,665	7	9	-5	-3	-29	-70	11	13	0	2	-23	-62
Patanui Stream	22,833	1	2	-10	-7	-26	-66	3	3	-9	-6	-24	-64
Pataua River	13,493	41	39	36	37	31	18	47	46	43	44	39	28
Patea River	99,642	40	41	36	38	28	14	45	46	41	42	34	21
Paturau River	21,657	9	-1	14	8	2	5	9	-1	14	8	2	5
Piako River	96,775	54	53	52	54	49	45	77	77	76	77	75	73
Pleasant River	13,151	61	61	56	58	51	39	65	65	61	63	57	45
Poerua River (Hikimutu Lagoon)	269,227	-4	-9	-9	-6	-15	-31	-4	-9	-9	-6	-15	-31
Porangahau River	1,093,890	38	39	33	34	24	8	71	71	69	69	64	57
Porirua Harbour	26,263	56	55	55	54	54	52	58	57	57	56	56	54
Pororari River	70,136	-42	-42	-56	-51	-77	-115	-42	-42	-56	-51	-77	-115
Port Puponga	202	29	23	34	34	25	21	29	23	34	34	25	21
Pouawa River	73,648	58	58	55	55	50	40	66	66	63	64	60	51
Puhoi River	6,719	33	35	29	33	29	15	34	35	29	34	29	15
Purakunui Inlet	319	40	40	37	36	31	17	41	41	38	37	32	18
Purangi River	1,875	36	36	34	35	30	23	59	59	58	58	56	51
Raglan Harbour System	212,373	55	56	52	53	49	39	64	65	62	63	59	52
Rangaunu Harbour	138,259	24	24	15	18	0	-34	36	36	28	31	16	-12
Rangitikei River	971,742	45	46	42	44	37	28	55	55	53	54	49	43

Estuary name	Baseline suspended sediment load (t yr⁻¹)	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Ruakaka River	11,004	52	52	53	53	53	55	60	60	61	61	61	62
Ruataniwha Inlet	941,125	17	15	13	14	5	-3	21	19	18	18	10	2
Saltwater Creek/ New River	57,627	-5	-4	-14	-9	-27	-56	-5	-4	-14	-9	-27	-56
Saltwater Lagoon	1,912	-6	-7	-11	-12	-21	-39	-6	-7	-11	-12	-21	-39
Sandfly Bay	3,211	-8	-25	1	-8	-20	-17	-8	-25	1	-8	-20	-17
Shag River	62,807	57	57	53	53	45	34	59	59	56	56	48	39
Tahakopa River	11,565	28	27	28	26	22	14	28	27	28	26	22	14
Tahoranui River	2,789	66	67	64	64	66	59	68	70	67	67	68	62
Tahunanui Estuary	39	-19	-22	-27	-24	-47	-70	-19	-22	-27	-24	-47	-70
Taieri River	231,338	55	57	56	55	49	46	73	74	73	73	69	67
Taiharuru River	637	58	61	63	61	59	59	64	66	68	66	65	65
Taipa River	272,992	-9	-9	-25	-21	-49	-102	1	1	-13	-9	-35	-82
Tairua Harbour	16,092	31	31	29	29	24	20	32	32	30	30	26	21
Takaka Estuary	1,568	72	70	73	73	70	64	77	75	77	78	75	69
Takou River	6,847	60	61	57	57	58	50	69	70	67	67	67	60
Tamaki River	580	45	43	40	42	36	21	51	50	47	49	44	30
Tapotupotu Bay	136	100	100	100	100	100	100	100	100	100	100	100	100
Tapuaetahi Creek	2,091	70	72	68	69	73	70	77	78	76	76	79	77
Taramakau River	1,095,956	-4	-9	-9	-7	-15	-30	-4	-9	-9	-7	-14	-30
Tauranga Harbour System	80,629	34	34	30	31	21	6	41	41	37	38	29	15
Tautuku River	1,054	9	5	9	4	-1	-11	9	5	9	4	-1	-11
Te Kouma Harbour	456	44	44	40	41	34	25	48	48	45	46	40	32
Te Muri-O-Tarariki	120	59	60	58	63	62	62	62	63	61	66	65	65
Three Mile Lagoon	8,059	-14	-12	-19	-19	-25	-42	-14	-12	-19	-19	-25	-42

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Toetoes Harbour	713,135	42	42	42	42	37	34	73	73	72	72	70	68
Tokomairiro River	34,177	51	51	47	47	40	27	55	55	52	51	45	32
Tongaporutu River	106,492	-15	-13	-27	-24	-46	-86	-15	-13	-26	-24	-45	-85
Torrent Bay	2,398	-9	-25	0	-9	-21	-19	-9	-25	0	-9	-21	-19
Totara_1 River	32,575	-19	-20	-28	-25	-40	-71	-19	-20	-28	-24	-40	-71
Totara_2 River	95,262	8	6	1	1	-8	-23	9	7	2	2	-8	-22
Totaranui Stream	1,157	-12	-15	-1	-9	-14	-18	-12	-15	-1	-9	-14	-18
Turakina River	608,382	60	61	56	57	49	37	71	72	69	70	64	56
Turanganui River	509,424	56	56	53	54	49	38	62	62	59	60	56	46
Uawa River	2,231,505	35	35	30	31	24	9	35	35	30	31	24	9
Urenui River	220,457	11	12	4	5	-9	-34	12	13	5	6	-8	-32
Waiaro Estuary	1,896	16	17	13	18	16	20	17	18	14	19	16	20
Waiatoto River	1,541,670	-11	-20	-24	-15	-33	-52	-11	-20	-24	-15	-33	-52
Waiaua River	26,714	23	25	22	20	19	24	23	26	22	20	19	24
Waihi Estuary	41,662	46	46	42	43	36	20	60	60	57	57	53	41
Waihou River	160,282	48	47	44	46	39	29	64	64	62	63	58	51
Waikanae River	21,837	21	19	18	19	16	16	21	19	18	19	16	16
Waikari River	113,158	42	43	39	40	34	22	69	69	67	67	64	58
Waikato Estuary	6,899	20	18	14	14	3	-13	21	19	15	15	4	-12
Waikato River	1,327,632	56	57	53	54	48	37	68	68	65	66	62	54
Waikawa Harbour	22,956	65	64	65	65	61	57	67	66	67	67	64	60
Waikawau Estuary	1,327	29	30	27	30	30	29	29	30	28	31	31	29
Waikouaiti River	40,993	71	71	70	70	67	62	74	74	74	73	72	67
Waimakariri River	526,111	1	-1	0	1	-3	-10	20	18	19	20	17	11

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Waimaukau River	131,840	-7	-8	-21	-19	-47	-97	-2	-3	-16	-13	-40	-87
Waimea Inlet	120,828	7	5	4	5	-7	-21	8	5	5	5	-6	-20
Wainui Inlet	6,880	22	12	28	24	17	16	22	13	29	24	17	17
Waioeka River	459,389	26	28	23	26	23	23	26	28	23	26	24	23
Waiomoko River	339,115	36	36	30	31	23	4	62	62	58	59	54	43
Waiongana Stream	12,085	76	76	75	77	76	74	84	84	83	85	84	83
Waiotahi River	27,727	21	28	19	21	22	22	22	29	20	22	23	23
Waipaoa River	6,101,242	47	47	43	44	37	24	51	51	48	48	43	30
Waipati Estuary	2,507	18	15	18	17	10	3	18	15	18	17	10	3
Waipoua River	2,118	13	13	13	13	9	20	13	13	13	13	9	20
Waipu River	28,446	32	33	32	32	28	24	47	47	46	47	44	40
Wairau River	472,220	31	31	34	33	31	28	31	31	34	33	31	28
Wairoa River	4,216,247	57	57	54	55	50	40	63	63	60	61	57	49
Wairoa_1 River	32,379	51	51	47	51	50	44	57	57	54	57	56	52
Waita River	113,690	-19	-24	-29	-26	-42	-67	-19	-24	-29	-26	-42	-67
Waitaha River	835,409	-12	-21	-22	-16	-25	-44	-12	-21	-22	-16	-25	-44
Waitahora Stream	53	100	100	100	100	100	100	100	100	100	100	100	100
Waitakaruru River	15,547	33	32	31	34	34	32	69	68	67	69	69	68
Waitara River	1,115,060	43	44	38	40	31	16	45	46	41	42	34	19
Waitemata Harbour System	6,492	41	40	37	41	38	32	43	42	40	43	41	35
Waitotara River	481,654	34	35	29	31	19	3	34	35	29	31	19	3
Waiwakaiho River	15,710	48	49	46	50	46	42	52	52	50	53	50	46
Waiwera River	4,128	26	27	20	24	16	-3	31	32	25	29	21	3
Wanganui River	4,101,427	42	44	37	38	27	8	47	48	42	43	33	15

Estuary name	Baseline suspended sediment load (t yr^{-1})	Reduction potential (%) – N60						Reduction potential (%) – N80					
		Mid-century RCP			End of century RCP			Mid-century RCP			End of century RCP		
		4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5	4.5	6.0	8.5
Weiti River	12,663	35	35	29	29	17	-7	42	42	37	37	27	5
Whakatane River	263,721	11	12	4	11	9	10	11	12	4	11	10	10
Whananaki Inlet	9,846	39	37	37	39	41	44	41	40	40	41	43	46
Whangaehu River	984,946	61	62	57	58	51	40	69	69	66	67	61	53
Whangamata Harbour	2,631	32	30	28	29	25	17	32	30	28	29	25	17
Whangamoa River	7,462	19	18	23	20	13	6	19	18	23	20	13	6
Whanganui Inlet	8,863	20	12	23	19	11	12	24	16	27	23	16	17
Whangapae Harbour System	641,588	25	25	15	16	-2	-37	28	28	19	20	2	-31
Whangaparaoa River	1,983,015	58	58	55	55	50	42	58	58	55	55	51	43
Whangapoua Creek	887	11	12	6	9	2	-10	13	13	8	11	4	-8
Whangapoua Harbour	5,719	40	40	39	40	40	36	40	41	39	41	40	36
Whangarei Harbour System	177,831	-5	-7	-19	-15	-39	-89	18	16	6	9	-9	-48
Whangateau Harbour	3,923	25	24	18	20	11	-8	29	29	23	25	16	-2
Whareama River	1,179,217	23	24	14	17	0	-31	48	48	42	44	32	12
Wharekahika River	585,786	41	41	37	38	31	20	43	43	39	40	33	22
Wharekawa Harbour	4,767	29	27	26	26	22	17	30	27	27	26	23	18
Whenuakura River	138,622	26	27	21	22	11	-7	27	28	22	23	12	-6
Wherowhero Lagoon	15,095	52	52	49	50	45	35	70	70	68	69	66	60
Whitford Embayment System	10,354	37	37	31	32	23	4	43	43	38	38	31	13
Whitianga Harbour	24,038	35	35	34	34	31	29	39	40	38	38	36	34

Appendix 7 – Time distribution of contaminant loads into New Zealand tidal estuaries

Time distribution of contaminant loads into New Zealand tidal estuaries

John Dymond[1] and Joseph Dymond[2]

[1]Manaaki Whenua – Landcare Research, Palmerston North

[2]JDJD, Palmerston North

Contents

Introduction

This technical memorandum describes results of task 2 (see below) of Managing Catchments for Healthy Estuaries – Land.

Task 2. Estimate time distribution of contaminant loads

(i). For rivers flowing into all estuaries (including case studies and focal estuaries), estimate the distribution (all time, separate seasons, el niño and la niña years) of contaminant discharge relative to the mean contaminant discharge (sediment, nitrogen, phosphorus – mass/second; E. coli – number/second). The approach will be to regionalise 2 parameter distributions as assessed from a national dataset referred to in Snelder et al. (2017).

(ii). For rivers flowing into all estuaries (including case studies and focal estuaries), estimate the distribution (all time, and separate seasons, el niño and la niña years) of water temperature and water discharge relative to mean values.

Contaminant discharge and units

The contaminants considered are total nitrogen (TN), total phosphorus (TP), *Escherichia coli* (E. coli), and suspended sediment (SS).

The units of TN concentration are gm/m^3 and the units of TN discharge are gm/s.

The units of TP concentration are gm/m^3 and the units of TP discharge are gm/s.

The units of E. coli concentration are cfu/100 ml the units of E. coli discharge are cfu/s.

The units of SS concentration are kg/m^3 and the units of SS discharge are kg/s.

Number of tidal estuaries in New Zealand

There are 210 tidal estuaries in New Zealand (see appendix 1), comprising 85 tidal river mouths, 95 tidal lagoons, and 30 shallow drowned valleys (Semadeni-Davies et al. 2021).

Methodology

(Snelder et al. 2017) have collated monthly measurements of TN, TP, and E. coli in New Zealand rivers from the 16 regional councils and unitary authorities and from NIWA. The raw data came from monthly samples collected at 1113 sites distributed across New Zealand, most of which are dated between 2000 and 2017. There are over 100 thousand measurements of TN; also TP; and also E. coli. Most of the TN, TP, and E. coli measurements have been associated with a water discharge measurement or estimate. The water discharge estimates have been used to convert the TN, TP, and E. coli concentration measurements (with units of mass/volume) to TN, TP, and E. coli discharge measurements (with units of mass/time), by multiplying concentration by discharge.

At each site, the mean contaminant discharge is estimated. Each measurement of contaminant discharge is then transformed by dividing by the mean and taking the natural log. This results in a near normal distribution of transformed contaminant discharge for each site, which appears to be independent of mean water discharge. We have lumped measurements of contaminant discharges from all sites (> 100,000) to estimate a national average distribution, from which percentiles of contaminant discharge at any estuary may be estimated (see following sections). The (Snelder et al. 2017) dataset does not include suspended sediment, which is a contaminant of interest for estuaries, so an analysis of turbidity was performed using data provided by (Whitehead 2018). Turbidity is linearly related to suspended sediment (SS) concentration so percentiles should be the same. (However, we are uncertain of the robustness of the turbidity measurements, so we currently recommend assuming that the percentiles of transformed SS discharge are the same as the percentiles of transformed TP discharge). The (Snelder et al. 2017) dataset does not include water temperature so this analysis could not be performed.

The time distribution of contaminant discharge for any river flowing into an estuary may be estimated from the percentiles (national average) of transformed contaminant discharge, estimated above, combined with the mean contaminant discharge of the river (see next section). Mean contaminant discharge (or annual contaminant load as commonly referred to) for rivers flowing into estuaries are provided by (Semadeni-Davies et al. 2021) and summarised in Appendix B. For those rivers flowing into estuaries where water discharge is measured (or modelled) as a time series, such as the case-study estuaries, it is possible to disaggregate mean contaminant discharge into a time series with the use of rating curves. The section Rating curves for contaminant discharge shows how these rating curves may be inferred from the percentiles (national average) of transformed contaminant discharge.

Estimation of contaminant discharge percentiles

A percentile of contaminant discharge (in discharge units) for any river, flowing into an estuary, or not, may be calculated by multiplying the mean contaminant discharge (in discharge units) of the river by the percentile (national average) of the relative contaminant discharge (unitless; see Tables 1-4). For example, the 0.10 percentile of TN discharge of the Moutere Inlet, which has an annual TN load of 150 t/yr (see Appendix B; FID=1) is calculated as:

Mean TN discharge = 150 t/yr = 150 x 10^6 gm/yr = 150 x 10^6/365.25*24*60*60 gm/s = 4.75 g/s

Table 1 gives the 0.1 percentile (i.e., exceeded 90% of the time) of relative TN discharge as 0.0773, therefore:

0.10 percentile of TN discharge = 0.0773*4.75 g/s = 0.36 g/s.

TN analysis

For estimating percentiles, TN_i discharge at a river site *i* was transformed as follows:

Transformed TN discharge = $\log\left(\frac{TN_i\, discharge}{\overline{TN_i discharge}}\right)$

where $\overline{TN_i discharge}$ is the mean total nitrogen discharge at river site *i*.

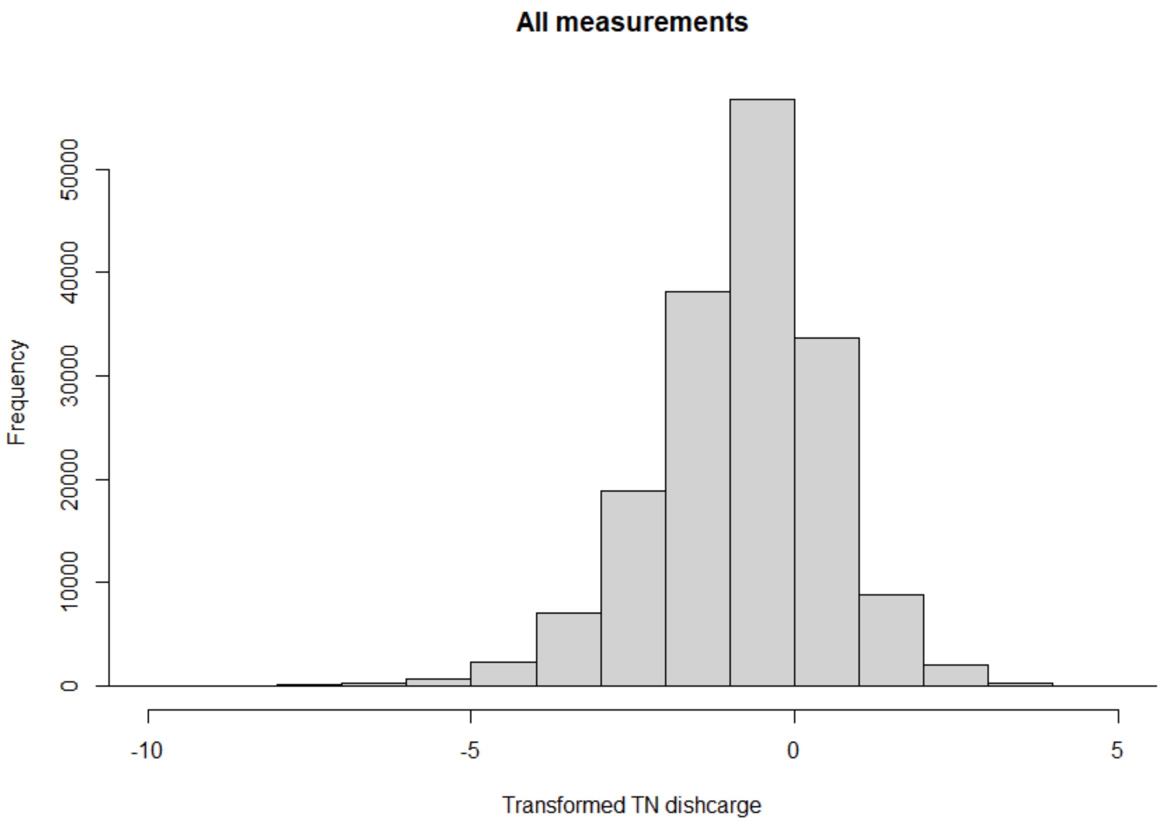

Figure 1. Histogram of all transformed TN discharge measurements in New Zealand rivers.

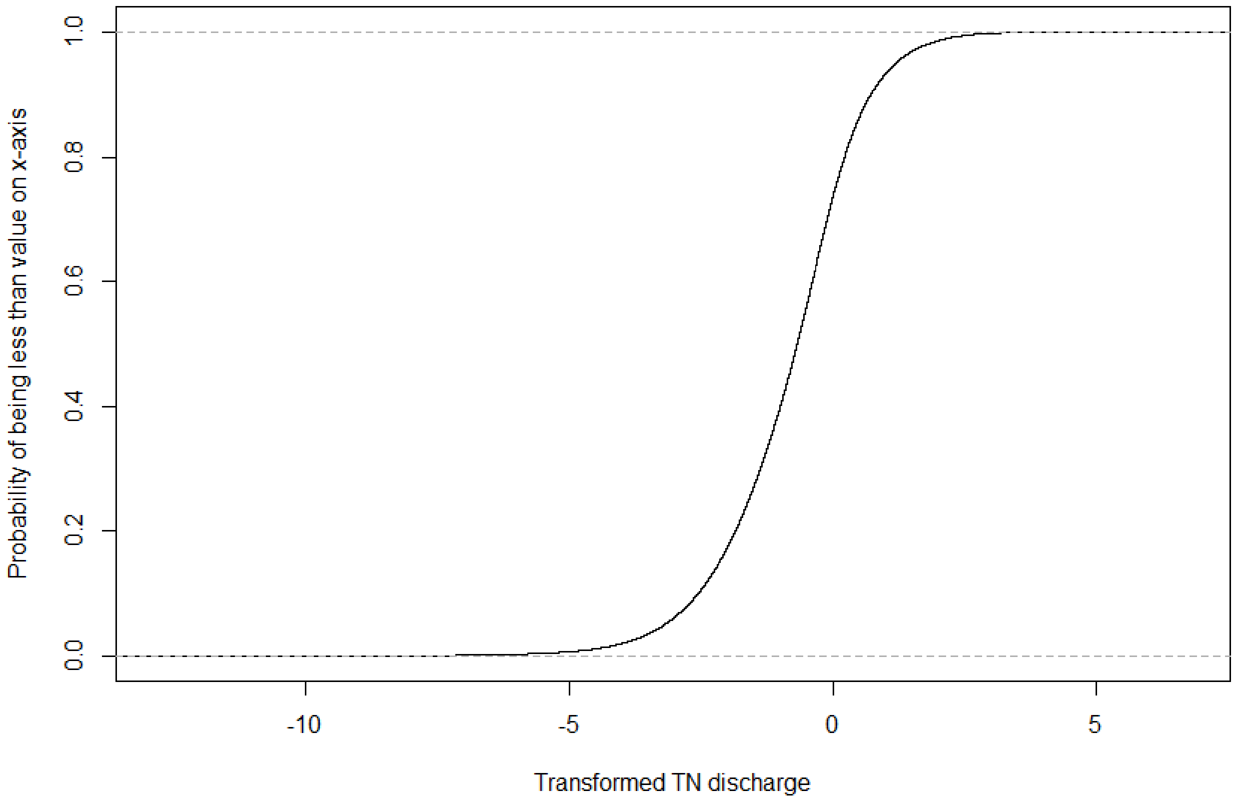

Figure 2. Cumulative distribution of all transformed TN discharge measurements in New Zealand rivers.

Table 1. Percentiles of transformed TN discharge and TN discharge relative to mean. Figures in brackets show standard error of estimate.

Percentile	Transformed TN discharge	Relative TN discharge
0.01	-4.63	0.0098
0.02	-4.00	0.0183
0.05	-3.19	0.0412
0.10	(±1.0) -2.56	0.0773
0.50	-0.68	0.5066
0.90	(±0.3) 0.72	2.0544
0.95	1.18	3.2544
0.98	1.78	5.9299
0.99	2.18	8.8463

TP analysis

For estimating percentiles, TP_i discharge at a river site *i* was transformed as follows:

Transformed TP discharge = $\log\left(\frac{TP_i\,discharge}{\overline{TP_i discharge}}\right)$

where $\overline{TP_i discharge}$ is the mean total nitrogen discharge at river site *i*.

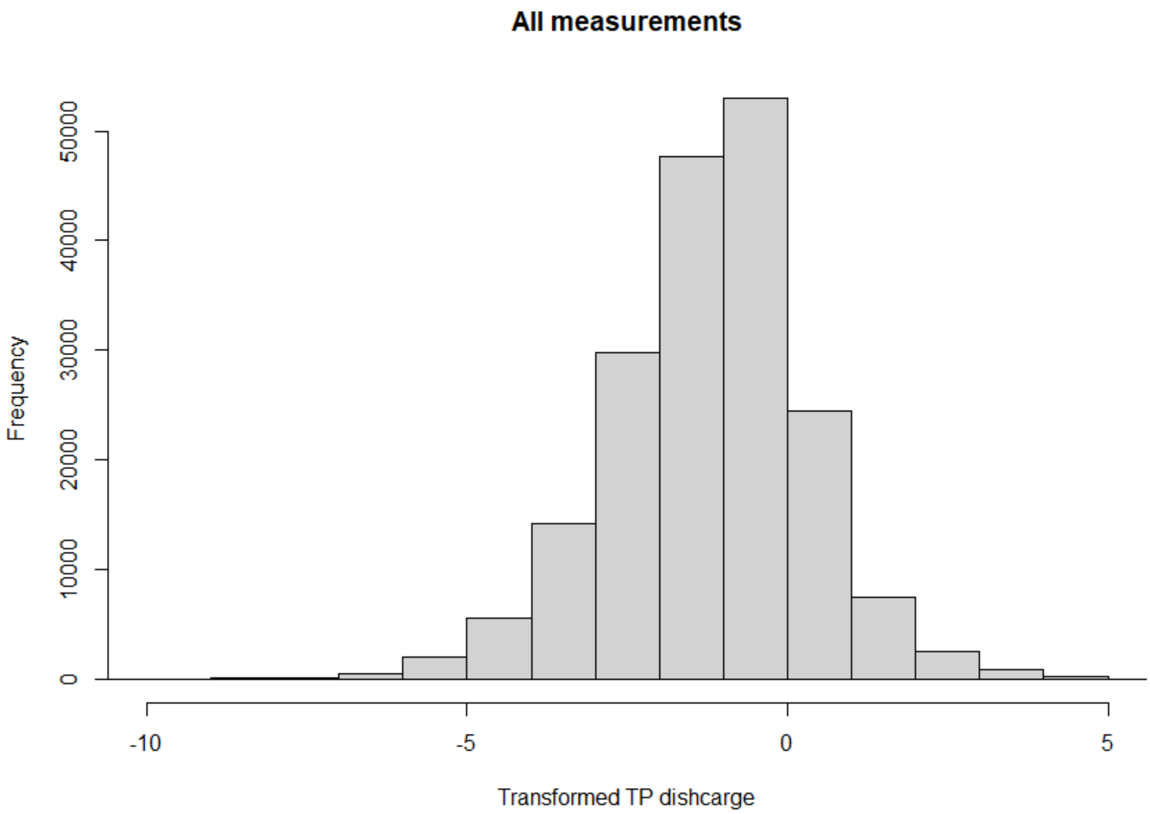

Figure 3. Histogram of all transformed TP discharge measurements in New Zealand rivers.

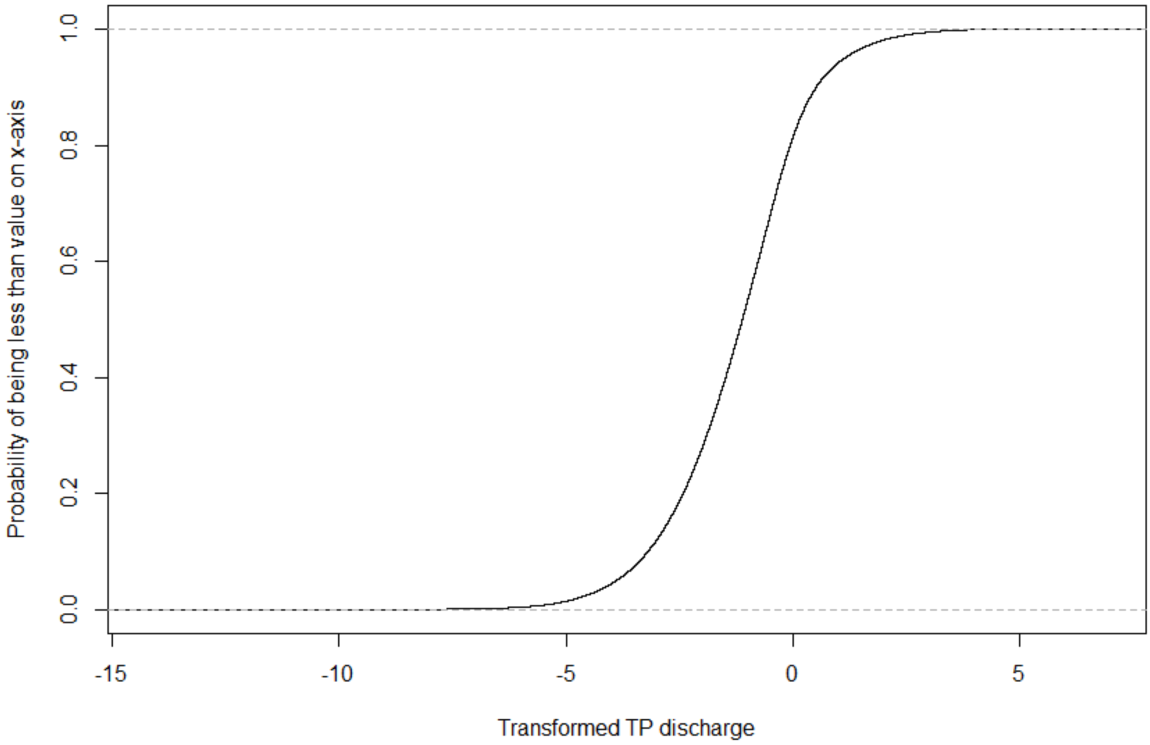

Figure 4. Cumulative distribution of all transformed TP discharge measurements in New Zealand rivers.

Table 2. Percentiles of transformed TP discharge and TP discharge relative to mean. Figures in brackets show standard error of estimate.

Percentile	Transformed TP Discharge	Relative TP Discharge
0.01	-5.31	0.0049
0.02	-4.74	0.0087
0.05	-3.89	0.0204
0.10	(±1.0) -3.20	0.0408
0.50	-1.11	0.3296
0.90	(±0.5) 0.52	1.6820
0.95	1.14	3.1268
0.98	1.96	7.0993
0.99	2.52	12.4286

E. coli analysis

For estimating percentiles, $ECOLI_i$ discharge at a river site *i* was transformed as follows:

Transformed E. coli discharge = $\log\left(\frac{ECOLI_i\, discharge}{\overline{ECOLI_i discharge}}\right)$

where $\overline{ECOLI_i discharge}$ is the mean *Ecoli* discharge at river site *i*.

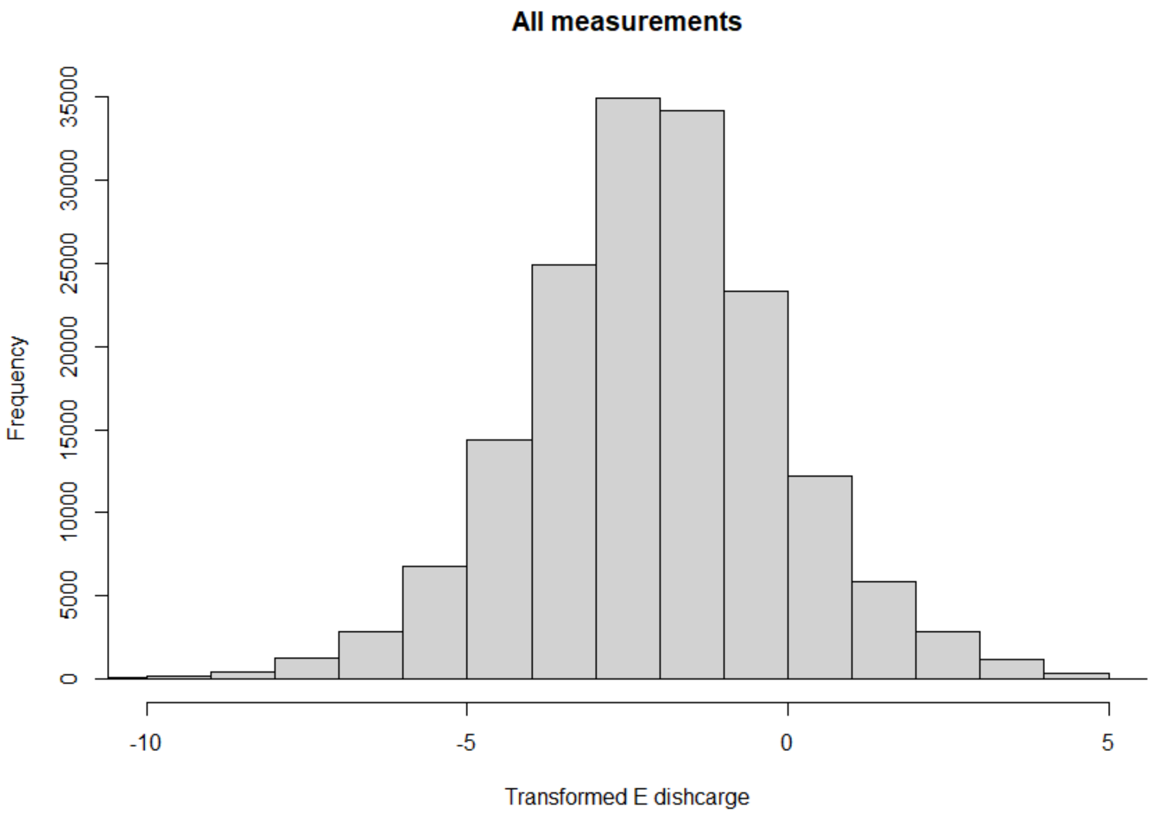

Figure 5. Histogram of all transformed E. coli discharge measurements in New Zealand rivers.

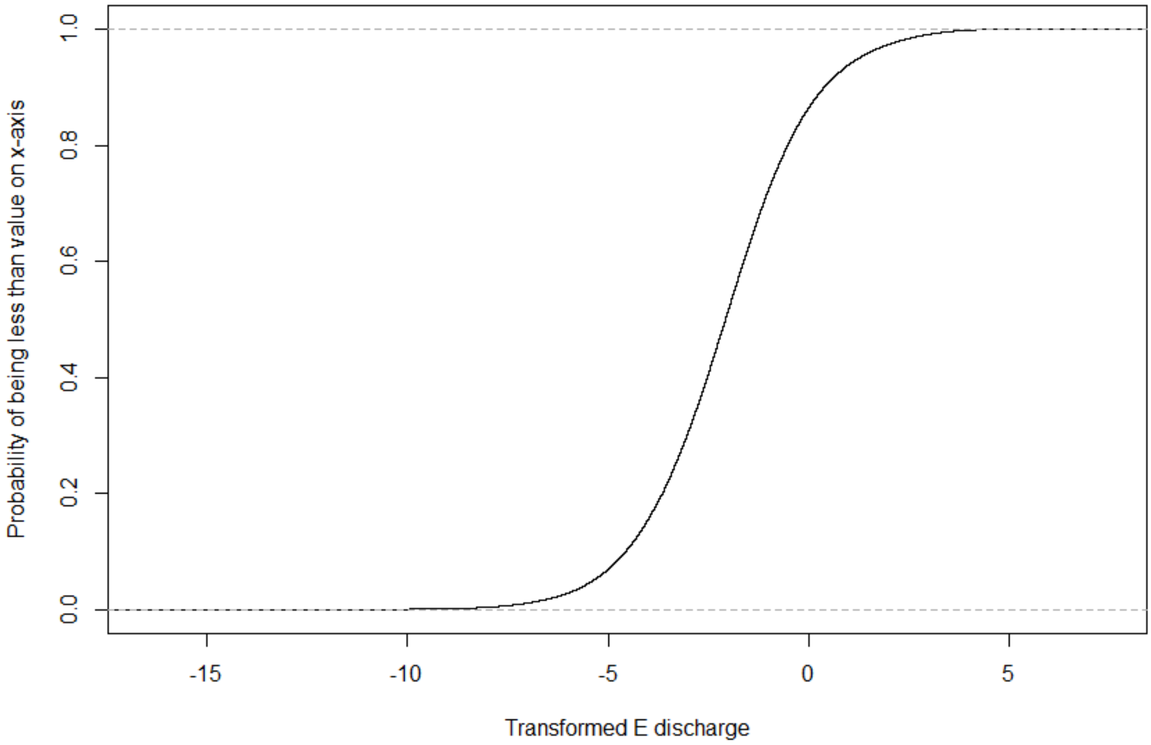

Figure 6. Cumulative distribution of all transformed E. coli discharge measurements in New Zealand rivers.

Table 3. Percentiles of transformed E. coli discharge and E. coli discharge relative to mean. Figures in brackets show standard error of estimate.

Percentile	Transformed E Discharge	Relative E Discharge
0.01	-7.15	0.0008
0.02	-6.40	0.0017
0.05	-5.39	0.0046
0.10	(±1.5) -4.58	0.0103
0.50	-2.09	0.1237
0.90	(±0.5) 0.37	1.4477
0.95	1.24	3.4556
0.98	2.27	9.6794
0.99	2.91	18.3568

TURB analysis

For estimating percentiles, $TURB_i$ discharge at a river site *i* was transformed as follows:

Transformed TURB discharge = $\log\left(\frac{TURB_i\, discharge}{\overline{TURB_i discharge}}\right)$

where $\overline{TURB_i discharge}$ is the mean turbidity discharge at river site *i*.

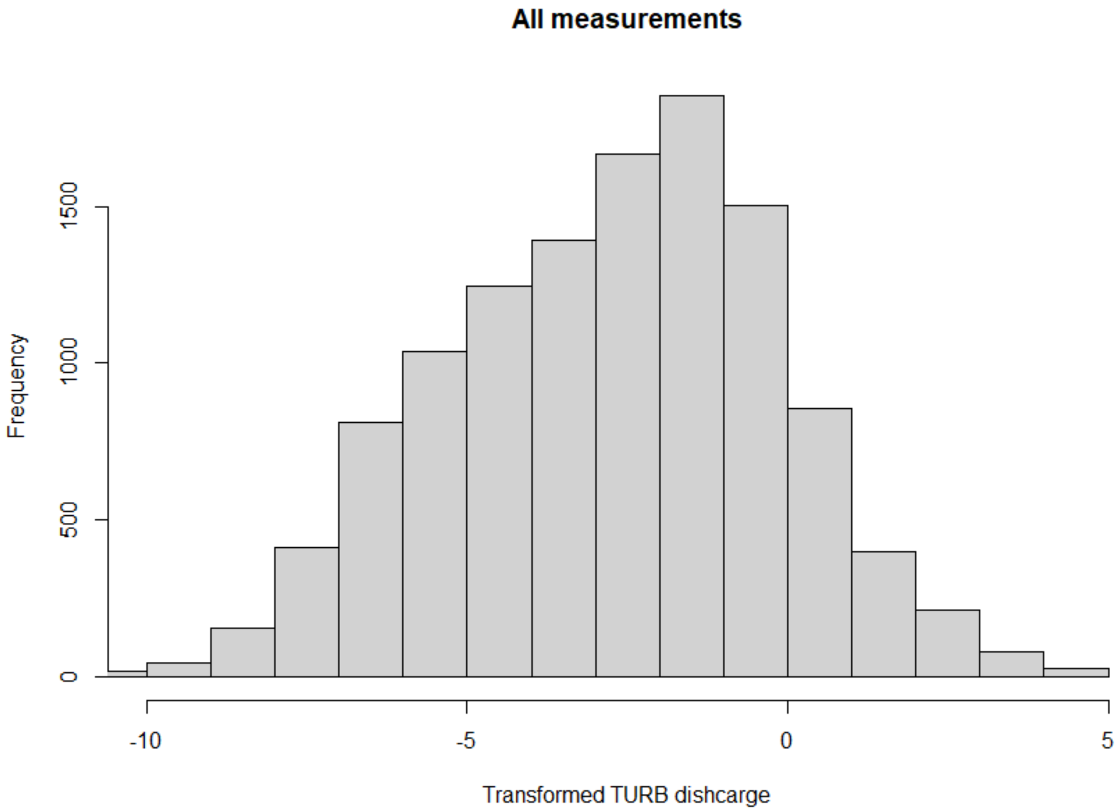

Figure 7. Histogram of all transformed TURB discharge measurements in New Zealand rivers.

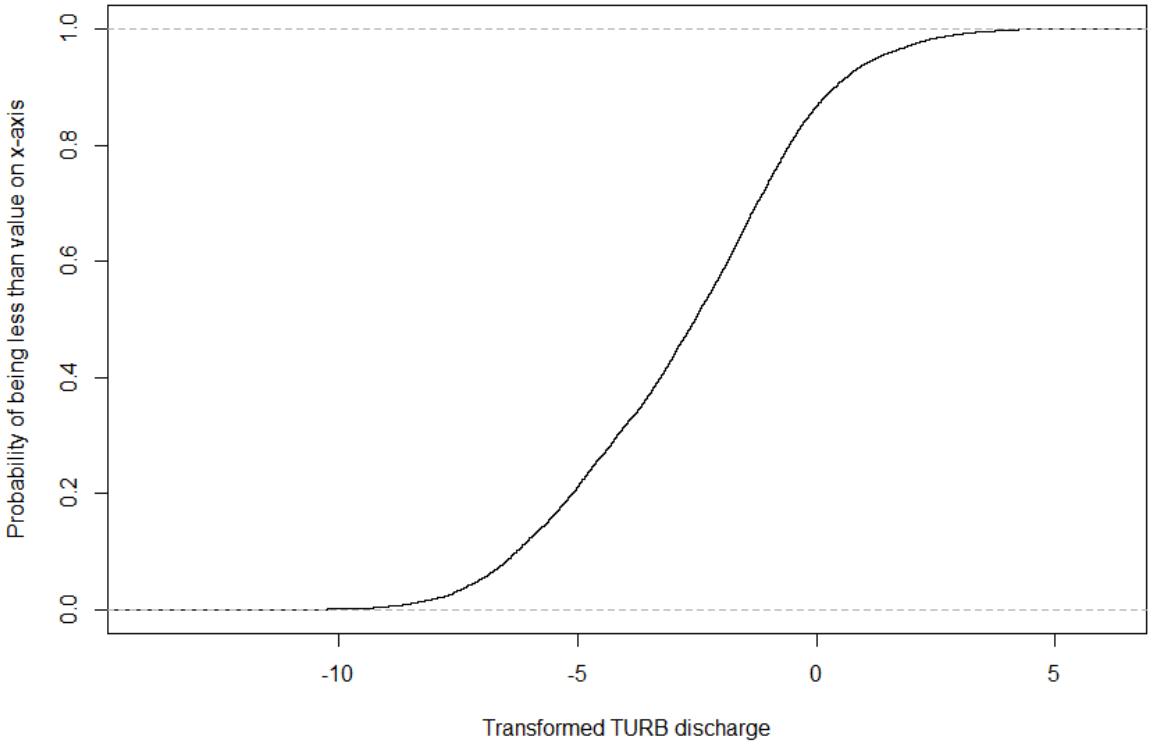

Figure 8. Cumulative distribution of all transformed TURB discharge measurements in New Zealand rivers.

Table 4. Percentiles of transformed TURB discharge and TURB discharge relative to mean.

Percentile	Transformed TURB Discharge	Relative TURB Discharge
0.01	-8.52	0.0002
0.02	-7.93	0.0004
0.05	-7.07	0.0009
0.10	-6.29	0.0019
0.50	-2.55	0.0781
0.90	0.39	1.4770
0.95	1.28	3.5966
0.98	2.3	9.9742
0.99	2.91	18.3568

Water discharge analysis

For estimating percentiles, discharge at a river site *i* was transformed as follows:

Transformed discharge = $\log\left(\frac{discharge_i}{\overline{discharge_i}}\right)$

where $\overline{discharge_i}$ is the mean discharge at river site *i*.

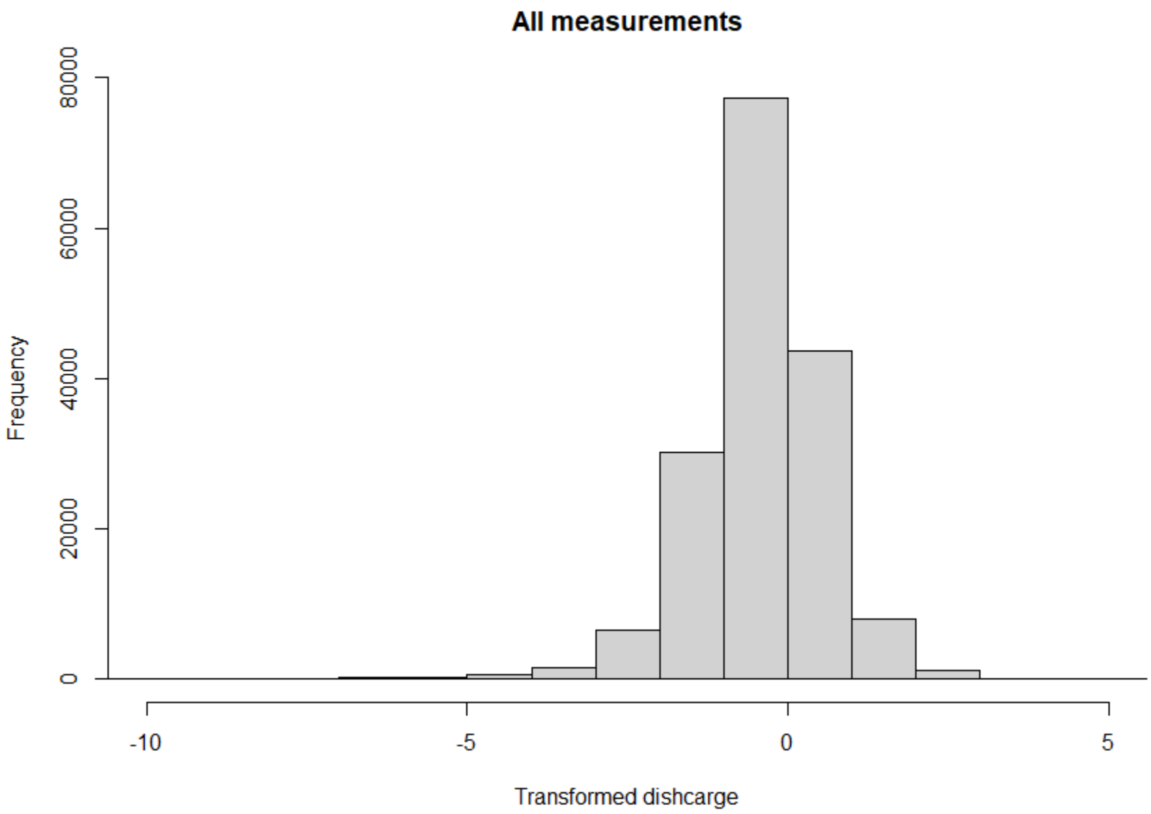

Figure 9. Histogram of all transformed discharge measurements in New Zealand rivers.

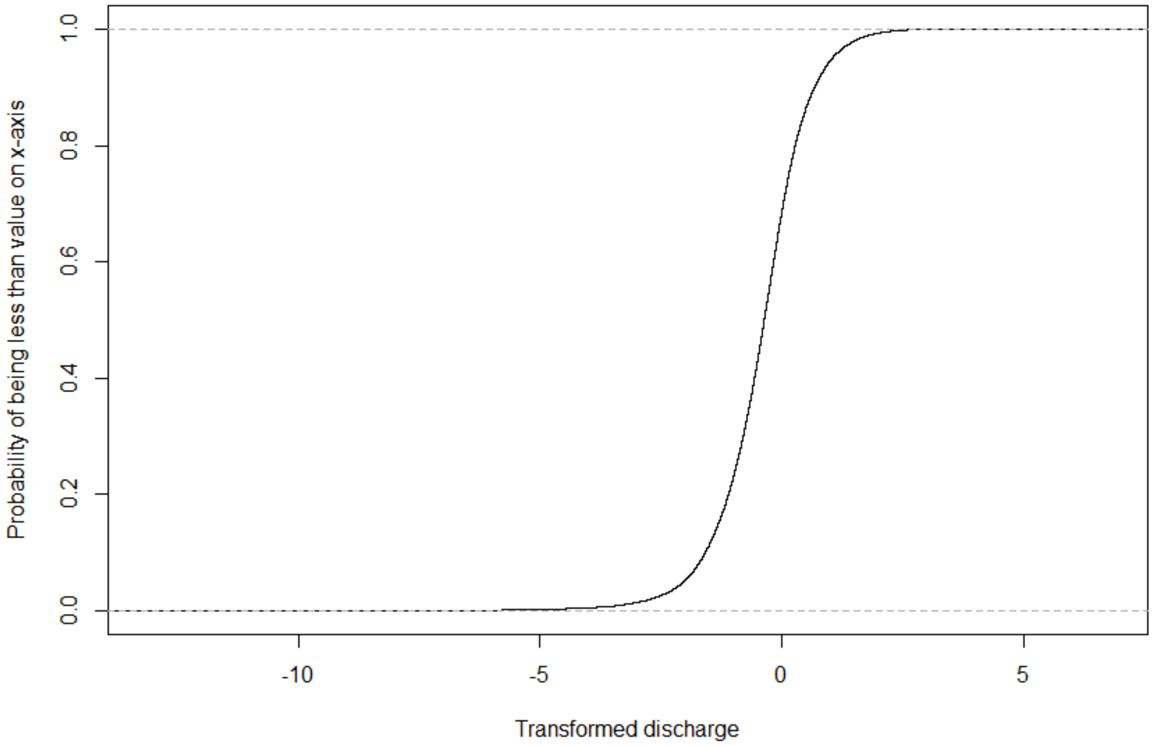

Figure 10. Cumulative distribution of all transformed discharge measurements in New Zealand rivers.

Table 5. Percentiles of transformed discharge and discharge relative to mean.

Percentile	Transformed Discharge	Relative Discharge
0.01	-3.29	0.0373
0.02	-2.72	0.0659
0.05	-2.04	0.1300
0.10	-1.59	0.2039
0.50	-0.37	0.6907
0.90	0.67	1.9542
0.95	1.03	2.8011
0.98	1.49	4.4371
0.99	1.82	6.1719

Seasonal variation

Table 6. Seasonal variation of mean relative contaminant discharge

	Summer	Autumn	Winter	Spring
Mean relative TN discharge	0.49	0.79	1.70	0.56
Mean relative TP discharge	0.59	0.79	1.56	0.70
Mean relative E. coli discharge	0.91	1.01	0.93	1.13
Mean relative TURB discharge	0.45	0.71	1.70	0.56

El Niño and La Niña variation

Table 7. El Niño and La Niña variation of mean relative contaminant discharge

	All years	El Niño years	La Niña years
Mean relative TN discharge	1.00	0.89	0.98
Mean relative TP discharge	1.00	0.85	0.96
Mean relative E. coli discharge	1.00	0.81	1.03
Mean relative TURB discharge	1.00	0.75	0.88

Rating curves for contaminant discharge

Contaminant discharge, p, may be estimated by applying a “rating curve” to water discharge, q :

$$p = \bar{p} \, . \, a \left(\frac{q}{\bar{q}}\right)^{b} \qquad (1)$$

where $\bar{p}$ is the mean contaminant discharge, $\bar{q}$ is the mean water discharge, and a and b are constants. Table 8 shows the rating curves inferred by matching percentiles in Tables 1-4 with those in Table 5. The rating curve for suspended sediment, in the absence of robust national data, is assumed to be the same as that for TP, as they often behave similarly (Parfitt et al. 2013). (The b value of 1.6 is consistent with national analysis (Hicks & Hoyle 2016)).

Table 8. Rating curves for contaminant discharge.

	a $(when\ q > \bar{q})$	b $(when\ q > \bar{q})$	a $(when\ q < \bar{q})$	b $(when\ q < \bar{q})$
TN discharge	1.0	1.2	1.0	1.5
TP discharge	0.6	1.6	0.6	1.6
E. coli discharge	0.3	2.3	0.3	3.5
SS discharge	0.6	1.6	0.6	1.6

The uncertainty of the rating curves can be estimated by the standard error of estimate of p. If we rewrite

$$f = a\left(\frac{q}{\overline{q}}\right)^{b}$$

then:

$$Var(p) = Var(\overline{p}\,.f)$$

$$\approx \overline{p}^{\,2}\, Var(f) + f^{2}\, Var(\overline{p}) \quad \text{(Independent errors)} \ (2)$$

Therefore, the fractional variance is approximately:

$$\frac{Var(p)}{p^2} \approx \frac{Var(\overline{p})}{\overline{p}^{\,2}} + \frac{Var(f)}{f^2} \qquad (3)$$

and the fractional standard error is approximately:

$$\frac{s.e.(p)}{p} \approx \sqrt{\frac{s.e.(\overline{p})}{\overline{p}} + \frac{s.e.(f)}{f}} \qquad (4)$$

Table 9. Fractional standard errors for estimating contaminant discharge with rating curve. Standard error of $\overline{p}$ comes from (Elliott et al. 2016). Standard error of f comes from Tables 1-3 in this technical memorandum.

	$\frac{s.e.(\overline{p})}{\overline{p}}$	$\frac{s.e.(f)}{f}$ $(when\ q > \overline{q})$	$\frac{s.e.(f)}{f}$ $(when\ q < \overline{q})$	$\frac{s.e.(p)}{p}$ $(when\ q > \overline{q})$	$\frac{s.e.(p)}{p}$ $(when\ q < \overline{q})$
TN discharge	1.5	2.5	1.5	3.0	2.0
TP discharge	1.8	2.5	1.5	3.0	2.5
E. coli discharge	2.7	4.5	1.5	5.0	3.0
SS discharge	1.8	2.5	1.5	3.0	2.5

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