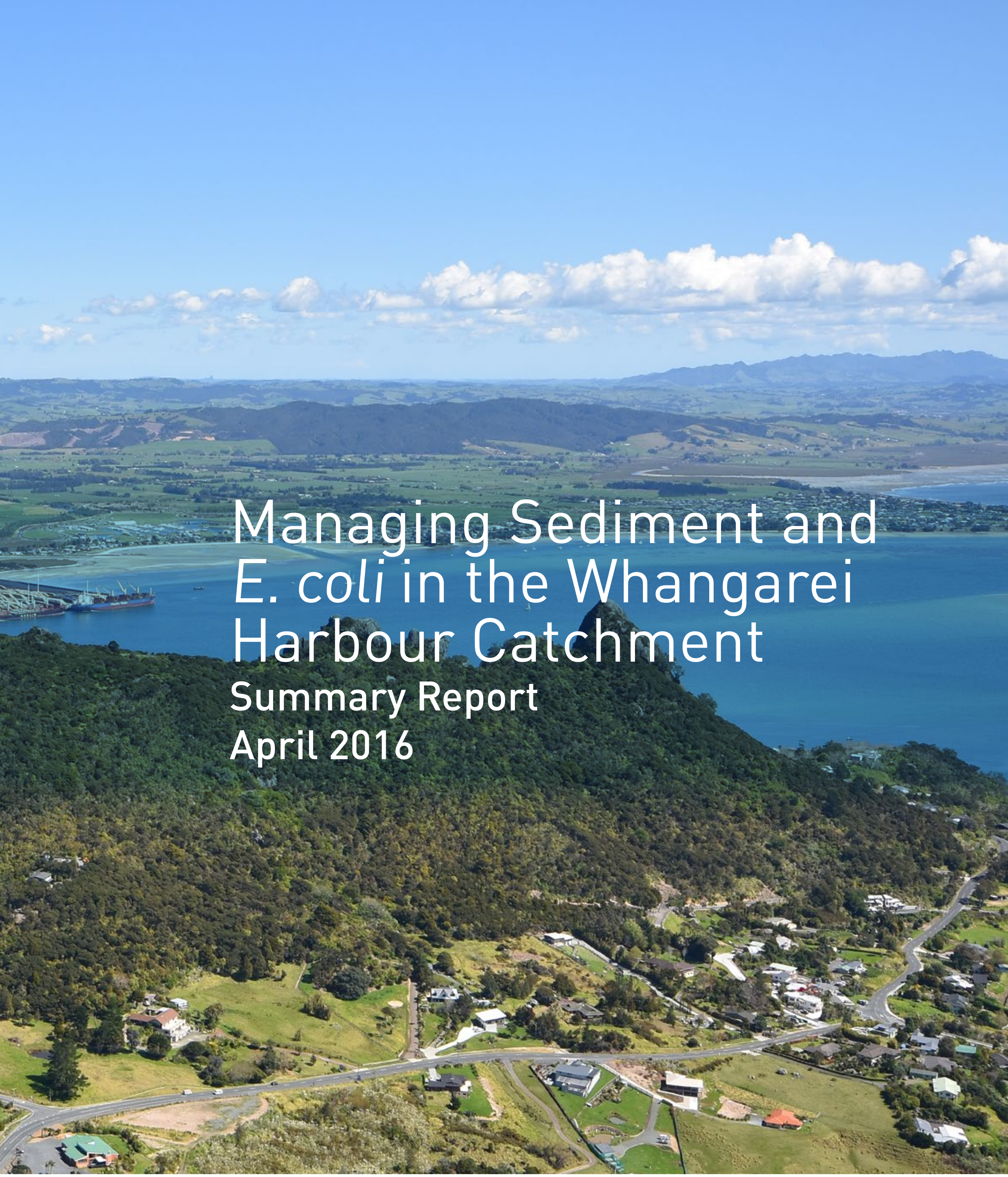

Managing Sediment and *E. coli* in the Whangarei Harbour Catchment

Summary Report

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Foreword

Since 2009, the Government has been undertaking a comprehensive set of reforms to improve the way we manage fresh water in New Zealand. The reforms emphasise that local communities, through councils, are in the best position to make decisions about managing the fresh water in their region, taking local conditions, needs and aspirations into account.

In 2011, the Government implemented the National Policy Statement for Freshwater Management. The National Policy Statement provides national direction under the Resource Management Act 1991. It requires councils to set objectives and limits for fresh water quality and quantity in a way that is consistent around the country. The National Policy Statement also requires councils to ensure land use and water are managed in an integrated way, and that iwi/hapū are involved in freshwater management and their values are reflected in decisions about the management of fresh water.

Policy development is now focusing on the implementation of the National Policy Statement. This includes providing better information, tools and processes to support communities to make decisions with their councils about their local rivers and waterways. The aim is to increase the value from more efficient use of freshwater, improve freshwater quality and ecosystem health, and ensure economic growth is based on good environmental practice.

To assist with this, the Ministry for Primary Industries and Ministry for the Environment have undertaken several environmental economic studies to build a strong evidence base to support decisions by central government, local government and community stakeholders. These studies demonstrate the link between environmental investment decisions and impacts, help to identify the most appropriate solutions for catchments to achieve particular objectives, challenge assumptions about the likely benefits of different approaches, and help to better target policies.

This paper provides an analysis of mitigations to manage sediment and *E. coli* loads in the Whangarei Harbour catchment in order to meet freshwater objectives and limits.

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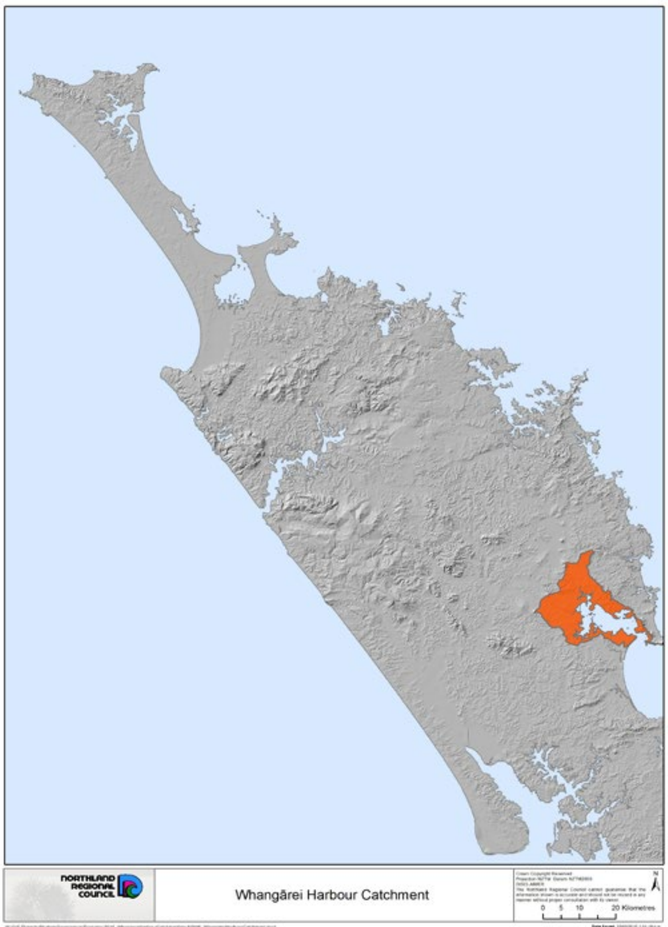
1 Introduction

Sediment and *Escherichia coli (E. coli)* have been highlighted as important water quality challenges for the Northland region of New Zealand. The Ministry for Primary Industries (MPI) and the Ministry for the Environment (MfE) worked with the Northland Regional Council (NRC) to conduct a sediment and *E. coli* study in the Whangarei Harbour catchment as part of a joint venture between MPI, MfE and the council. This paper provides a summary of the study. A detailed technical report is available here.

The Whangarei Harbour is located on the south-east coast of Northland (Figure 1). The catchment covers approximately 300 square kilometres and drains through a number of rivers and streams to a large estuarine harbour of nearly 100 square kilometres. Population growth and associated changes in land use will place pressure on the harbour, particularly in the upper areas where water quality is often degraded. Over a third of the land area comprises sheep and beef farms. A quarter of the catchment is native forest and 9 percent is urban (Figure 2).

The study develops a model that integrates science and economics to assess the potential economic costs and environmental outcomes of meeting sediment and *E. coli* objectives and limits in freshwater and estuarine environments in the Whangarei Harbour catchment. Because some management practices, such as riparian planting and stock exclusion, are effective for managing both sediment and *E. coli*, economic modelling can help identify cost-efficient mitigation options and target locations to reduce the loads of both contaminants.

Figure 1: Northland and Whangarei Harbour catchment



The study is also intended to be a useful case study to inform further work on sediment attributes for the National Objectives Framework (NOF), which sits within the National Policy Statement for Freshwater Management (NPS-FM). In addition, the study has a broader goal of helping further develop a national understanding of cost-effective management of sediment and *E. coli*, especially since both contaminants have typically received less analysis at the catchment scale, relative to nitrogen, and to a lesser extent, phosphorus.

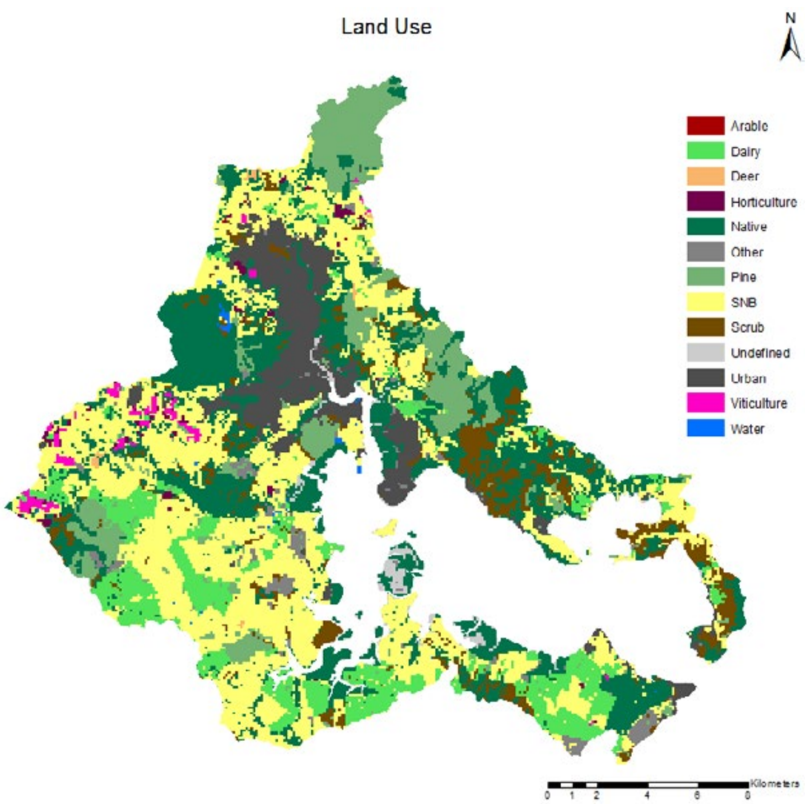
The study has two main objectives:

1. Develop models to assess catchment sediment and *E. coli* loads and determine how to express these loads as freshwater attributes.
2. Incorporate the sediment and *E. coli* models developed in Objective 1 into a catchment economic model to identify cost-effective ways of managing sediment and *E. coli* loads in freshwater rivers and streams and in the Whangarei Harbour itself.

The National Institute of Water and Atmospheric Research (NIWA) was contracted to deliver the first objective and Landcare Research was contracted to deliver the second.

Section 2 discusses the different estuary and freshwater sediment and *E. coli* attributes used to assess the effectiveness of different mitigations. Section 3 outlines how the baseline sediment and *E. coli* loads were estimated for the Whangarei Harbour catchment. It also sets out the development of the harbour sedimentation budget. Section 4 provides an overview of the catchment economic model. Results are presented in Section 5 followed by a discussion of the limitations in Section 6. Section 7 provides a summary and conclusion.

Figure 2: Land use in the Whangarei Harbour catchment



2 Selecting sediment and *E. coli* attributes to be assessed

The National Policy Statement for Freshwater Management (NPS-FM) establishes a legal and policy framework for building a national limits-based scheme for freshwater management. The policy requires maintaining or improving overall water quality in a region and safeguarding the life-supporting capacity, ecosystem processes and indigenous species (including their associated ecosystems) of freshwater. It also requires protection of the health of people and communities by sustainably managing the use and development of land, and discharges of contaminants.

The NPS-FM requires councils to establish freshwater objectives, limits and methods for different attributes that communities deem to be important for a particular catchment or region. The relationship between values, attributes and states in a range of freshwater environments are set out in the National Objectives Framework (NOF) within the NPS-FM. The NPS-FM does not set specific requirements for coastal zones but requires councils to consider the impact on coastal zones when setting freshwater objectives.

High levels of pathogens in rivers, streams and estuaries may pose risks to human health. When numbers are above health standards, people exposed to water that contain bacteria may end up with a fever, diarrhoea and abdominal cramps, chest pain or hepatitis.

E. coli is used in this study as a proxy for pathogens of faecal origin that are a threat to human health. *E. coli* is a type of bacteria that normally lives in the intestines of people and animals. Most *E. coli* are harmless and are actually an important part of a healthy human intestinal tract. However, some *E. coli* are pathogenic, meaning they can cause illness such as diarrhoea or illness outside of the intestinal tract. The types of *E. coli* that can cause diarrhoea can be transmitted through contaminated water or food or through contact with animals or people.

E. coli is used as an indicator of freshwater faecal contamination as part of risk assessments of pathogen infection and is one of the attributes of the "human health" water quality value in the NOF.

There are currently no sediment attributes in the NPS-FM. Regional councils are able to establish their own attributes and limits and objectives if managing sediment is of particular importance to that community.

For this study, attributes for sediment and *E. coli* were selected that reflect values that are important to people in the Northland region. These values primarily relate to the ability to swim in rivers and in the harbour, secondary contact uses (such as wading or fishing) and other amenity or aesthetic values, such as the clarity of the water. The estimated impact on these attributes from applying a range of different mitigations was assessed through the catchment economic model.

2.1 *E. coli* attributes

The two NOF *E. coli* attributes are used to assess *E. coli* in freshwater environments in the Whangarei Harbour catchment. The *E. coli* median concentration is used for representing secondary contact in streams and rivers. To meet the minimum required state, people should only be exposed to a moderate risk of getting sick (less than 5 percent risk) from activities with some immersion and some ingestion of water (such as wading and boating).

To represent the value that people obtain from being able to swim in rivers in the Whangarei catchment, the 95th percentile NOF target is used. For people to be able to swim in a water body, *E. coli* levels should be less than 540 *E. coli* per 100 millilitres at the 95th percentile (which means there is a less than 1 percent risk of getting sick from swimming).

Microbial loads in the upper harbour are also of concern to the council. For this study, it was decided that a terminal-reach[1] annual *E. coli* loading be used as a proxy for overall microbial contamination risk.

1 "At the location just before the river debouches into the harbour".

This includes point source loadings. This is not a NOF target, but provides an indication of bacterial loads into the harbour. Changes to the *E. coli* load at the harbour reach are analysed for each of the policies that control sediment and *E. coli* loading to the harbour.

A more complete analysis would include Enterococci loading, which is related to marine bathing water quality, and possibly pathogens related to human health risks. However, suitable data or models were not available for estimating these loadings nor were the resources available to run dynamic estuary models that would be required for quantitative microbial risk assessment.

2.2 Estuary sediment attributes

As there are no nationally established attributes for monitoring sediment, a workshop was held with experts to determine freshwater and estuary sediment attributes for assessment in this study. The use of freshwater sediment attributes in this study are also informing the development of sediment attributes for the NOF.

Sediment deposition in estuaries may have effects on benthic biota through smothering and indirect effects by muddying the seabed. Increased mud content of the seabed affects ecosystem functioning and services such as nutrient assimilation and remineralisation.

To account for these effects, the annual-average sedimentation rate (AASR) is used as the single estuary sediment attribute in the Whangarei study. This is defined as:

> *Mass of sediment deposited per year/(settled-sediment density*area over which sediment deposits).*

Using a simple parameter such as the AASR means it is relatively easy to measure and explain progress towards achieving it. It may also be a suitable "master attribute" that is indicative of a wide range of sediment effects in estuaries. The AASR is unambiguous, readily measurable (by, for example, repeat bathymetric surveys or sedimentation plates) and easy to relate to catchment sediment inputs (Green, 2013). It is reasonable to assume that the AASR is indicative of a wide range of sediment effects in the Whangarei Harbour.

The natural temporal variability of suspended sediment in estuaries meant it was not possible to formulate a suspended sediment attribute for use in this study. Even if certain conceptual issues were resolved, an event-scale catchment sediment model would need to be used to evaluate the attribute. The SedNetNZ catchment sediment model, which is used in the Whangarei study, is an annual-average model, which prevents us from evaluating event-scale attributes. Event-scale models exist, but they are typically expensive to run.

2.3 Freshwater sediment attributes

Overall, ecological effects of suspended fine sediment in streams and rivers have been less extensively researched than those of deposited fine sediment. Physical effects of suspended sediment include reduced visual water clarity and reduced light penetration (euphotic depth).

To account for these effects, the following three attributes are used in the study to assess the impact of suspended fine sediment:

- suspended sediment concentration: the ratio of the mass of dry sediment in a water–sediment mixture to the volume of the mixture;
- water clarity: the distance of water through which an object can be clearly seen;
- euphotic depth: the distance of water through which light travels and becomes attenuated to 1 percent of the surface light intensity. This distance defines the euphotic zone in which there is sufficient light for photosynthesis and periphyton and macrophytes to be sustained.

Deposited fine sediment can adversely affect benthic invertebrates, fish and benthic algae. Most farmland streams are affected by multiple stressors acting simultaneously, and recent research in New Zealand has shown that deposited fine sediment interacts with other agricultural stressors when affecting stream communities (Townsend et al, 2008; Matthaei et al, 2010; Wagenhoff et al, 2011, 2012, 2013; Piggott et al, 2012, 2015a, 2015b; Lange et al, 2014).

Embeddedness is used as a freshwater attribute for deposited fine sediment trapped in the channel gravel. Embeddedness is assumed to be equal to the suspended sediment concentration at the discharge when bedload transport stops, where that discharge is about one-quarter of the mean annual flood. However, further work is required to confirm the relationship between embeddedness and the suspended-sediment concentration at one quarter of the mean annual flood, and the extent to which fine sediments accumulate on streambeds between floods.

3 Estimating baseline sediment and *E. coli* loads

This section provides an overview of the methodology used to generate baseline sediment and *E. coli* loads in the Whangarei Harbour catchment. A catchment economic model was used to show how these loads are likely to change if different mitigation practices are used.

3.1 Estimating *E. coli* loads

The National Institute of Water and Atmospheric Research (NIWA) provided estimates of baseline mean annual loads of *E. coli* at sites of importance in the Whangarei Harbour catchment using the Catchment Land Use for Environmental Sustainability (CLUES) model. The estimates were calibrated to measured loads where these were available. The predicted *E. coli* loads were converted into *E. coli* concentrations to enable the *E. coli* attributes to be assessed.

A linear relationship was assumed between loads and concentrations, that is, if a mitigation option reduces loads by X percent then current concentrations are assumed to reduce by X percent as well. This linearity assumption has not been validated with experimental data because it would require long-term observations covering a period of substantial change. It is possible to envisage situations where the relationship may break down, such as under large climate shifts, timing of loading or large land-use changes. Nevertheless, this is a reasonable assumption, and significantly more detailed modelling and measurement would be required to improve on it.

The *E. coli* load to the Whangarei Harbour was also determined. While *E. coli* loads into the harbour were not investigated by the catchment economic model, changes in harbour *E. coli* loads are still considered to be of interest as co-benefits from policies for controlling sediment loading to the harbour and *E. coli* concentrations in streams. For example, fencing undertaken to reduce streambank erosion will also reduce *E. coli* losses from that farm.

Within the Whangarei Harbour catchment, the model predicted that the overwhelming bulk of the *E. coli* load was derived from streams flowing directly into the harbour, rather than the areas of land surrounding the harbour or point source discharges. These apparent anomalies cannot be explained at present, but could be related to decay factors and possibly inputs from feral animals in forested areas.

Sources of uncertainty in the model include:

- water quality monitoring sites where there is no coincident flow site, so that flow data is used from a nearby site if there is one;
- a lack of knowledge around *E. coli* land and stream dynamics;
- groundwater, which is not included in the model, although it is unlikely this is a significant factor for *E. coli*;
- measured loads, which are used for calibration;
- potential biases in the load estimates (a tendency to under-estimate or over-estimate the measured load in relation to the actual true load). These sources of measurement error limit the accuracy and precision of the model.

3.2 Estimating sediment loads

Landcare Research provided estimates of baseline sediment loads in the catchment using the model SedNetNZ. The catchment erosion and sediment model simulates several erosion processes, sediment storages and transfers. Sediment loads are estimated at the farm scale.

Annual sediment loads (tonnes per year) for 11 reporting zones are estimated for the current land cover and for pre-human vegetation (that is, indigenous forest everywhere). On average, the pre-human sediment loads are about 45 percent of the current sediment loads.

A methodology for translating these loads into the various attributes outlined in Section 2.3 was also provided to enable an assessment of the impact of mitigations on these attributes in the catchment economic model.

There are only three sites in the Kaipara Harbour catchment where sediment loads have been measured. These are Kaipara at Waimauku, Kaukapakapa at Taylors, and Hoteo at Gubbs

(Curran-Cournane et al, 2013). Table 1 compares the measured sediment loads with those predicted by SedNetNZ. Modelled sediment load is about the same as measured sediment load for Kaukapakapa, 50 percent more for Hoteo, and about twice for the Kaipara River. These ratios show reasonable agreement given that the measurement records are only for several years, do not include major events and are based on surface sampling of sediment concentration, which will generally underestimate sediment loads. There is a great deal of uncertainty with sediment data. Landcare Research advise that results with plus or minus 50 percent uncertainty are quite normal for sediment load estimates.

3.3 Harbour sedimentation budget

A harbour sedimentation budget was derived by NIWA to show how catchment sediment loads deposit in four depositional basins in the harbour. The budget was used to assess the impact of different mitigations on the annual average sedimentation rate in the harbour. The model determines the amount of sediment deposited per year in each depositional basin, originating from each sub-catchment in the Whangarei Harbour catchment.

Table 1: Comparison of measured sediment loads with those predicted by SedNetNZ

	Kaipara at Waimauku	Kaukapakapa at Taylors	Hoteo at Gubbs
Measured sediment load (tonnes per year)	5 200	4 700	19 800
Modelled sediment load (tonnes per year)	10 000	3 700	33 300

4 Catchment economic modelling

The catchment economic model is based on Landcare Research's economic land-use model, the New Zealand Forest and Agriculture Regional Model (NZFARM). NZFARM is designed for detailed modelling of land uses at a catchment scale. Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as how a policy aimed at one environmental issue could affect other environmental factors.

The version of the model used for this study can track changes in land use, land management, agricultural production, and sediment and *E. coli* loads by imposing policy options that range from having landowners implement specific mitigation practices to identifying the optimal mix of land management to meet a particular target. The model is parameterised such that responses to policy are not instantaneous but instead assume a response that landowners are likely to take over a 10-year period.

The *E. coli* and sediment baseline loads and the harbour sediment budget were inputs into the catchment economic model to assess the impact of various mitigations on sediment and *E. coli* loads in rivers and streams in the Whangarei Harbour catchment, and in the Whangarei Harbour itself.

While the list of feasible farm management options is extensive, not all of the possible options are included to mitigate losses from diffuse sources into waterways. The results from NZFARM are reliant on input data (for example, farm budgets, mitigation costs, and contaminant loss rates) from external sources and may vary if alternative data are used.

NZFARM also does not account for the broader impacts of changes in land use and land management beyond the farm gate.

It is not intended that the catchment economic model define or analyse any specific policy or reduction target. Thus, the scenarios presented in this report should be taken as illustrative examples of how the model works and can be used in future analyses, as opposed to a rigorous analysis of a proposed policy or rule change.

Figure 3 shows the various components of the study and how they are linked together.

4.1 Baseline data

A baseline was established before assessing the impact of different mitigation scenarios. The baseline assumes no sediment or *E. coli* mitigation practices or policies have been implemented (including existing farm plans or stream fencing).[2] The "no mitigation" baseline is the same assumption that was used for sediment modelling in SedNetNZ but not for the *E. coli* modelling in CLUES.

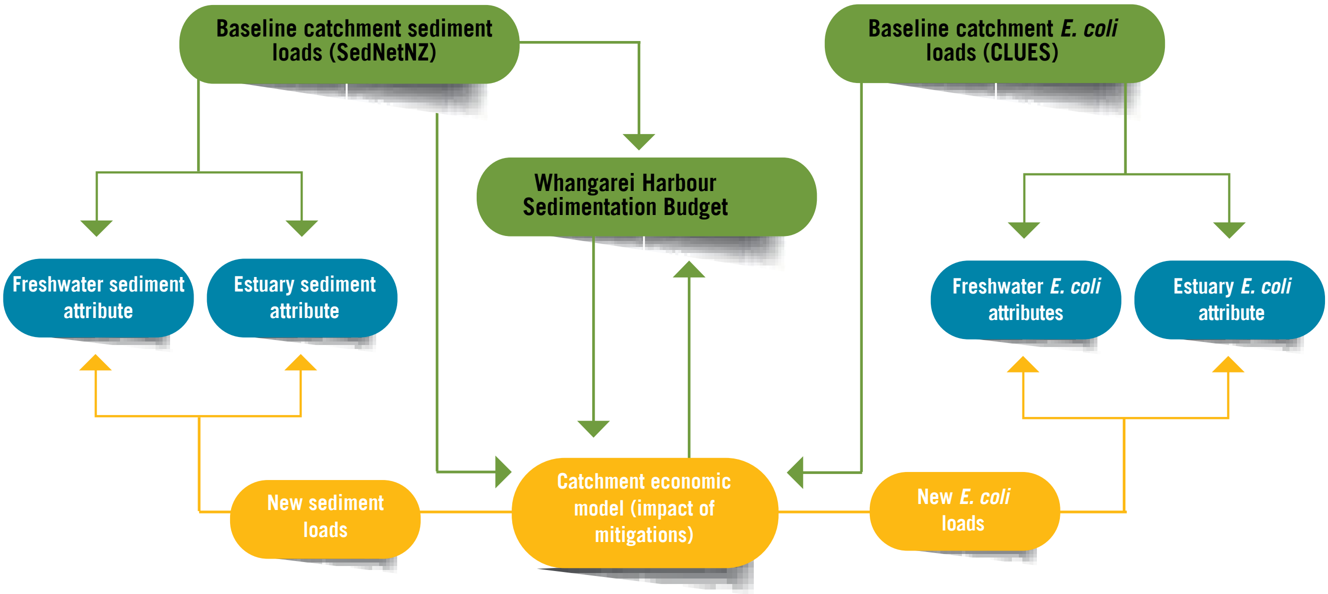
In the case of *E. coli*, NIWA calibrated the model to empirical data in Northland, which implicitly accounts for management such as stream fencing within the catchment. However, because there was no spatially explicit information on which farms in the catchment are currently fenced nor how effective that fencing is, this mitigation was not incorporated into the NZFARM baseline.[3] Thus, the NZFARM *E. coli* mitigation figures may be an overestimate of the actual reduction that could occur under the different model scenarios.

A summary of the key baseline economic and environmental outputs is listed in Table 2. Total net farm income from land-based operations with the current land use mix is estimated at $16.6 million per year or $548 per hectare for all land and $964 per hectare for land that is currently earning revenue from farming and forestry. Total sediment load is over 31 000 tonnes, of which more than 85 percent comes from landmass erosion. Nearly 20 000 tonnes of sediment is deposited into the four depositional basins in the harbour. The total stream and harbour *E.coli* loads are estimated to be 84 peta and 293 peta per year, respectively.

2 In reality, some mitigation practices such as fencing streams have been imposed by some landowners in the catchment. Thus, the baseline used for this study is likely to overestimate the impact of mitigation.

3 Current fencing is modelled in one of the scenarios, which presents a possible sensitivity in the no mitigation assumption.

Figure 3: Components of the Whangarei Harbour study



Note: CLUES = Catchment Land Use for Environmental Sustainability.

Table 2: Baseline area, farm earnings, and environmental outputs by land use

Scenario	Area (ha)	Total net farm revenue ($)	Net farm revenue ($/ha)	Landmass erosion (t)	Streambank erosion (t)	Total erosion (t)	Harbour deposit (t)	Stream *E. coli* (peta)	Harbour *E. coli* (peta)
Dairy	3 236	9 961 530	3 078	2 059	345	2 404	1 517	13.3	84.3
Sheep and beef	10 435	2 082 365	200	9 524	1 689	11 213	6 998	42.0	53.5
Forestry	3 094	1 929 094	623	3 824	279	4 103	2 565	1.2	15.6
Hort & arable	490	2 661 541	5 431	158	38	196	121	0.4	0.0
Native	9 674	0	0	10 129	1 138	11 267	7 386	8.1	17.0
Urban	2 851	0	0	731	886	1 618	1 034	16.3	115.7
Other	576	0	0	458	97	554	348	2.7	6.6
Total	**30 356**	**16 634 530**	**548**	**26 883**	**4 472**	**31 355**	**19 968**	**84.0**	**292.7**

Note: ha = hectare; hort = horticulture; t = tonnes.

4.2 Mitigation practices

Assumptions about mitigation cost and effectiveness in reducing sediment and *E. coli* loads were established by the project team during workshops in April 2015 and June 2015 and refined accordingly as new information and assumptions arose. Additional details on the wetland mitigation were provided by Chris Tanner of NIWA. The costs are broken down by initial capital, ongoing and periodic maintenance, and opportunity costs from taking land out of production. A summary of these costs is outlined in Table 3.

The costs are converted to an annual figure so they can be directly compared to the costs already included in the baseline net farm revenue calculation. Initial capital and periodic maintenance costs are annualised over 25 years using a discount rate of 8 percent. Annual maintenance and opportunity costs are assumed to accrue on a yearly basis and thus are directly subtracted from the base net farm revenue figure.

Table 3: Mitigation costs and effectiveness assumptions

	Mitigation option	Eligible land uses	Max coverage	Cost component			Mitigation effectiveness (percent from baseline)		
				Initial capital	Maintenance	Opportunity	Landmass erosion	Bank erosion	*E. coli**
1	Farm plan	Pasture	All farms	Plan: $5000/farm up to 100 ha + $10/ha for each additional ha Implementation: $250/ha	None	None, as plan assumed to identify options where benefits offset production losses	70%	0%	0%
2	Fencing	Pasture	All permanent streams	Sheep and beef: $35/m, including materials, construction and reticulation; Dairy: $7.50/m	None	None	0%	80%	60%
3	Retention bund/wetland combo	All, including native and urban	1 per 20 ha	$6100/system, including planting and fencing	$6/system/yr $2000/system for sediment clearing in year 25	40% of farm income in occupied area	70%	0%	50%
4	Sedimentation pond/wetland combo	All, including native and urban	1 per 20 ha	$6000/system, including planting and fencing	$15/system/yr	80% of farm income in occupied area	70%	0%	50%
5	Mid-catchment constructed wetland	All, including native and urban	1 per 400 ha	$100 000/ system, including planting and fencing	$300/system/yr	40% of farm income in occupied area	70%	0%	50%
6	Farm plan + fencing	Pasture	See 1 & 2	Sum of #1 and 2	None	None	70%	80%	60%
7	Farm plan + fencing + wetland	Pasture	See 1 to 5	Sum of #1, 2 and 3, 4 or 5	Sum of #1, 2 and 3, 4 or 5	40% of farm income in area occupied by wetland	70%	80%	60%

Note: * Assumed to have same effect on median and 95th percentile concentrations. Ha = hectare; m = metre; yr = year.

4.3 Scenarios modelled

NRC, with input from MPI, specified a range of policy scenarios to be analysed. These include (1) practice-based approaches, such as fencing streams for stock exclusion; and (2) target-based approaches that include reducing erosion to reach harbour-wide sedimentation targets or decreasing *E. coli* in key sites to achieve secondary contact recreation targets.

The practice-based scenarios investigate the maximum amount of reductions that could be achieved when implementing certain mitigation options. The target-based scenarios investigate the impact of setting a specific reduction target but then allowing landowners to collectively select the set of mitigation options that will meet the target. Table 4 provides a summary of the policy scenarios modelled.

Table 4: Policy scenarios modelled

Scenario name	Description	Sediment target	*E. coli* target
	Minimum loads		
Afforestation – all	Afforestation of all non-native land in the catchment with native bush to estimate the minimum loads possible	n/a	n/a
Afforestation – pasture	Afforestation of all pasture (dairy, dry stock and lifestyle) in the catchment with native bush	n/a	n/a
	Practice-based scenarios		
Current fencing	Proportion of dairy (75%) and some dry stock and lifestyle (20%) to match current stream fencing data from NRC to establish status quo impact of mitigation	n/a	n/a
Fence all	Fence all permanent streams adjacent to pasture for stock exclusion	n/a	n/a
Farm plan	All pastoral farms implement farm plans for hillside and landmass erosion control	n/a	n/a
Wetlands	Construct wetlands and sediment ponds on maximum amount of land possible, including urban and forested areas	n/a	n/a
Max mitigation	Raise fences for stock exclusion, implement farm plans and construct wetlands on all possible land	n/a	n/a
	Target-based scenarios: Harbour sediment load reduction below the baseline		
Harbour sediment 20%	20% reduction in total annual sediment to each depositional basin	20%	n/a
Harbour sediment 40%	40% reduction in total annual sediment to each depositional basin	40%	n/a
Harbour sediment 60%	60% reduction in total annual sediment to each depositional basin	60%	n/a
	Target-based scenarios: *E. coli* load reduction below the baseline		
E. coli 20%	20% reduction in total stream and harbour *E. coli* load in each REC2 sub-catchment	n/a	20%
E. coli 40%	40% reduction in total stream and harbour *E. coli* load in each REC2 sub-catchment	n/a	40%
E. coli 60%	60% reduction in total stream and harbour *E. coli* load in each REC2 sub-catchment	n/a	60%
	Target-based scenarios: *E. coli* secondary contact recreation attribute target		
Secondary contact "B"	Stream *E. coli* concentrations at all "sites of importance" meet NPS-FM "B" attribute state of 540 cfu/100mL	n/a	540 cfu/100mL
Secondary contact "A"	Stream *E. coli* concentrations at all "sites of importance" meet NPS-FM "A" attribute state of 260 cfu/100mL	n/a	260 cfu/100mL

Note: cfu = colony forming unit; mL = millilitre; NPS-FM = National Policy Statement for Freshwater Management; NRC = Northern Regional Council; REC2 = River Environment Classification v2.0.

5 Results of the analysis

5.1 Catchment-wide results

The extent of possible reductions in contaminant loads is limited in this analysis because only 46 percent of the Whangarei Harbour catchment is in pasture, with a significant proportion classified as native or urban, so management options that only target pastoral enterprises will not be enough to achieve large reductions in environmental contaminants. At the extreme, afforesting all land (including Whangarei city itself) would reduce sediment loads by 49 percent and *E. coli* loads by 73 percent. Even with this reduction, it would not be possible to meet the NPS-FM *E. coli* target for primary contact recreation based on current measurement procedures, although many of the sites could achieve the secondary contact recreation target.

To achieve specific targets for the attributes modelled at lowest cost, the mitigations need to be targeted to the particular land uses in the areas of significant importance in a catchment. For the Whangarei Harbour catchment, the most cost-effective approach focuses effort where particular hot spots of sediment and *E. coli* occur. These areas are upstream of sites with important water quality objectives and use a combination of fencing, farm plans and wetlands, with landowners deciding on the optimal combination of mitigations for their farm.

The total estimated impacts for the entire Whangarei Harbour catchment are listed in Table 5. The table indicates that the impacts vary widely across scenarios. Further insight on each scenario is provided in sections 5.2 to 5.10.

Given the considerable uncertainties with the *E. coli* and sediment baseline load estimates, the findings from the catchment economic model should only be used to assess the relative impacts of the different mitigations. The results should not be interpreted as specific predictions of the likely cost of a policy.

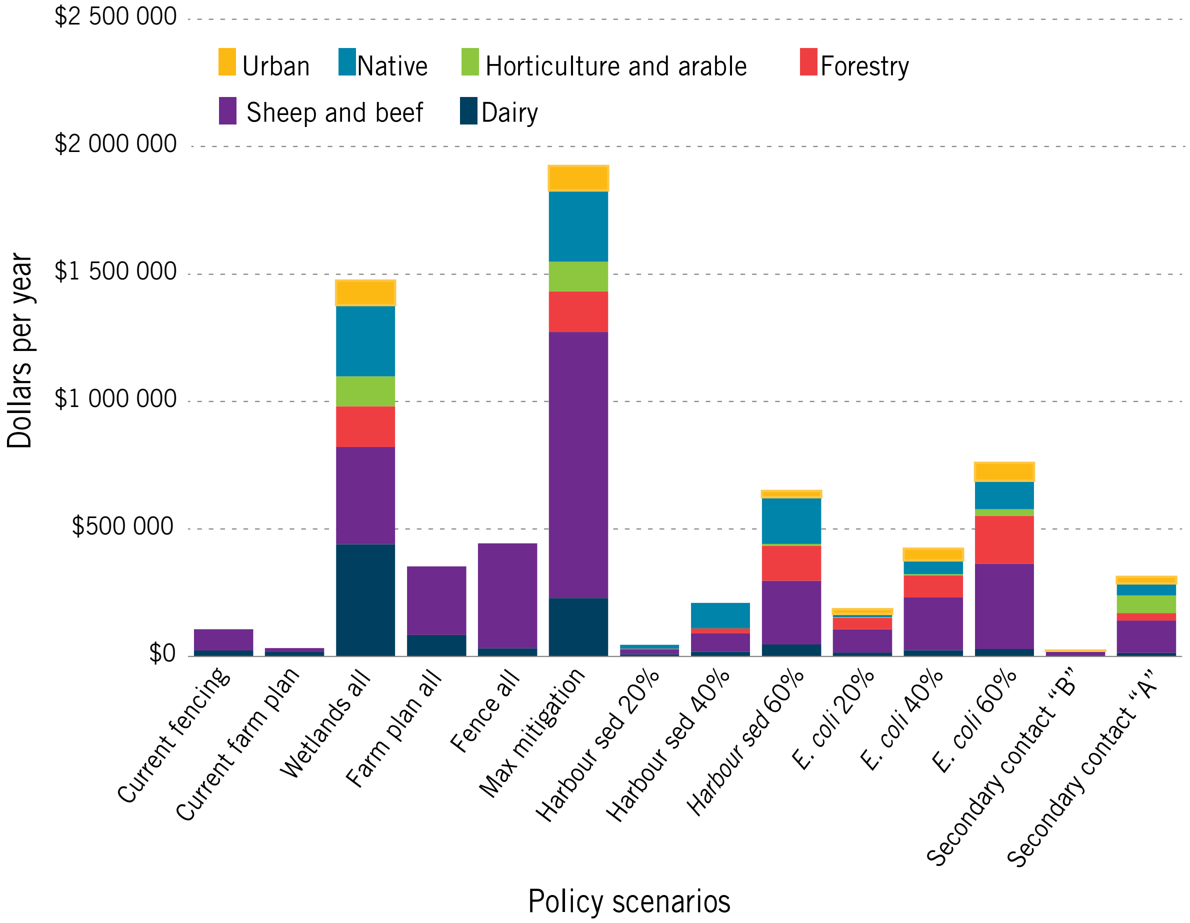
Costs for the non-afforestation scenarios range from $20 000 per year, for achieving the secondary contact *E. coli* target, to about $1.9 million per year, for implementing the maximum amount of mitigation on all land in the catchment. Sheep and beef farms face the greatest total costs for nearly all scenarios (as shown in Figure 4). This is to be expected because this enterprise makes up the largest area of productive land and pasture in the catchment.

Table 5: Key model scenario estimates for the entire Whangarei Harbour catchment

Policy scenarios	Net revenue (mil $)	Total annual cost (mil $/yr)	Land/hill erosion (t/yr)	Streambank erosion (t/yr)	Total erosion (t/yr)	Total harbour deposition (t/yr)	*E. coli* load – stream (peta)	*E. coli* load – harbour (peta)
No mitigation	16.6	0.00	26 883	4 472	31 355	19 968	84.0	292.7
Afforest – all	0.0	16.63	13 437	2 463	15 901	10 175	22.5	75.8
Afforest – pasture	4.6	12.04	16 436	2 643	19 079	11 454	36.7	177.6
Current fencing	16.5	0.11	26 883	3 995	30 878	19 689	69.3	233.6
Current farm plan	16.6	0.03	26 495	4 472	30 967	19 715	84.0	292.7
All wetlands	15.2	1.47	7 866	4 472	12 338	7 928	43.3	149.7
All farm plan	16.3	0.35	18 429	4 472	22 901	14 731	84.0	292.7
Fence all streams	16.2	0.44	26 883	2 845	29 728	18 988	39.8	182.5
Max mitigation	14.7	1.92	7 866	2 845	10 711	6 948	32.3	122.1
Harbour sediment 20%	16.6	0.04	20 705	4 357	25 062	15 975	74.2	224.2
Harbour sediment 40%	16.4	0.19	14 680	4 303	18 983	11 981	71.3	224.1
Harbour sediment 60%	16.0	0.60	9 229	3 548	12 777	7 967	47.8	189.7
E. coli 20%	16.4	0.19	25 366	4 077	29 443	18 751	67.2	234.2
E. coli 40%	16.2	0.42	23 151	3 621	26 772	17 031	50.4	175.6
E. coli 60%	15.9	0.76	20 836	2 980	23 816	15 132	33.6	117.1
Secondary contact "B"	16.6	0.02	26 779	4 254	31 033	19 770	71.1	292.7
Secondary contact "A"	16.3	0.31	24 017	3 770	27 787	17 754	59.0	292.7
Change from no mitigation baseline								
Afforest – all	–100%	16.63	–50%	–45%	–49%	–49%	–73%	–74%
Afforest – pasture	–72%	12.04	–39%	–41%	–39%	–43%	–56%	–39%
Current fencing	–1%	0.11	0%	–11%	–2%	–1%	–18%	–20%
Current farm plan	–0.2%	0.03	–1%	0%	–1%	–1%	0%	0%
All wetlands	–9%	1.47	–71%	0%	–61%	–60%	–48%	–49%
All farm plan	–2%	0.35	–31%	0%	–27%	–26%	0%	0%
Fence all streams	–3%	0.44	0%	–36%	–5%	–5%	–53%	–38%
Max mitigation	–12%	1.92	–71%	–36%	–66%	–65%	–62%	–58%
Harbour sediment 20%	–0.3%	0.04	–23%	–3%	–20%	–20%	–12%	–23%
Harbour sediment 40%	–1%	0.19	–45%	–4%	–39%	–40%	–15%	–23%
Harbour sediment 60%	–4%	0.60	–66%	–21%	–59%	–60%	–43%	–35%
E. coli 20%	–1%	0.19	–6%	–9%	–6%	–6%	–20%	–20%
E. coli 40%	–3%	0.42	–14%	–19%	–15%	–15%	–40%	–40%
E. coli 60%	–5%	0.76	–22%	–33%	–24%	–24%	–60%	–60%
Secondary contact "B"	–0.1%	0.02	0%	–5%	–1%	–1%	–15%	0%
Secondary contact "A"	–2%	0.31	–11%	–16%	–11%	–11%	–30%	0%

Note: mil = millions; t = tonnes; yr = year.

Figure 4: Total annual cost of mitigations ($ per year), by land use



Tables 6 and 7 show that the mean annual mitigation costs differ on a per hectare basis. It is apparent from these figures that there is a wide distribution of impacts across both land use and scenario. Per hectare costs are generally higher for the wetlands scenarios because they account for opportunity costs from taking some land out of production. Many of the estimates from the outcome-based scenarios appear relatively cheaper than the practice-based scenarios because mitigation is not necessarily implemented on every parcel of land in the catchment.

On average, sheep and beef farmers face the highest costs per hectare, followed by forestry and then horticulture and arable. This is because:

- sheep and beef farms have a lot of streams that need to be fenced, and they are often on steep land;
- most forestry is on steep land with relatively high erosion rates, thus more wetlands would be constructed there than other places, particularly for the practice-based scenarios;
- horticulture and arable face high opportunity costs when constructing wetlands.

Table 6: Mean annual mitigation costs ($ per hectare per year)*

Scenario	Dairy ($)	Sheep and beef ($)	Forestry ($)	Hort and arable ($)	Native ($)	Urban ($)	All ($)	Pastoral only ($)
Afforest – all	3 078	200	623	5 432	0	0	548	881
Afforest – pasture	3 078	200	0	0	0	0	397	881
Current fencing	7	8	0	0	0	0	4	8
Current farm plan	5	1	0	0	0	0	1	2
Wetlands all	136	37	52	239	29	34	49	60
Farm plan all	26	26	0	0	0	0	12	26
Fence all	10	39	0	0	0	0	15	32
Max mitigation	71	100	52	239	29	34	63	93
Harbour sediment 20%	2	2	0	0	2	0	1	2
Harbour sediment 40%	6	7	6	0	8	0	6	7
Harbour sediment 60%	12	21	44	14	18	8	20	19
E. coli 20%	5	9	14	5	1	7	6	8
E. coli 40%	7	20	28	11	5	16	14	17
E. coli 60%	9	32	61	52	12	25	25	27
Secondary contact “B”	0	2	0	0	0	0	1	2
Secondary contact “A”	4	12	10	141	5	9	10	10

Note: * Estimated as total mitigation cost divided by total area for each land use. Hort = horticulture.

Table 7: Per hectare cost – Rank by land use (1 = highest cost)

Scenario	Dairy	Sheep and beef	Forestry	Hort and arable	Native	Urban	Other
Afforest – all	2	4	3	1	5	5	5
Afforest – pasture	1	2	3	3	3	3	3
Current fencing	2	1	3	3	3	3	3
Current farm plan	1	2	3	3	3	3	3
Wetlands all	2	4	3	1	6	5	7
Farm plan all	1	2	3	3	3	3	3
Fence all	2	1	3	3	3	3	3
Max mitigation	3	2	4	1	6	5	7
Harbour sediment 20%	3	2	4	5	1	5	5
Harbour sediment 40%	4	2	3	5	1	6	6
Harbour sediment 60%	5	2	1	4	3	6	7
E. coli 20%	5	2	1	4	6	3	7
E. coli 40%	5	2	1	4	6	3	7
E. coli 60%	6	3	1	2	5	4	7
Secondary contact “B”	2	1	4	5	5	3	5
Secondary contact “A”	6	2	3	1	5	4	7
Average rank	**3.125**	**2.125**	**2.6875**	**3**	**4**	**4**	**5.3125**

Note: Hort = horticulture.

5.2 Effectiveness of wetlands

Constructing wetlands and sediment ponds has an effect on landmass erosion and *E. coli* from all land uses. It is estimated to be the most effective option from a single management perspective because it is the only mitigation that can be applied to all land uses. As a result, total sediment is estimated to be reduced by 61 percent while stream and harbour *E. coli* are estimated to be reduced by nearly 50 percent.

The use of wetlands is also the only mitigation option that has a positive impact on the sediment attributes of water clarity and euphotic depth in all three measured sites in the catchment. Wetlands, however, are assumed to have no effect on streambank erosion, so landowners may have to consider coupling them with fencing to get even further reductions (for example, the maximum mitigation scenario).

It is estimated that implementing the maximum amount of wetland mitigation in the Whangarei Harbour catchment would result in costs of $1.47 million per year, or an average of $49 per hectare per year. The costs of implementing wetlands on a particular parcel of land are sometimes higher than other mitigation options, particularly if accounting for high opportunity costs from taking highly profitable land out of production. Co-ordination and cost constraints could also limit the level of uptake in reality.

5.3 Effectiveness of fencing

The current fencing option assumed that 75 percent of dairy and 20 percent of sheep, beef, and deer farms have already fenced waterways. Current fencing is estimated to have some effect on reducing streambank erosion (11 percent) and *E. coli* loads (about 20 percent) relative to a no-mitigation baseline. As streambank erosion is only about 15 percent of total erosion in the catchment and fencing is assumed to have no impact on landmass erosion, total erosion is only estimated to be reduced by two percent. The total cost of current fencing along pastoral streams is estimated to be $107 000 per annum or about $8 per hectare per year.

Fencing all pasture land (current fencing plus all remaining streams) has an effect on streambank erosion and *E. coli* from pasture but no impact on landmass erosion. As a result, the greatest impact of this management option is on stream *E. coli* loads, which are estimated to be reduced by more the 50 percent relative to the baseline. Fencing streams is also expected to make 10 of the 11 sites of importance reach at least the NOF "B" state for secondary contact recreation (for the annual median concentration).

Streambank erosion from pasture is a relatively small proportion of total sediment in the catchment (15 percent), so although fencing all streams adjacent to pasture results in a 36 percent reduction in streambank erosion, that equates to just a five percent reduction in total erosion. Thus, more mitigation may have to be carried out in the catchment to achieve significant improvements in sediment-related attributes.

The total cost of fencing all streams in the catchment is estimated to be $443 000 per year (or $336 000 per year if current fencing is excluded). This equates to an average of $32 per hectare per year for all pastoral farms.

5.4 Effectiveness of farm plans

Farm plans are assumed to only mitigate landmass sediment from pastoral enterprises but not other land uses. They are also assumed to have no effect on streambank sediment or *E. coli*. Because pasture is 46 percent of total land cover and not necessarily located at the top of the catchment where there can be high levels of erosion, farm plans may not achieve the desired outcome for all sediment and *E. coli* related impacts in the catchment.

The current farm plan option assumed that just 1240 hectares of farm plans that have been implemented by the NRC on pastoral farms are mature and fully effective. Farm plans are only assumed to affect landmass erosion, which is estimated to be reduced by one percent relative to the baseline. Although the plans are found to have limited impact on sediment and *E. coli* in the catchment (and the related attributes), these plans may be focusing on alternative issues and thus have more of an impact on other metrics not measured in this study. The total cost of the current farm plans, which consist of the cost to prepare and implement the plans, is estimated to be $32 000 per annum, or about $26 per hectare per year on the area where they have been implemented.

NZFARM estimates that implementing farm plans on all pasture (current farm plans plus remaining farms) results in a 31 percent reduction in landmass erosion and a 27 percent reduction in total sediment in the catchment. Implementing farm plans across all pastoral farms in the catchment can reduce harbour sediment by 26 percent relative to the baseline and, thus, has some measurable impact on the harbour sediment attribute (AASR) in each of the four deposition basins. The total cost of implementing farm plans on all pastoral land in the catchment is estimated to be $354 000 per year (or $322,000 per year if current farm plans are excluded). This equates to an average of $26 per hectare per year for all pastoral farms.

Farm plans, however, do not have an effect on two of the three sites of importance that were assessed for freshwater sediment attributes because the land surrounding these sites is primarily native forest, scrub and/or urban. This suggests farm plans need to be implemented with wetlands to produce an improvement in some freshwater sediment attributes at the Whangarei Harbour catchment's sites of importance.

5.5 Maximum mitigation (farm plans, fencing and wetlands)

The maximum mitigation scenario assumes that all pastoral farms implement farm plans and fencing while all other land constructs wetlands. This mitigation approach results in significant reductions in sediment load (66 percent) and *E. coli* loads (58 percent to 62 percent), although at a relatively high cost. The change in the landmass erosion is the same as the farm plan scenario, but adding the fencing reduces streambank erosion as well, thus reducing total erosion by more than either "standalone" mitigation option.

The *E. coli* concentrations target for the A-state secondary contact recreation is estimated to be met in six sites of importance, while the B-state is met in the other five sites. In addition, an AASR rate of 1.9 millimetres per year or less is achieved in all four harbour basins. These findings suggest that, if a full mitigation plan is implemented in the catchment, large improvements in sediment and *E. coli* related attributes can be achieved.

The total cost of this mitigation option is estimated to be about $1.9 million per year. This equates to an average of $63 per hectare per year.

5.6 Harbour sediment deposition reduction policies

These scenarios estimate the impact of achieving a 20 percent, 40 percent and 60 percent reduction in harbour sediment in the four deposition basins. The scenarios do not mandate a particular management option but, rather, allow the model to estimate how landowners in the catchment could collectively implement cost-effective mitigation to achieve the targets.

The low reduction target scenarios are estimated to produce a minimal change in certain areas of the catchment. This suggests that it is optimal to target specific "hotspots" with farm plans and wetlands.

It is also estimated that there are larger relative reductions in landmass sediment (23 percent to 66 percent) than streambank sediment (three percent to 21 percent), regardless of the reduction target, highlighting that fencing streams with the sole intent of reducing erosion may be a less cost-effective option.

A 20 percent reduction target is estimated to reduce the basin-level AASR by between 10 and 19 percent relative to the baseline, while a 60 percent reduction target is estimated to reduce the AASR by 30 percent to 57 percent. The 20 percent reduction target does not have much of an effect on freshwater sediment attributes because of where the mitigation is implemented in the catchment, but the 60 percent reduction target results in estimates similar to the maximum mitigation practice-based scenario.

A policy that targets sediment reduction results in the implementation of some practices, such as wetlands and fencing, that also affect *E. coli* loads. This is an unintended co-benefit. As a result, stream

E. coli loads could be reduced by 12 percent to 43 percent and harbour *E. coli* loads by 23 percent to 35 percent. The 60 percent reduction target also leads to eight of the 11 sites of importance achieving at least the "B" state for secondary contact recreation, two more sites than the baseline.

The total cost of these scenarios is estimated to range from $43 000 per year for the 20 percent target to about $600 000 per year for the 60 percent reduction scenario. These figures equate to $1 per hectare per year and $20 per hectare per year, respectively.

5.7 *E. coli* load reduction policies

The *E. coli* attribute state for secondary contact recreation at the sites of importance does not change much from its current state for the 20 percent reduction scenario. However, the 60 percent reduction scenario results in six sites achieving the A-state of less than 260 colony forming units (cfu) per 100 millilitres and four of the five remaining sites reaching the B-state for secondary contact recreation. This suggests that large reduction targets may have to be specified in the catchment to achieve the best attribute state at all sites.

The total cost of these scenarios is estimated to range from $19 000 per year for the 20 percent target to about $760 000 per year for the 60 percent reduction scenario. These figures equate to about $6 per hectare per year and $25 per hectare per year, respectively.

For these scenarios, the model selected the optimal distribution of mitigation practices required to achieve the "B" and "A" secondary contact recreation attribute states at the Whangarei Harbour catchment's 11 sites of importance (based on an annual median estimate at each site). Taking this approach results in the implementation of fencing and wetland practices that reduce stream *E. coli* loads by 15 percent to 30 percent and total sediment loads by one percent to 11 percent. There is no change in harbour *E. coli* loads because all of the sites are located towards the middle of the catchment.

The model estimated that implementing practices above each of the sites can lead to reductions in *E. coli* concentration that allow all of the sites in the catchment to reach at least the "B" state of a maximum of 540 cfu per 100 millilitres for secondary contact recreation (using annual median estimates). However, it is also found that the "A" state concentration of 260 cfu per 100 millilitres or less could not be achieved at four of the 11 sites, although all of these sites had median concentrations of less than 330 cfu per 100 millilitres. This suggests that additional research may be needed to find even more effective mitigation options than those included in this study (that is, practices that reduce *E. coli* by more than 60 percent) in order to achieve the desired outcome.

The total cost of achieving the respective "B" and "A" attribute state targets is estimated to be $22 000 and $312 000 per annum respectively. These figures equate to about $1 per hectare per year and $10 per hectare per year, respectively, if the costs are spread across all 30 000 hectares in the catchment. However, if only the area where mitigation is actually implemented is accounted for, then the respective costs are $22 per hectare per year and $43 per hectare per year.

5.8 Impact of mitigations on sediment attributes

The different mitigation options have variable effects on water clarity, euphotic depth, suspended sediment concentration, and embeddedness at the three sites where measurements could be taken in the Whangarei Harbour catchment (see Table 8, Table 9 and Table 10). Changes in sediment loads were estimated to have a noticeable impact at the Otaika River site because it is surrounded by a variety of pastoral and other land uses where a range of mitigation practices could be implemented.

Attributes in the Otaika sub-catchment are estimated to have the largest improvement because it is situated in a sub-catchment with a significant amount of sheep and beef farming. As a result, water clarity and euphotic depth could increase by as much as 77 percent and 35 percent respectively, if maximum mitigations are put in place.

However, the two other sites are located in areas of the catchment mostly comprising native bush

Table 8: Water clarity at three Whangarei Harbour catchment sites*

Scenario	Hātea River		Waiarohia Stream		Otaika River	
	Value	% Change	Value	% Change	Value	% Change
Water clarity (metres)						
No mitigation	1.65	0%	1.77	0%	1.07	0%
Afforest – all	1.79	9%	1.79	1%	1.82	71%
Afforest – pasture	1.65	0%	1.77	0%	1.73	62%
Wetlands	2.29	39%	1.88	6%	1.24	16%
Farm plan	1.65	0%	1.77	0%	1.11	4%
Fence all	1.65	0%	1.77	0%	1.51	41%
Maximum mitigation	2.29	39%	1.88	6%	1.89	77%
Harbour sediment 60%	2.29	39%	1.77	0%	1.75	64%
E. coli 20%	1.86	13%	1.81	2%	1.16	9%
E. coli 40%	2.13	29%	1.86	5%	1.27	19%
E. coli 60%	2.29	39%	1.88	6%	1.41	32%
Secondary contact "A"	1.65	0%	1.88	6%	1.76	65%

Note: * Mitigation options that had no impact have been removed from the table.

Table 9: Euphotic depth at three Whangarei Harbour catchment sites*

Scenario	Hātea River		Waiarohia Stream		Otaika River	
	Value	% Change	Value	% Change	Value	% Change
Euphotic depth (metres)						
No mitigation	2.22	0%	2.42	0%	1.76	0%
Afforest – all	2.31	4%	2.44	1%	2.34	33%
Afforest – pasture	2.22	0%	2.42	0%	2.27	29%
Wetlands	2.64	19%	2.52	4%	1.91	8%
Farm plan	2.22	0%	2.42	0%	1.80	2%
Fence all	2.22	0%	2.42	0%	2.12	20%
Maximum mitigation	2.64	19%	2.52	4%	2.38	35%
Harbour sediment 60%	2.64	19%	2.43	0%	2.29	30%
E. coli 20%	2.36	7%	2.46	2%	1.84	4%
E. coli 40%	2.54	14%	2.50	3%	1.93	10%
E. coli 60%	2.64	19%	2.52	4%	2.04	16%
Secondary contact "A"	2.22	0%	2.52	4%	2.29	30%

Note: * Mitigation options that had no impact have been removed from the table.

or urban land that produced minimal erosion. Thus, these sites only had estimated changes in the freshwater sediment attribute levels in the few scenarios where there was significant wetland mitigation in their vicinity.

5.9 Impact of mitigations on the annual average sedimentation rate

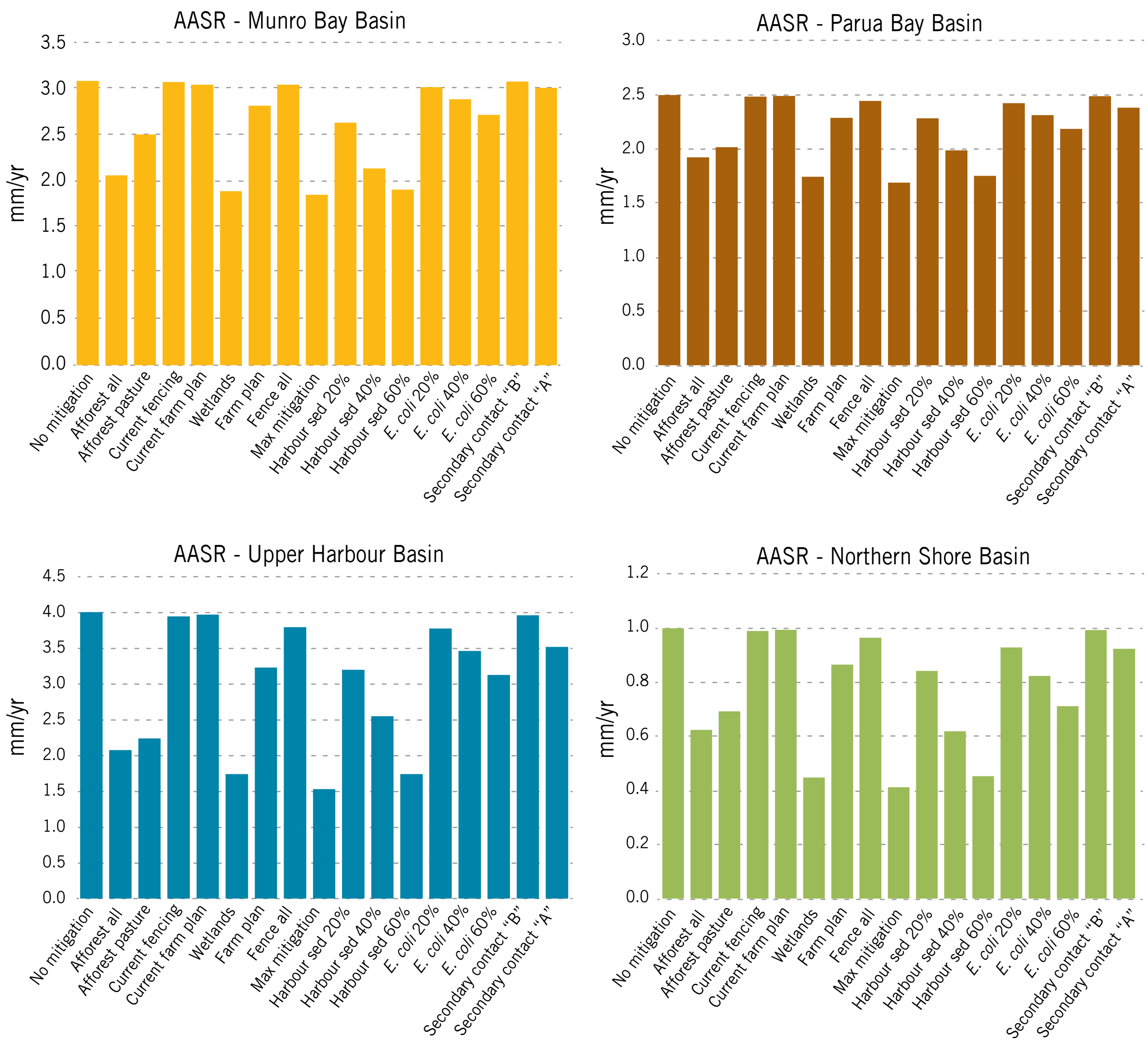
Figure 5 shows the results of the mitigations on the annual average sedimentation rate in the Whangarei Harbour. Nearly all scenarios estimated a noticeable reduction in the harbour sediment attribute. Estimates varied widely across the four deposition basins, however, because they are all affected differently in terms of the amount of sediment they receive annually from both land and marine sources. Thus, the suggested "high" attribute state of 1 millimetre per year may not be achievable for all harbour basins.

Table 10: Suspended sediment concentration and embeddedness at three Whangarei Harbour catchment sites*

Scenario	Hātea River		Waiarohia Stream		Otaika River	
	Value	% Change	Value	% Change	Value	% Change
Suspended sediment (grams per cubic metre of water)						
No mitigation	3.60	0%	3.60	0%	4.30	0%
Afforest – all	3.34	–7%	3.54	–2%	2.45	–43%
Afforest – pasture	3.60	0%	3.60	0%	2.59	–40%
Wetlands	2.66	–26%	3.32	–8%	3.67	–15%
Farm plan	3.60	0%	3.60	0%	4.17	–3%
Fence all	3.60	0%	3.60	0%	2.99	–31%
Maximum mitigation	2.66	–26%	3.32	–8%	2.36	–45%
Harbour sediment 60%	2.66	–26%	3.60	0%	2.55	–41%
E. coli 20%	3.22	–11%	3.49	–3%	3.94	–8%
E. coli 40%	2.84	–21%	3.38	–6%	3.58	–17%
E. coli 60%	2.66	–26%	3.32	–8%	3.22	–25%
Secondary contact "B"	3.60	0%	3.32	–8%	4.30	0%
Secondary contact "A"	3.60	0%	3.32	–8%	2.55	–41%
Embeddedness (grams of trapped sediment per cubic metre of water)						
No mitigation	n/a	n/a	122.6	0%	n/a	n/a
Afforest – all	n/a	n/a	120.6	–2%	n/a	n/a
Wetlands	n/a	n/a	113.1	–8%	n/a	n/a
Maximum mitigation	n/a	n/a	113.1	–8%	n/a	n/a
E. coli 20%	n/a	n/a	118.8	–3%	n/a	n/a
E. coli 40%	n/a	n/a	115.0	–6%	n/a	n/a
E. coli 60%	n/a	n/a	113.1	–8%	n/a	n/a
Secondary contact "B"	n/a	n/a	113.1	–8%	n/a	n/a
Secondary contact "A"	n/a	n/a	113.1	–8%	n/a	n/a

Note: * Mitigation options that had no impact have been removed from the table.

Figure 5: Annual average sediment rate (millimetres per year) for four Whangarei Harbour depositional basins



Note: AASR = annual average sedimentation rate.

5.10 Impact of mitigations on *E. coli* attributes

Table 11 provides the results for the *E. coli* targets for primary and secondary contact recreation. Implementing mitigation practices in the Whangarei Harbour catchment can lead to reductions in *E. coli* concentration that allow many, and sometimes all, of the important sites in the catchment to reach at least the "B" state of a maximum of 540 cfu per 100 millilitres for secondary contact recreation (this is based on an annual median estimate). None of the modelled scenarios, even the case of full afforestation, results in all of the sites of importance achieving the "A" state of a maximum of 260 cfu per 100 millilitres for secondary contact recreation.

Achieving *E. coli* targets for primary contact recreation is not possible in the Whangarei Harbour catchment. Even if the catchment was completely covered in forest, it would not be possible to meet the NPS-FM target required for it to be safe to swim in freshwater bodies (a maximum of 540 cfu per 100 millilitres, with a less than 1 percent chance of getting sick) in any of the 11 key sites of importance.

This does not mean that a particular site is always unsuitable for swimming. For example, at the popular swimming site Hātea at Whangarei Falls, the recreational swimming programme results for 2014/15, where sampling is carried out weekly over summer months (end of November to end of February), were lower than 540 *E. coli* per 100 millilitres on 18 out of 24 sampling occasions, or 75 percent of the time. Those lower results compared to modelled year round concentrations are to be expected as summer months tend to be drier with less rainfall related land run-offs.

Additional work is required to assess if there are other methods to estimate 95th percentile concentrations in the catchment, perhaps under different flow assumptions or time constraints. Also, it is valuable to reflect on the way that microbial concentrations at the 95th percentile are related to microbial loads, given that this result has been identified in a framework in which one is assumed to be a linear function of the other.

5.11 Co-benefits

Catchment-wide policies that only target reductions in either *E. coli* or sediment can have a noticeable effect on reducing the non-targeted contaminant as well, but not necessarily to the same degree. Therefore, mitigations that focus on simultaneously reducing both *E. coli* and sediment are likely to be the most effective options (for example, wetlands). This also highlights that the specific location of these mitigations within the catchment can have an effect on other attributes that are not necessarily targeted by the policy.

Table 11: Estimated *E. coli* concentrations (colony forming units per 100 millilitres) for the Whangarei Harbour catchment's sites of importance

Scenario	Whangarei Falls	Waiarohia at confluence with Waiarohia and Waikahitea	Hātea at Mair Park footbridge	Raumanga just before it joins the Waiarohia	Waiarohia at Second Ave	Kirikiri just before it joins the Raumanga	Raumanga at Bernard Street	Raumanga Stream at swimming pool below falls	Otaika at Otaika Valley Road	Otaika weir (Golden Bay surface-water take)	Puwera just before it joins Otaika
Annual median concentration (secondary contact recreation)											
No mitigation	439	525	259	942	399	722	903	211	484	871	1 354
Afforest – all	143	383	80	226	161	320	204	48	133	234	228
Afforest – pasture	201	415	118	642	287	358	517	88	147	249	231
Current fencing	388	504	230	858	380	676	805	184	382	682	981
Current farm plan	439	525	259	942	399	722	903	211	484	871	1 354
Wetlands	221	263	130	472	200	365	452	106	244	437	678
Farm plan	439	525	259	942	399	722	903	211	484	871	1 354
Fence all	216	419	127	540	304	491	436	83	135	234	280
Maximum mitigation	165	236	97	371	176	307	335	74	156	278	409
Harbour sediment 20%	436	467	248	903	386	558	877	204	474	819	1 325
Harbour sediment 40%	409	385	240	896	376	525	872	203	461	806	1 188
Harbour sediment 60%	260	277	155	799	237	391	777	176	247	432	643
E. coli 20%	349	420	207	752	313	567	722	170	388	698	1 083
E. coli 40%	259	315	155	563	237	430	540	127	291	524	813
E. coli 60%	173	221	104	387	168	298	371	85	195	350	542
Secondary contact "B"	439	410	259	540	229	540	540	115	371	540	540
Secondary contact "A"	260	223	202	328	164	278	277	58	172	260	275
95th percentile concentration (primary contact recreation)											
No mitigation	2 003	3 485	6 306	12 844	5 421	9 852	13 164	3 076	4 378	7 883	18 470
Afforest – all	652	2 541	1 937	3 089	2 185	4 360	2 978	698	1 207	2 119	3 111
Afforest – pasture	919	2 753	2 863	8 759	3 896	4 878	7 541	1 289	1 331	2 249	3 154
Current fencing	1 771	3 344	5 596	11 701	5 163	9 220	11 739	2 686	3 459	6 166	13 379
Current farm plan	2 003	3 485	6 306	12 844	5 421	9 852	13 164	3 076	4 378	7 883	18 470
Wetlands	1 009	1 743	3 166	6 431	2 713	4 977	6 586	1 539	2 203	3 955	9 246
Farm plan	2 003	3 485	6 306	12 844	5 421	9 852	13 164	3 076	4 378	7 883	18 470
Fence all	986	2 782	3 086	7 369	4 130	6 694	6 357	1 210	1 218	2 120	3 814
Maximum mitigation	754	1 568	2 361	5 063	2 391	4 187	4 885	1 073	1 413	2 515	5 582
Harbour sediment 20%	1 990	3 100	6 049	12 320	5 242	7 609	12 780	2 971	4 290	7 412	18 075
Harbour sediment 40%	1 865	2 556	5 837	12 217	5 103	7 166	12 712	2 952	4 166	7 287	16 197
Harbour sediment 60%	1 187	1 841	3 771	10 897	3 222	5 339	11 328	2 573	2 237	3 909	8 765
E. coli 20%	1 593	2 788	5 046	10 253	4 253	7 731	10 523	2 474	3 507	6 310	14 776
E. coli 40%	1 184	2 091	3 770	7 685	3 224	5 861	7 877	1 845	2 635	4 737	11 082
E. coli 60%	792	1 466	2 526	5 280	2 279	4 070	5 412	1 235	1 767	3 169	7 388
Secondary contact "B"	2 003	2 724	6 306	8 584	3 108	7 365	7 872	1 672	3 356	4 884	7 365
Secondary contact "A"	1 187	1 480	4 919	4 467	2 229	3 793	4 034	839	1 552	2 352	3 750
NPS-FM attribute state	A (< 260)		B (260–540)			C (540–1 000)			D (> 1 000)		

Note: NPS-FM = National Policy Statement for Freshwater Management.

6 Limitations of the study

NZFARM has been developed to assess economic and environmental impacts over a wide range of land uses, but it does not account for all sectors of the economy. The economic land use model should be used to provide insight on the relative impacts and trade-offs across a range of policy scenarios (for example, practice versus outcome-based targets), rather than for explicitly modelling the absolute impacts of a single policy scenario. Thus, it should be used to compare impacts across a range of scenarios or policy options.

The parameterisation of the model relies on biophysical and economic input data from several different sources. Therefore, the estimated impacts produced by NZFARM should be used in conjunction with other decision support tools and information not necessarily included in the model to evaluate the "best" approach to manage sediment and *E. coli* in the Whangarei Harbour catchment. Some of the modelling limitations from the study include:

1. **Representative farms:** The model only includes data and mitigation practices for representative farms for the Whangarei Harbour catchment that were parameterised based on their physical characteristics (for example, land use capability, slope and so on). It does not explicitly model the economic impacts on a specific farm in the catchment. As a result, some landowners in the catchment may actually face higher or lower costs than what are modelled using this representative farm approach.
2. **Contribution of dairy and forestry:** It is not possible to reliably differentiate between the contribution of dairy and other pastoral activities to *E. coli* loads (apart from the influence of dairy effluent).
   - The overall loading from pasture is approximately six-times larger than that from forested areas;
   - Runoff from some of the forested catchments have unexpectedly high *E. coli* concentrations. This applies especially to sites in the Whangarei Harbour catchment;
   - This information implies that reducing *E. coli* loads by controlling pasture sources alone may not be as effective, making it difficult to achieve concentration targets;
   - Investigating some of the forested catchments would be beneficial to identify the sources of *E. coli* and measures most likely to minimise *E. coli* concentrations in runoff.
3. **Uncertainty in *E. coli* modelling:** Overall, there is high uncertainty in model predictions, due to currently unknown factors. This uncertainty should be acknowledged when determining risks (that is, which catchments should be prioritised for implementation of mitigation strategies?) and prioritising investment (that is, which mitigation tools should be implemented, and where should they be implemented in the catchment?).
4. **Not all sites are measured:** Stream flows and *E. coli* concentrations are not currently measured at all of the sites of interest in the catchment (sites of importance). The estimated concentrations and loads at some of these sites are high and relatively uncertain. It would be advantageous to monitor *E. coli* at these sites to improve load estimates.
5. **Baseline conditions:** The NZFARM baseline assumed that (1) land use in the catchment was the same as a 2011 land use map; (2) that net farm revenue was based on a five year average of input costs and output prices; and (3) that no landowners were implementing management practices intended to reduce sediment and *E. coli* in the catchment. Assumption number three is likely to have the greatest impact on model estimates, as NRC has indicated that some farms in the catchment have implemented farm plans and/or fenced their streams. However, the number of farms that have implemented these management options to their maximum effectiveness is uncertain and likely to be relatively small.

6. **Mitigation effectiveness:** Each management practice included in the model is assumed to have a fixed relative rate of effectiveness for reducing sediment and *E. coli* loads (for example, 50 percent of baseline loads). In reality, the actual impact of a given practice is likely to vary, depending on where, when and how well the practice is implemented.
7. **Optimisation routine:** For this analysis, NZFARM has been programmed such that all landowners are assumed to collectively select the "optimal" combination of management practices required to achieve specific outcomes related to managing sediment and *E. coli* in the Whangarei Harbour catchment. In reality, not all landowners will necessarily select the option that is considered most optimal.

7 Summary and conclusions

NRC has identified that sediment and *E. coli* are important water quality challenges in the Northland region. As a result, the council engaged in a joint venture with MPI and MfE to undertake a sediment and *E. coli* study in the Whangarei Harbour catchment.

The study's objective was to identify cost-effective ways to manage sediment and *E. coli* loads in streams and rivers in the Whangarei Harbour catchment, as well as in the harbour itself. The study had a particular focus on the impact of mitigation on various sediment and *E. coli* attributes.

The Whangarei Harbour catchment has a lot of area classified as urban or native, which is managed differently from rural productive land uses such as dairy, sheep and beef, and forestry. Only 46 percent of the catchment is in pasture, so management options that only target pastoral enterprises may not be enough to achieve large reductions in environmental contaminants.

The most effective mitigations are those that focus on a combination of fencing, farm plans and wetlands, with landowners deciding on the optimal combination of mitigations for their farm. This mitigation enables a focus on the particular hot spots of sediment and *E. coli*. This mitigation cost of $65 000 per year reduced net revenue in the

catchment by around 4 percent, but total sediment loads are estimated to fall by around 60 percent, with total sediment deposition in the harbour also estimated to be reduced by 60 percent. *E. coli* loads in streams are estimated to reduce by around 44 percent.

In considering each mitigation practice on its own, constructing wetlands and sediment ponds is estimated to be the most effective option, because it is the only mitigation that can be applied to all land uses. Sediment loads are estimated to reduce by 61 percent and *E. coli* loads in streams by 48 percent. It is also the only mitigation option that has a positive impact on the sediment attributes of water clarity and euphotic depth in all three measured sites in the catchment. For example, constructing wetlands near the Otaika River improves water clarity at median flows by up to 77 percent and euphotic depth by 35 percent.

However, co-ordination and cost constraints could limit uptake of this management option. For example, wetlands were estimated to cost $1.5 million per year across the catchment, which represents an annual cost of $49 per hectare. This compares with the cost of fencing pastoral streams estimated at $443 000 per year or $15 per hectare per year.

Fencing all pasture land has an effect on streambank erosion and *E. coli* from pasture, but no impact on landmass erosion (85 percent of sediment in the catchment results from landmass erosion). As a result, the greatest impact of this management option is on *E. coli* loads in streams, which are estimated to be reduced by more than 50 percent relative to the baseline.

Implementing farm plans on pastoral farms is only assumed to mitigate sediment from hill and landmass erosion. Most of the pasture in the catchment is not located at the top of the catchment where there can be high levels of landmass erosion, so farm plans may not be the most cost-effective option for reducing sediment and *E. coli* loads in the catchment.

Nearly all scenarios estimated a noticeable reduction in the harbour sediment attribute included in the Whangarei Harbour study, the AASR. Estimates varied widely across the four deposition basins, though, as they are all affected differently in terms of the amount of sediment they receive annually from both land and marine sources. Thus, the suggested “high” attribute state of 1 millilitre per year may not be achievable for all harbour basins.

Implementing mitigation practices in the Whangarei Harbour catchment can lead to reductions in *E. coli* concentration that allow many, and sometimes all, of the important sites in the catchment to reach at least the “B” state of a maximum of 540 cfu per 100 millilitres for secondary contact recreation (this is based on an annual median estimate). Some sites of importance reach the “A” state of a maximum of 260 cfu per 100 millilitres when particular mitigations are applied.

Achieving *E. coli* targets for primary contact recreation is not possible in the Whangarei Harbour catchment. Even if the catchment was completely covered in forest, it would not be possible to meet the NPS-FM target for primary contact recreation (a maximum of 540 cfu per 100 millilitres) in any of the 11 key sites. This target is based on the 95th percentile measurements. Additional work is required to assess if there are other methods to estimate 95th percentile concentrations in the catchment, perhaps under different flow assumptions or time constraints.

Catchment-wide policies that only target reductions in either *E. coli* or sediment can have a noticeable effect on reducing the non-targeted contaminant as well, but not necessarily to the same degree. For example, a policy that targets a 40 percent reduction in sediment can also reduce *E. coli* loads in the catchment by 15 percent to 23 percent, while a policy that targets a 40 percent reduction in *E. coli* can reduce sediment by 15 percent. It also highlights that the specific location of these mitigations within the catchment can have an effect on other attributes that are not necessarily targeted by the policy.

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