LANDCARE RESEARCH
MANAAKI WHENUA

An ecosystem services assessment for the Living Water Partnership – Upper Wairua Catchment

An ecosystem services assessment for the Living Water Partnership – Upper Wairua Catchment

Adam Daigneault, John Dymond, Anne-Gaelle Ausseil, Chris Tanner, Norman Mason, Olivia Burge, Fiona Carswell

Landcare Research

Prepared for:

Living Water Partnership

Private Bag 4715
Christchurch Mail Centre
Christchurch 8140
New Zealand

July 2017

Landcare Research, 231 Morrin Road, St Johns, Private Bag 92170, Auckland 1142, New Zealand, Ph +64 9 574 4100, Fax +64 9 574 4101, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
Suzie Greenhalgh Portfolio Leader Landcare Research	Gary Houliston Portfolio Leader – Enhancing Biodiversity Landcare Research

Landcare Research Contract Report: LC2811

Disclaimer

This report has been prepared by Landcare Research for the Living Water Partnership. If used by other parties, no warranty or representation is given as to its accuracy and no liability is accepted for loss or damage arising directly or indirectly from reliance on the information in it.

Contents

Summary

Project and client

Landcare Research was contracted by the Living Water Partnership to conduct a catchment-scale study of how to reduce flooding severity and sedimentation while optimising ecosystem services in the Hikurangi area. An advisory committee made up of representatives from Northland Regional Council, Whangarei District Council and DairyNZ recommended a boundary change, and so the project area was renamed the Upper Wairua Catchment (UWC) and the total area extended from 35,000 to 75,000 ha.

The purpose of the assessment was to conduct a scenario analysis to identify opportunities to enhance ecosystem services, possible land management options that could be implemented in the catchment, and the potential economic and environmental trade-offs that could result from managing the UWC in a variety of ways.

Objectives

While focusing on whole-catchment modelling of flood water, water storage, sediment, water quality and habitat for biodiversity:

- develop ecosystem-based solutions and ecosystem service enhancement scenarios
- undertake catchment scale modelling and mapping, and site-scale modelling of priority ecosystem services
- conduct economic modelling and evaluation of scenarios
- undertake stand-alone biodiversity modelling.

Methods

We used Landcare Research's economic land-use model (New Zealand Forest and Agriculture Regional Model − NZFARM) to estimate the possible catchment-scale impacts for a range of management/mitigation approaches. The model expressly includes the costs of conducting mitigation, which is mostly made up from costs to individual landholders. Living Water held workshops for stakeholders in the catchment, who confirmed that flood mitigation and sedimentation are the key ecosystem service concerns at a catchment scale.

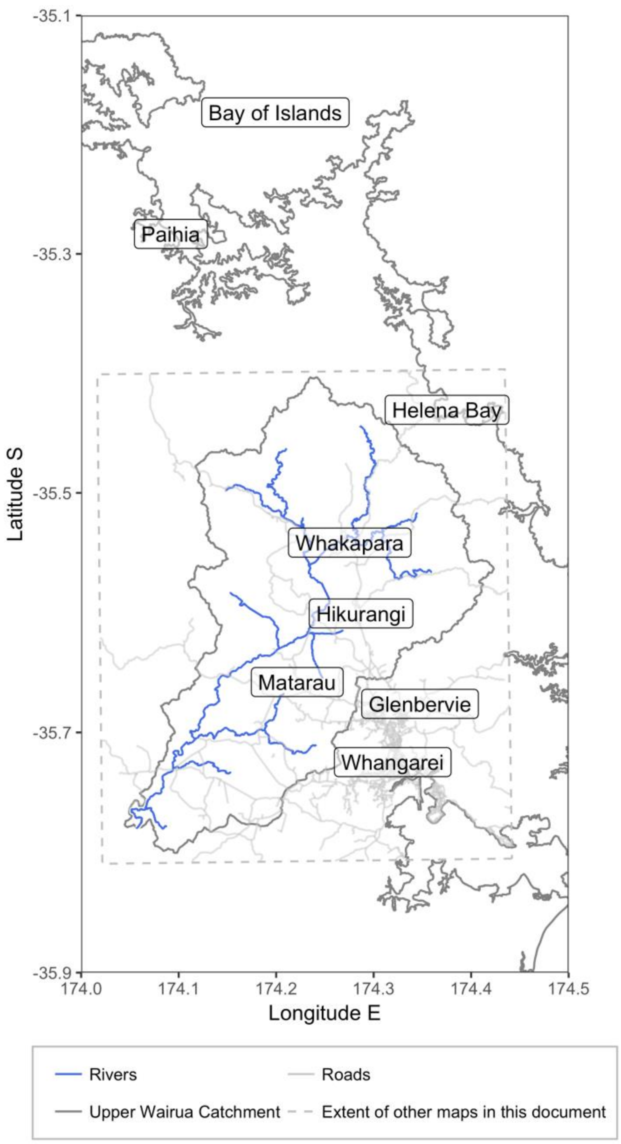

Figure S1 The Upper Wairua Catchment (UWC), in which the economic modelling (NZFARM) and ecological modelling described in this report was undertaken.

The concept of 'ecosystem services' was developed to quantify the value that humans derive from the natural world. Most analyses recognise four major classes of ecosystem service: cultural, regulating (e.g. water purification), provisioning (e.g. food production) and supporting (e.g. nutrient cycling). Biodiversity is not an ecosystem service in itself, but it does underpin most of the ecosystem services if all biological diversity is considered (in other words it doesn't need to be indigenous in most instances).

Because ecosystem service optimisation does not expressly cater for biodiversity, stand-alone analyses also examined some scenarios to enhance indigenous biodiversity and analysed them, both quantitatively and qualitatively. Only scenarios that resulted in some overall ecosystem service improvement were also considered for biodiversity gain.

Results

Maximising ecosystem services

A favoured scenario was to improve the catchment-wide ecosystem services significantly, for little cost. Fencing of streams, prioritised soil conservation plantings and flood retention bunds in all first-order catchments would reduce in-river sediment load by over 50%, reduce in-river *Escherichia coli* load by 60%, and reduce water spilled in a design flood by 25%. The cost is reasonable, at $4 million per year. This scenario represents a significant improvement to the priority ecosystem services in the catchment, as identified by the stakeholders.

A flood retention bund is an earth dam on a first-order stream (i.e. a stream without any tributaries). The proposed bunds would average 1 m high and 50 m wide. The bunds would have a narrow drainage pipe at the bottom, and would be able to drain 1,250 m^3 of water over a period of several days. On top of the bunds, a wide drainage pipe would be able to drain large flows during storm events. Most of the time the reservoir would be empty, so in large rains the bunds would retain rainfall and only slowly release it to the main flood control scheme in the Hikurangi floodplain. When this bunding system was combined with fencing of all streams and making sure riparian planting was conducted for the 20% most erosion-prone land holdings, multiple ecosystem service benefits could be realised simultaneously for a reasonable annual cost.

Sacrificing the entire Otonga[1] pocket for flood control measures would reduce water spilled in a design flood by 17%, but the cost would be about 35% more than the flood retention bunds option. The location of the pocket also means that if that were the only measure implemented in the UWC, it would not benefit any areas upstream of the pocket (with respect to flooding).

Enhancing biodiversity at the same time

With respect to biodiversity gains, fencing and natural regeneration and/or planting of riparian buffers (to 10 m width) offered considerable benefits. Carbon storage gain was also high. Riparian buffers would increase connectivity and native habitat within the UWC. The buffers would also provide the opportunity to plant otherwise threatened species.

'Sacrificing' the Otonga pocket in favour of natural forest regeneration for biodiversity (and carbon) benefit offered the best value in terms of gain per hectare. An alternative scenario would be to reclaim this pocket as a novel (swamp) wetland, which would result in a bigger gain for highly threatened (nationally and regionally) wetlands. This creation of habitat would also be expected to increase the abundance of native bird species (such as the Australasian bittern, North Island fernbird, bellbird and tūī), native invertebrates, as well as threatened and uncommon plant species, such as swamp hebe (*Hebe* aff. *bishopiana*

[1] The Otonga pocket was chosen for the 'sacrificial pocket' scenario because it was a real proposal made to the Whangarei District Council by the major landowner in the pocket. The results of the Otonga pocket can be considered representative of the other large pockets.

Hikurangi Swamp), heart-leaved kōhūhū (*Pittosporum obcordatum*), mingimingi, swamp coprosma, *Coprosma rotundifolia, Neomyrtus pedunculata* and *Myrsine divaricata.* We would recommend planting these threatened plant species.

The creation of this wetland is not expected to compromise the hydrological capacity of the Otonga pocket to mitigate flood events, but it should be noted that this was a slightly less effective flood mitigation option overall than the creation of the upland bunds (i.e. 17% reduction of spilled water in a design flood rather than 25%).

Conclusions

- Ecosystem services were maximised by the combination scenario of fencing streams, and prioritising soil conservation planting and flood retention bunds
- Of the scenarios tested specifically for biodiversity gain, the least gain would be derived from enhancing the upland bunds with native plants. Forest habitat would be maximised by planting and fencing buffers along all streams in the catchment (width = 10 m). Wetland habitat and threatened species gain would be maximised by the creation of a wetland in the Otonga pocket. This would also provide flood benefits and water treatment services.

1 Introduction

Landcare Research was contracted by the Living Water Partnership between Fonterra and the Department of Conservation to develop an integrated ecosystem services assessment of the Hikurangi Catchment, Northland. An advisory committee made up of representatives from Northland Regional Council, Whangarei District Council and DairyNZ recommended a boundary change, and so the project area was renamed the Upper Wairua Catchment (UWC) and the total area extended from 35,000 to 75,000 ha.

The ecosystem services assessment was intended to focus on whole-catchment modelling of flood water, water storage, sediment, water quality and habitat for biodiversity. Economic modelling was used to conduct a scenario analysis to identify opportunities to enhance ecosystem services, possible land management options that could be implemented in the catchment, and the potential economic and environmental trade-offs that could result from managing the UWC in a variety of ways.

Landcare Research contributed to research in the Upper Wairua Living Water Programme through three phases/objectives:

- the development of ecosystem-based solutions and ecosystem service enhancement scenarios
- catchment-scale modelling and mapping, and site-scale modelling of priority ecosystem services
- economic modelling and evaluation of scenarios.

This report provides background on the relationship between ecosystem services and biodiversity, and then focuses on the methodology and findings from phase 3 of the project. As additional outputs (not contained here), we have demonstrated the potential benefit of riparian fencing and planting at a national scale. Others (Clarkson et al. 2015) have also provided direct advice on the priority actions for biodiversity.

1.1 Ecosystem services: introduction

The concept of ecosystem services comes from economic theory and is intended to capture the value humans derive from the natural world (Mace et al. 2012). Ecosystem service theory attempts to place an economic value on ecosystems for the practical benefits they provide to humans. Ecosystem services have been reviewed at a global scale by the Millennium Ecosystem Assessment (MEA) and defined as:

> the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits. (MEA 2003)

Biodiversity and ecosystem services do not mean the same thing. Biodiversity can be thought of as the variety of all biological life − plants, animals, fungi and microorganisms −

the genes they contain and the ecosystems on land or in water where they live (New Zealand Biodiversity Strategy, February 2000). The New Zealand Biodiversity Strategy also notes that Māori have a holistic view of the environment and biodiversity in which humans share a common whakapapa (ancestry) with animals and plants. As people linked with the natural world, the wellbeing of people is directly linked to the wellbeing of natural resources.

There is naturally an overlap between the services provided by the natural world and the variety of biological life in the natural world: biodiversity contributes directly and indirectly to ecosystem service provision (MEA 2005). On the other hand, the MEA (2005) notes that increasing ecosystem service provision (at least in the short term) through converting natural ecosystems to human-dominated systems has led to reductions in biodiversity, indicating that managing for ecosystem services will not necessarily lead to benefits for biodiversity.

1.1.1 Ecosystem services in New Zealand

The value of land-based ecosystem services to New Zealand in 2012 was estimated to be $57 billion dollars, or around 27% of GDP (gross domestic product) for the same period (Patterson & Cole 2013). This value includes use values (e.g. the provisioning and recreational services in the MEA definition above) and non-use values. Quantification of non-use ecosystem services is difficult (Hein et al. 2006), and in New Zealand has been limited to only one aspect of ecosystem services' valuation: their existence value, or how much individuals will pay to preserve an ecosystem even though they may not ever intend to use or visit it. The non-use value of New Zealand's ecosystems is predominantly derived from national and forest parks, land reserves (including camping grounds), wetlands, and estuarine and freshwater systems (Patterson & Cole 2013).

Use values from ecosystem services include: water provisioning, food production, climate regulation, erosion control, pollination, recreation, waste treatment, biological control, soil formation and nutrient cycling. Agricultural ecosystems are the largest ecosystem land-use type, making up 37% of the land area of New Zealand and 35% of the gross ecosystem service provision value. Gross ecosystem service provision is made up of provisioning services (e.g. food provision), regulating services (e.g. flood control), cultural services (e.g. scientific knowledge), and supporting services (e.g. nutrient cycling). Agricultural areas primarily provide erosion control and commercial food production services. Marginal pastoral land ('intermediate agriculture-scrub ecosystem' land-use types) includes areas with significant coverage of scrub and fern vegetation mixed with exotic grasses. Areas like this provide pollination, biological control and soil formation services, in addition to food production and wool provisioning services (Patterson & Cole 2013).

1.1.2 Wetlands: historical and current ecosystem service provision

Wetlands contribute more to ecosystem services than any other ecosystems. Worldwide they cover 1.5% of the Earth but provide 40% of global ecosystem services (Zedler & Kercher 2005). New Zealand has lost more than 90% of its wetlands in the past 150 years, and only 4.9% of the historical cover remains in the more intensively developed North Island (Figure

1) (Clarkson et al. 2013). Wetlands now cover only 0.61% of New Zealand's land area but are estimated to provide 13% of the gross ecosystem service provision (Patterson & Cole 2013).

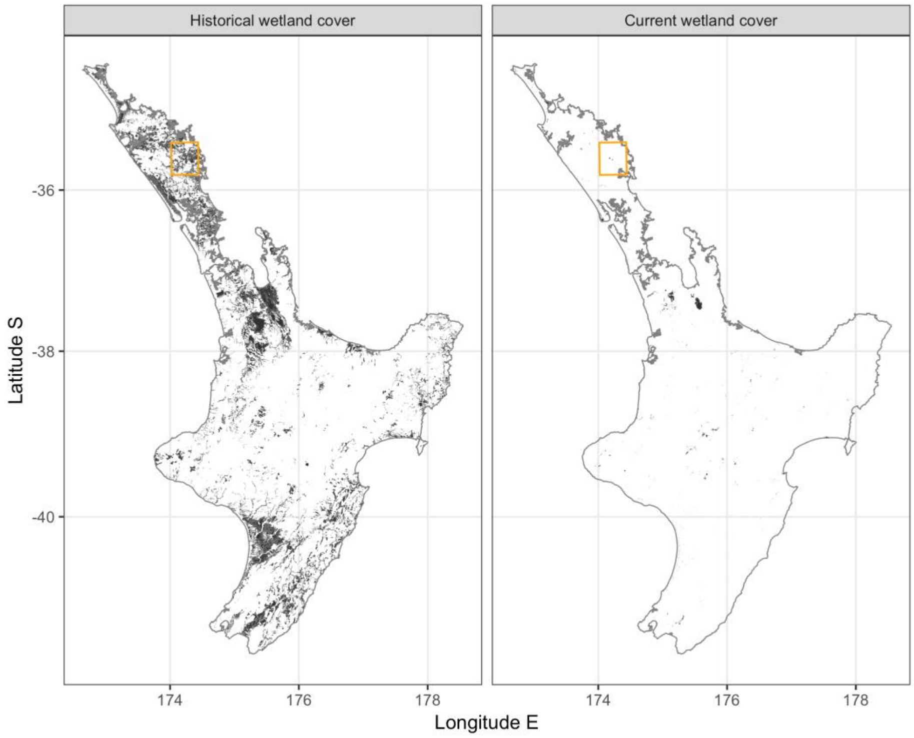

Figure 1 Historical and current wetland cover in the North Island, New Zealand. Data sourced from Freshwater Environments of New Zealand (Ausseil et al. 2008). The UWC location is shown in yellow.

The services provided include removing excess nutrients from surface water; providing cultural, recreational and educational opportunities; flood regulation; water storage; and carbon sequestration.

Wetland nutrient removal depends on location within the catchment. Wetlands in lower parts of large catchments are best positioned to remove nitrogen, while wetlands in the upper parts of small catchments are most effective at removing phosphorus (Clarkson et al. 2013).

Flood protection is provided by wetlands, because they form a physical barrier to slow the speed and reduce the height of floods, and reduce flood peak magnitude by acting as a natural reservoir for floodwaters (Clarkson et al. 2013). It is recommended that 3 to 7% of a river catchment be retained as wetland to provide adequate flood mitigation and maintain water quality (Mitsch & Gosselink 2000). In the UWC, wetland coverage has dropped from an estimated 52% of the catchment to 0.6% (Figure 2).

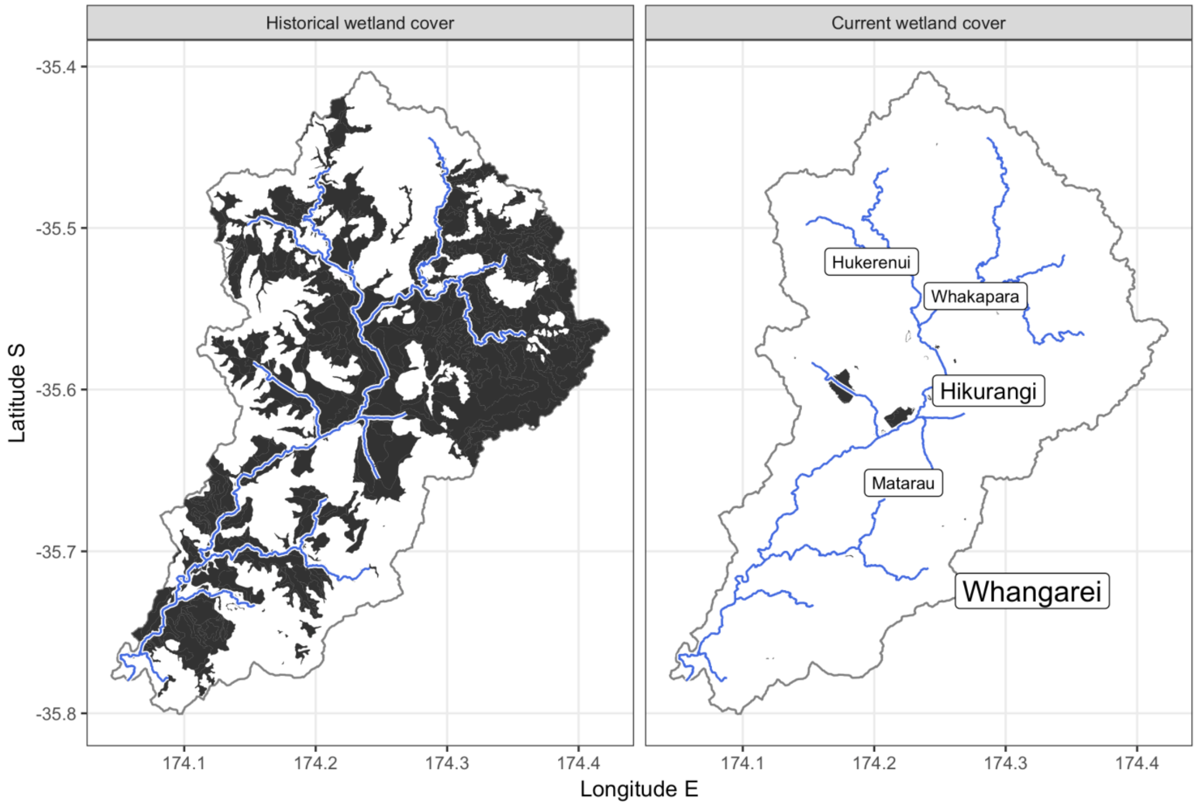

Figure 2 Historical and current wetland cover within the UWC. The two largest remaining wetlands are Otakairangi swamp (west) and Hikurangi swamp/ Wairua River (east). Major rivers are shown in blue with white outline. Data sourced from Freshwater Environments of New Zealand (Ausseil et al. 2008).

1.1.3 Māori and ecosystem services in the Upper Wairua Catchment

Harmsworth and Awatere (2013) describe a model of ecosystem services based on Māori knowledge and perspectives in which cultural values apply across the entire ecosystem services framework. In this model, cultural values include provisioning ecosystem values and cultural ecosystem services. 'Cultural ecosystem services' is an umbrella term to capture all the 'non-material benefits people obtain from ecosystems' (MEA 2005).

Living Waters and Ngā Kaitiaki o Ngā Wai Māori have partnered to report on the customary and traditional practices of Māori at the Hikurangi repo (swamp) (Armstrong-Read 2016). The report focuses on the loss of food provisioning services, particularly tuna (eel) species, and cultural ecosystem services following drainage and development of the swamp, which began in 1919. The MEA notes that ecosystem changes typically lead to costs placed on some groups of people and benefits accruing to other groups of people, and it is commonly the poor, women and indigenous people who are harmed by such changes. Where changes in ecosystem management cause a shift from shared resources to private control of resources, marginalised groups such as indigenous peoples tend to lose access to the resource (MEA 2005).

Cultural ecosystem services, and scenarios redressing the loss of historical food provisioning values of wetlands to Māori, were not within the scope of existing or future projections for the catchment provided to Landcare for modelling. Ecosystem services of most interest to Māori are therefore not captured by this report, and readers are directed to the Living Water and Ngā Kaitiaki o Ngā Wai Māori report for further information.

1.1.4 Existing and enhancing biodiversity values within the Upper Wairua Catchment

There is little public conservation land within the UWC, meaning that much of the remaining indigenous vegetation is on private land. Within the Hikurangi floodplain (Figure 3) 16 sites were surveyed for a Living Water report on opportunities for restoration (Clarkson et al. 2015). More than 99% of the Hikurangi floodplain is classified as being in a 'threatened environment' (Clarkson et al. 2015); that is, one in which much indigenous vegetation has been cleared or little remaining indigenous vegetation is protected (Cieraad et al. 2015). Therefore, all areas of indigenous vegetation on the floodplain are considered to be important as representative examples of lowland floodplain forest ecosystems.

The floodplain supports two nationally threatened plant species, *Hebe* aff. *bishopiana*, a 'nationally critical' shrub, and *Pittosporum obcordatum* (heart-leaved kohuhu, a species in 'national decline'). Threatened and at-risk bird and fish species are also present in the floodplain, including the Australasian bittern, black mudfish and long-fin eel.

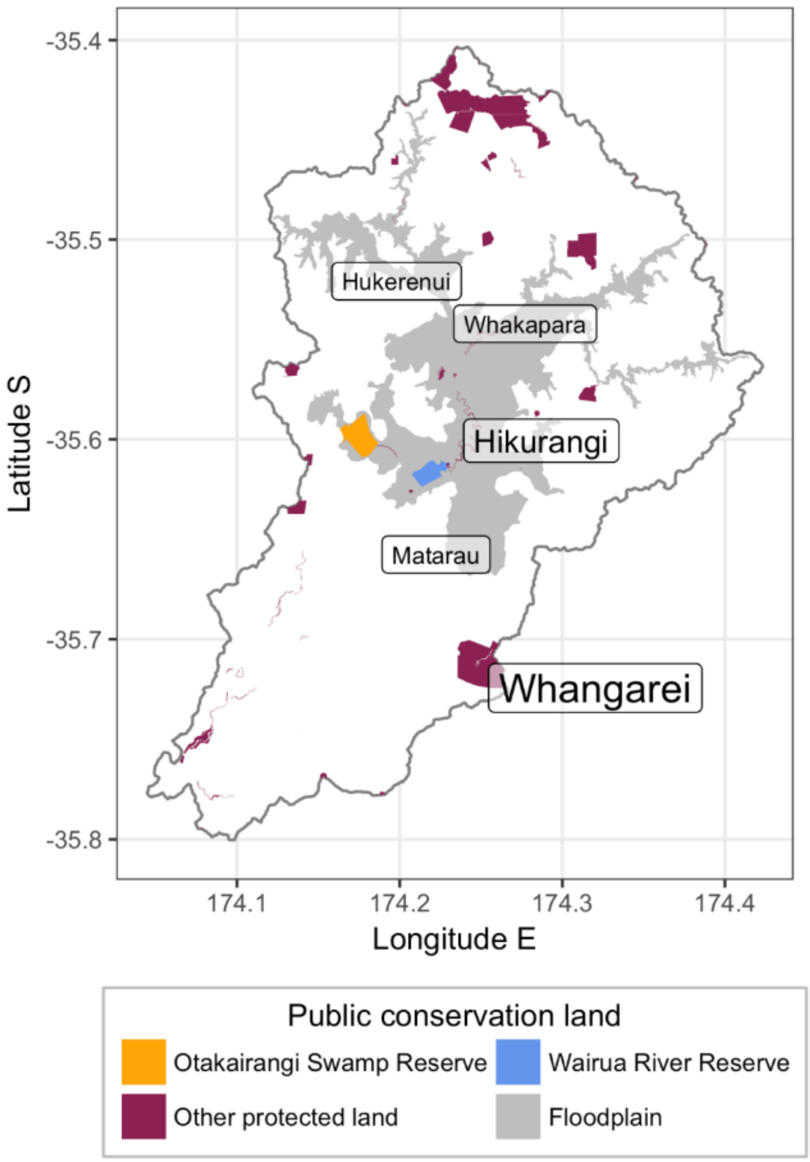

Figure 3 Public conservation land within the UWC. Public conservation land covers around 3.5% of the catchment. The remaining large areas of wetland (shown in Figure 2) are located within the Otakairangi swamp and Wairua River reserves. Floodplain GIS layer provided by Living Water.

Major threats to existing indigenous biodiversity on private land, and on public conservation land, have been identified in the restoration report (Clarkson et al. 2015) as being:

- hydrological changes, from drains, channelisation, artificial oxbows, pumping stations and channels
- domestic stock damage on private land, resulting from stock access to unfenced or poorly fenced remnants, or across dry areas that are usually inundated
- exotic plant invasion, particularly the spread of *Tradescantia*
- introduced feral animal damage to native plants and animals through herbivory and predation

- habitat loss on private land, through vegetation clearance, land development and fire
- nutrient enrichment in natural areas (e.g. from run-off from agriculture) – nutrient enrichment reduces water quality and can encourage exotic plant species invasion.

Opportunities for restoring the natural hydrological regime are limited by the existing Hikurangi Swamp Scheme. Within the scenarios modelled as alternatives in this report, there may be scope within the 'sacrificial pocket' (the Otonga pocket area proposed by stakeholders as a possible area for flood inundation) option to restore natural hydrological fluctuations within the pocket. This would need to be integrated into the design process.

Protection of existing remnants of indigenous vegetation from stock, weed and pest species, clearance and nutrient incursion would address the remaining major threats. Implementation would not detract from modelled scenarios for the catchment. Creating or assisting natural regeneration of wetland and forest areas would improve the lack of native habitat in the catchment, but given the extent of land in private ownership in the catchment this may not be possible.

The existing biodiversity values within Otakairangi wetland, on public conservation land (Figure 3), has scope for enhancement. *Sporadanthus ferrugineus* is an endemic peat-forming rush species that was historically dominant in raised bogs throughout the North Island. It now occurs naturally at only three sites within the Waikato region and is locally extinct in Northland. It was probably extirpated from Otakairangi wetland due to the increased fire frequency that accompanied post-European settlement land clearance. *Sporadanthus ferrugineus* could be re-established at Otakairangi, following consultation with hapū and stakeholders, by translocating plants and raising the water table. Successful reintroductions have been undertaken in the Waikato region (Clarkson et al. 2015).

Creating new and stronger links between existing remnants is also recommended as positive action for biodiversity in the restoration report (Clarkson et al. 2015). Increasing connectivity through careful planting along riparian areas could facilitate birds to move between remnants. Revegetation of riparian areas and oxbows is a focus of the Hikurangi Swamp Floodway Riparian and Ox-Bow/Cut Off Channel Management Plan 2011. The Management Plan refers to 1995 New Zealand research as suggesting 1 to 3 m width per 100 m slope feeding into waterways as being ideal, and as a result 1 to 3 m-wide riparian areas are recommended for the main river, and up to 2 m from the top of channel banks for oxbows. Wider riparian plantings are suggested under more recent guidance (Daigneault, Eppink & Lee 2017) for sediment, nitrogen and phosphorus reduction. Riparian planting width and species selection (both for birds and ongoing maintenance requirements) will determine the operational effectiveness of any future riparian plantings.

Finally, afforestation – even of exotic species – can provide valuable habitat for native bird species. Eucalypts have been observed to attract bellbirds even when considerable distances from native forest remnants (Norton & Miller 2000); willow (although invasive species of willow such as grey willow *Salix cinerea* will have a net cost for biodiversity), poplar and elm provide seasonal food to kererū (Clout et al. 1991) and breeding habitat for native falcons (Seaton et al. 2009). Exotic forestry can provide roosting and foraging habitat for native New

Zealand bats (Borkin & Parsons 2010), and pine plantations can also support dense and diverse native plant understoreys (Allen et al. 1995; Ogden et al. 1997), and are considered to have a higher conservation value than intensive agriculture (Brockerhoff et al. 2008).

1.1.5 Value of the ecosystem service approach

An ecosystem service approach attempts to quantify the economic value of services provided by different land uses, thereby informing decisions on land-use policy, particularly where there are trade-offs. As noted above, biodiversity and ecosystem services overlap, but debate is ongoing as to whether using an ecosystem services approach adequately captures the value of biodiversity (Silvertown 2015; Potschin et al. 2016). Cultural, social, spiritual and heritage ecosystem services are particularly poorly represented in existing ecosystem service work (Chan et al. 2012).

This report quantifies the provision of selected ecosystem services by existing land uses in the UWC, and by possible future-land use configurations vetted by a stakeholder group. It cannot capture ecosystem services provided by the pre-human extent of forests and wetlands, because ecosystem services are an anthropocentric (human-focused) concept. From this perspective, there are no benefits from ecosystems unless humans reap these benefits.

This report focuses on the ecosystem values identified by the working group as being of most importance to landowners, including flood spill-over, sediment loss, stream *E. coli* load, and greenhouse gas (GHG) emissions. It does not quantify cultural services such as recreation, or services to agriculture such as pollination from natural areas. This report therefore should be considered a resource to aid decision-making in relation to the UWC, complementing parallel work relating to the value of biodiversity within the catchment and to Māori priorities for the Hikurangi.

1.2 Upper Wairua Catchment economic model

The integrated model of the UWC consists of two key components:

- baseline contaminant losses for each hectare of land in the study regions
- how these are modified with the use of mitigation actions (both on- and off-farm).

The model allows for any combination of mitigation measures to be applied at farm, sub-catchment and catchment levels to achieve spatially distributed environmental objectives, which are expressed as attribute states.

The UWC model is based on the New Zealand Forest and Agriculture Regional Model (NZFARM), Landcare Research's economic land-use model (Daigneault et al. 2012, 2013, 2017). NZFARM is designed to provide detailed modelling of land uses at a catchment scale. It enables the consistent assessment of multiple policy scenarios by estimating and comparing the relative changes in economic environmental outputs. The UWC version of

NZFARM tracks a wide range of ecosystem services (or outputs that serve as proxies), including agriculture and forest commodity production, nitrogen and phosphorus loss, sediment and *E. coli* loads, and GHG emissions.

The model also tracks several options for mitigating these outputs:

- implementing soil conservation plans
- fencing streams
- constructing wetlands.

While the list of feasible farm management options is extensive, we do not include all possible options to mitigate losses from diffuse sources into waterways or to reduce GHG emissions. We also do not allow for fencing that is required under the Sustainable Dairying Water Accord or the Clean Streams Accord. The results from NZFARM are reliant on input data (e.g. farm budgets, mitigation costs and contaminant loss rates) from external sources and may vary if alternative data are utilised. NZFARM also does not account for the broader impacts of changes in land use and land management beyond the farm gate.

This report presents the results from several scenarios to investigate the range of costs of reducing sediment loads in the catchment, because soil erosion was identified by stakeholders as being one of the most pressing issues in the catchment. These include both practice-based approaches (such as fencing all streams for stock exclusion), and outcome-based approaches that include reducing erosion to reach an aggregated catchment load target.

The focus of this part of the Living Water study is to develop and test an economic catchment model that looks at sediment management in an integrated framework. It is not intended to define or analyse any specific policy or reduction target. As a result, the scenarios presented here should be taken as illustrative examples of how the model works and can be utilised in future analyses, as opposed to a rigorous analysis of a proposed policy or rule change.

2 Methodology

This report presents an assessment of the potential economic and environmental impacts of reducing sediment, controlling flooding and enhancing ecosystem services in the UWC, Northland. The economic analysis is conducted using the NZFARM model. Baseline estimates of sediment were obtained through a number of biophysical models and data sources. Economic impacts are estimated as the cost to landowners of implementing mitigation options relative to their current management practices.

Note that the catchment is modelled without allowance for the stock exclusion fencing carried out under the Clean Streams Accord and Sustainable Dairying Water Accord. This was intentional, to illustrate the effort and contribution already being made by dairy farmers. Environmental impacts are measured as changes in freshwater contaminants, flood control and GHG emissions. A more detailed description of the integrated economic model is presented below and elaborated further in Appendix 2.

2.1 New Zealand Forest and Agriculture Regional Model (NZFARM)

NZFARM is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale, developed by Landcare Research (Daigneault et al. 2012, 2013). 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. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners.

The version of the model used for this analysis can track changes in land use, land management, agricultural production and environmental outputs 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.

NZFARM estimates the impact of mitigation scenarios on a range of environmental indicators: stream bank sediment, hill/landmass sediment, total sediment, flood spill-over, stream *E. coli* load, nitrogen (N) leaching, phosphorous (P) loss, GHG emissions and forest carbon sequestration. However, an establishment meeting with stakeholders suggested that sediment and flood control are the environmental indicators of greatest concern to landowners. Further details and equations used in the model are provided in Appendix 2.

2.2 Environmental outputs

Landcare Research analysed baseline erosion rates and sediment yields in the UWC using the SedNetNZ model (Dymond 2016). The catchment erosion and sediment model simulates several erosion processes, sediment storages and transfers. For this analysis SedNetNZ has been calibrated for the UWC and downscaled to the farm scale. Sediment is estimated to come from two sources: hill/landmass[2] erosion and streambank erosion. Nutrient (i.e. N and P) losses for pastoral enterprises, the largest primary sector area in New Zealand, are estimated using the OVERSEER® (v6) nutrient budgeting tool, while N and P estimates for other land uses are derived from research reports for New Zealand (e.g. Parfitt et al. 1997; Lilburne et al. 2010). *E. coli* load estimates are based on average yields for each land use in the catchment, as estimated in a recently used version of the CLUES model (Elliot et al. 2016). GHG emissions are derived using national GHG inventory methodologies (MfE 2014b).

[2] Note: hill/landmass erosion is represented in NZFARM as an aggregate of landslide, earthflow, gully and surficial erosion, as well as floodplain deposition, which are all measured separately in SedNetNZ because it is assumed that certain mitigation practices such as farm plans would address all of these processes at once.

2.3 Mitigation practices

We model several mitigation options for reducing sediment and other freshwater contaminants in the catchment. The wetland and retention bund options are also assumed to have an effect on flooding. Some of the practices also have an effect on GHG emissions and carbon sequestration (i.e. net emissions), although we do not include any specific scenarios that target these emissions. A brief description of each option is listed in Table 1.

We note that some other scenarios were also favoured by some of the stakeholders, such as cut and carry in the bermlands, but these scenarios are not directly related to the stakeholder-assessed priorities of sediment reduction and flood control. Further, they do not represent land-use changes that can be paramaterised for NZFARM and therefore they can be handled only qualitatively. More details on mitigation practices, costs and effectiveness are provided in section 2.5 and Appendix 3.

Table 1 Summary of the modelled mitigation options

Option	Description
Soil conservation plan	Specific to individual farms, but can include slope stabilisation, afforestation, channel diversion and natural wetland remediation
Stream bank fencing	Construct fences along streams that run through pastoral land
Wetland construction	Construct or rehabilitate wetlands, the specifics of which can vary based on slope and location (see Appendix 1)
Retention bund	Retention bund at bottom of each of 2,000 Wairua sub-catchments (River Environment Class 2)
Riparian planting	Fence and plant 5 m riparian buffer along stream banks
Nutrient mitigation bundle	Low-, medium- and high-cost bundles of mitigation practices targeting nutrient mitigation
Afforestation	Plant non-native land with pine plantations or native bush
Combination	Includes a combination of the practices listed above

2.4 Model data and parameterisation

NZFARM accounts for a variety of land-use, enterprise and land management options in a given area. The data required to parameterise each land use, enterprise and land management combination include financial and budget data (e.g. inputs, costs, and prices), production data, and environmental outputs (e.g. sediment loads, *E. coli* loads).

Table 2 lists the key variables and data requirements used to parameterise NZFARM, while Table 3 provides specific elements of the model. More details on the data and parameter assumptions used to populate the UWC version of the model are provided below. All of the figures in NZFARM are converted to per hectare values and 2012 NZ dollars so that they are consistent across sources and scenarios.

Table 2 Data sources for NZFARM's modelling of the Upper Wairua Catchment

Variable	Data requirement	Source	Comments
Land cover and enterprise mix	GIS data file(s) of current land use with the catchment Key enterprises (e.g. dairy)	National land-use map based on AgriBase and LCDBv2	Land-use map verified by project partners
Management practices	Distribution of feasible management practices (e.g. stream fencing, farm management plan, etc.)	List developed during workshop in February 2016	Data and assumptions verified by project partners
Climate	Temperature and precipitation	Historical data Future climate projections being developed in alternative project	Analysis assumes constant climate and production
Soil type	Soil maps used to divide area into dominant soil types	S-map (partial coverage only), Fundamental Soil Layer and the NZ Land Resource Inventory (NZLRI)	Not necessary for this project, so assumed a single generic soil type
Stocking rates	Based on animal productivity model estimates or carrying capacity map	Average land-carrying capacity from NZLRI and detailed 'stocking budgets' for various pastoral enterprise systems	Used to estimate production and net farm revenue for dairy, sheep & beef, and deer enterprises
Input costs	Stock purchases, electricity and fuel use, fertiliser, labour, supplementary feed, grazing fees, etc.	Obtained using a mix of: personal communications with farm consultants and regional experts, MPI farm monitoring report, Lincoln Financial Budget Manual	Verified with local land managers and industry consultants
Product outputs	Milk solids, dairy calves, lambs, mutton, beef, venison, grains, fruits, vegetables, timber, etc.	Used yields for Northland Region, but nothing specific to UWC	Verified with local land managers and industry consultants
Commodity prices	Same as outputs, but in \$/kg or \$/m^3	Obtained from MPI and other sources	Assume 5-year average
Environmental indicators	• Soil erosion/sediment • Stream *E. coli* • N leaching • P loss • GHG emissions	• Sediment based on SedNet model • *E. coli* sourced from NIWA • Nutrients based on OVERSEER and other sources • GHGs follow MfE (2014b) accounting methods	

Table 3 List of key components of NZFARM, Upper Wairua Catchment

Enterprise (E)	Mitigation practice (M)	Sub-catchment (S)	Reporting zone (R)	Environmental indicators (ENV)
Dairy Sheep & beef Deer Forestry Grapes Horticultural crops Arable crops Scrub Native Urban Other	None Farm-specific soil conservation plan (e.g. mix of pole planting, retention bund, etc) Fencing Retention bund Wetland Riparian planting Nutrient mitigation bundle – low Nutrient mitigation bundle – medium Nutrient mitigation bundle – high Afforestation Combination of practices	2,000 sub-catchments	Upper Wairua (Wairua) Catchment	Streambank sediment Hill/landmass sediment Total sediment Flood spill-over Stream E. *coli* load N leaching P loss GHG emissions Forest carbon sequestration Net GHG emissions

2.4.1 Land use and net farm revenue

Observed baseline land-use information is required to fit the model to an empirical baseline. Baseline land-use areas for this catchment model are based on a 2011 GIS-based land-use map created by Landcare Research using the latest information from Agribase and the NZ Land Cover Database version 2 (LCDBv2) (Figure 4). The catchment is approximately 84,000 ha in size, and key land uses include sheep & beef (41%), dairy (38%), plantation forestry (9%), and native bush (6%). Requests were made to Fonterra for additional information, but this information was not readily available so we were unable to separate dairy platform and dairy run-off area. As a result, some land classified as dairy may indeed have characteristics similar to sheep & beef.

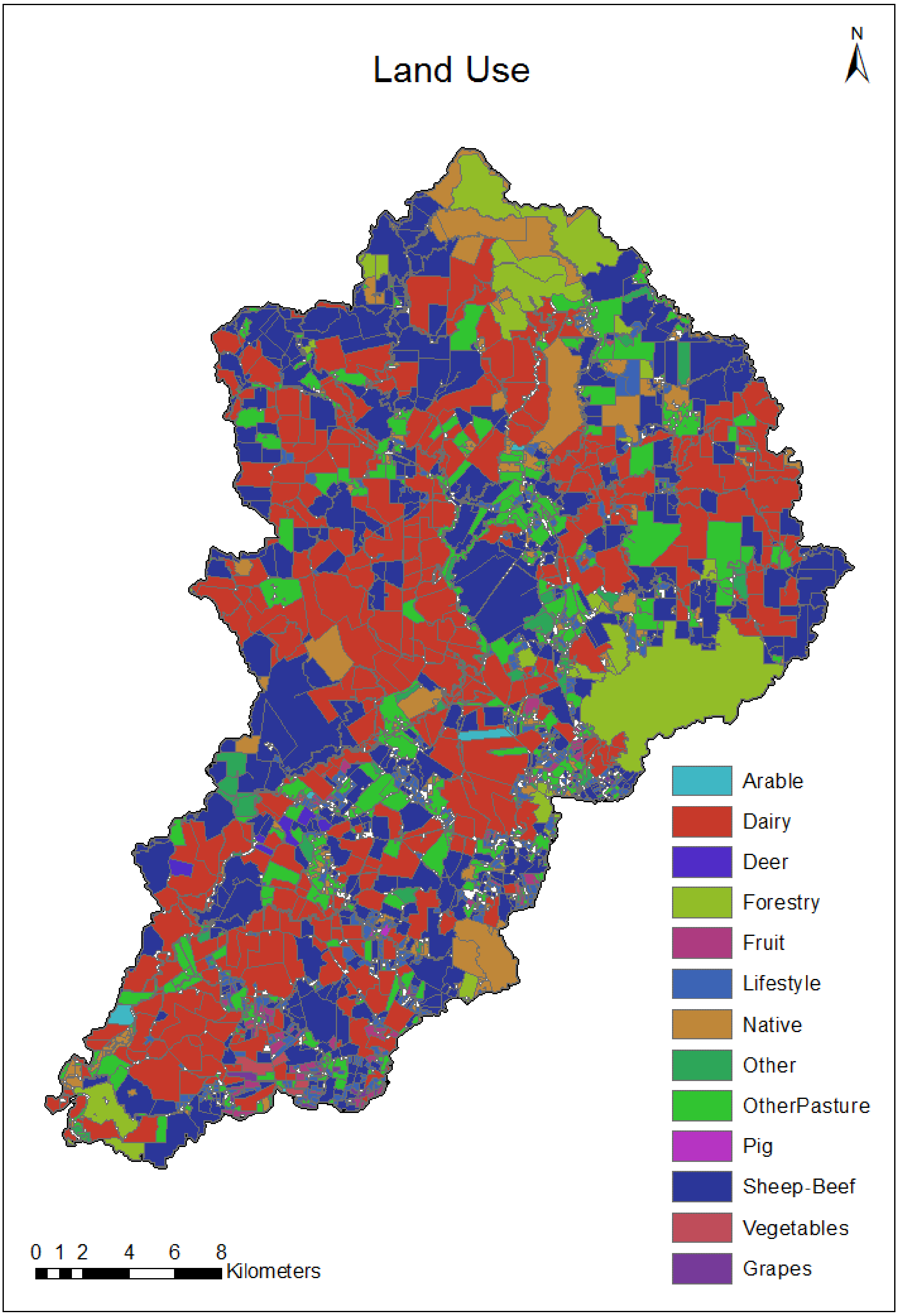

Figure 4 Upper Wairua Catchment land use.

The baseline farm financial budgets for the catchment are based on estimates for production yields, input costs and output prices that come from a wide range of literature and national-level databases (e.g. *Situation and Outlook for Primary Industries*, MPI 2013b;

Farm Monitoring Report, MPI 2013a; *Lincoln University Budget Manual*, Lincoln University 2013). These farm budgets form the foundation of the baseline net revenues earned by landowners, and are given as earnings before interest and taxes. These figures assume that landowners currently face no mitigation costs such as fencing streams or constructing wetlands (more details are provided below).

The national-level figures have been verified with agricultural consultants and enterprise experts, and documented in Daigneault et al. 2017. In addition, the UWC-level figures have been shared with local land managers and consultants working in the catchment and adjusted accordingly. Dairy figures for the catchment were adjusted for this analysis based on input from DairyNZ (pers. comm., October 2016).

The distribution of net farm revenue across the catchment is shown in Figure 5. Although dairy makes up less than half the proportion of land use, it produces about 72% of farm net revenue in the catchment, followed by horticulture and arable (11%), forestry (8%), and sheep & beef farming (8%).

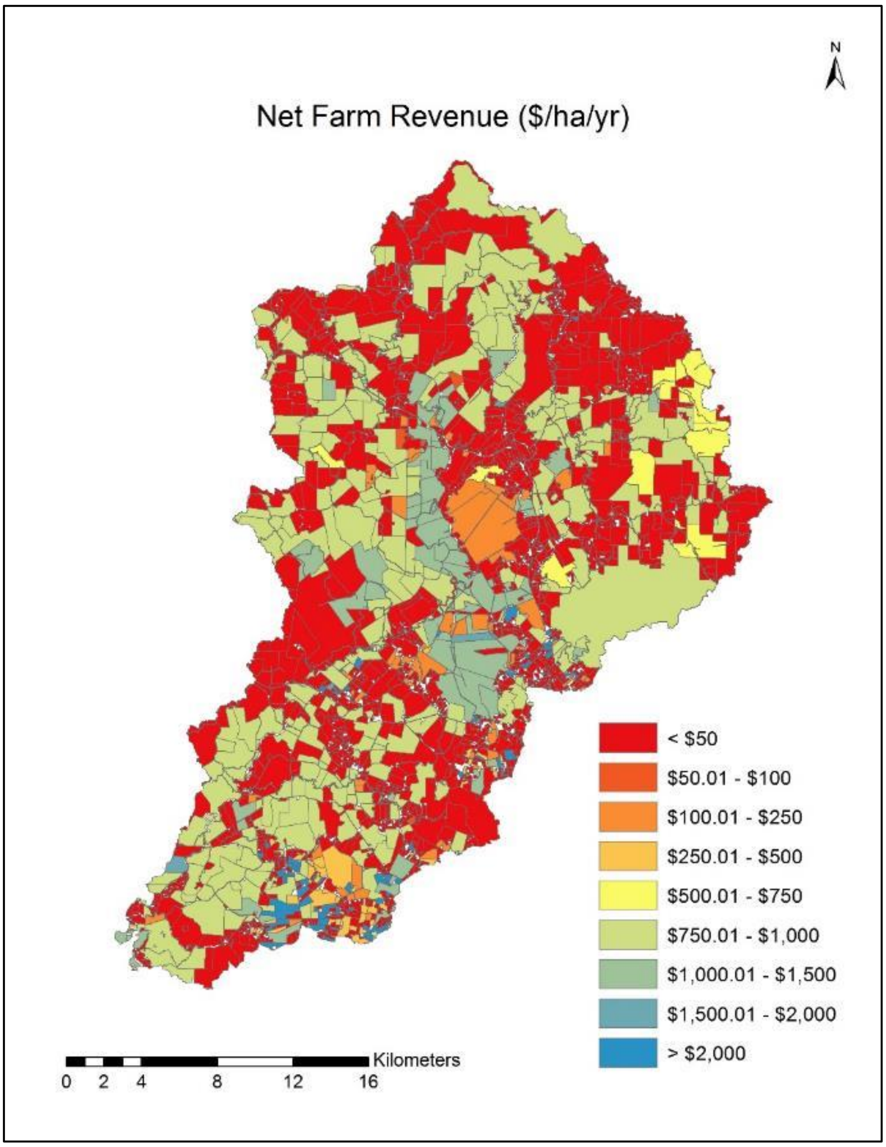

Figure 5 Baseline net farm revenue ($/ha/yr).

For this study the net farm revenue figures are used to estimate the opportunity costs of taking land out of production in order to implement certain mitigation options, specifically wetlands. Most of the pasture-based mitigation assumes an increase in capital and maintenance expenses, but no opportunity costs for production losses, and hence do not take net revenues into account. In addition, the study is focused on management change within the current land use as opposed to land-use change.[3] Thus the net farm revenue figures for this analysis are not as crucial as other catchment-level studies recently conducted to look at other impacts of the NPS-FM[4] (e.g. nutrients reduction targets in Daigneault et al. 2013).

2.4.2 Sediment loads

Sediment load estimates are taken directly from the SedNetNZ model. The land-use contribution to sediment is estimated for both hill/landmass and streambank erosion. SedNetNZ estimates that the total load in the catchment is more than 156,000 tonnes of sediment per year. About 65% of this is estimated to arise from hill and landmass erosion (Figure 6), while the remainder is from streambank erosion (Figure 7).

The bulk of the total sediment is estimated to come from dairy, including both platform and run-off (44%), and from sheep & beef (40%). About 15% of total erosion in the UWC comes from pine plantations and native bush. A noticeable amount of sediment comes from forested areas because they are generally located on less productive areas with steeper slopes relative to the rest of the catchment. Note that if any of the forested area were converted to pasture, the level of erosion could increase by a factor of 5 to 10, depending on whether it was originally planted as a productive plantation or was a permanently forested area (Dymond et al. 2010).

2.4.3 *E. coli* loads

E. coli loads for the UWC are estimated using a recent version of the CLUES model (Elliott et al. 2016; Semadeni-Davies et al. 2011). Stream *E. coli* loads were calculated for each land block based on average yields in the region for a particular land use (Figure 9). That is, all sheep & beef farms were assigned the same per ha *E.coli* yield (in peta *E. coli*/yr), based on estimates derived for the region in Daigneault et al. 2016. Note that although this is a simplification compared to more detailed *E.coli* studies conducted in the area, the baseline yielded similar aggregate estimates. That is, more than 95% of total *E. coli* load in the UWC waterways was estimated to come from dairy (70%) and sheep & beef (29%) farms.

---

[3] Two afforestation scenarios assess the possible lower bound of sediment and *E.coli* loads that could occur in the catchment. All the other scenarios assume no land use change.

[4] National Policy Statement – Freshwater Management. http://www.mfe.govt.nz/fresh-water/national-policy-statement/supporting-impact-papers-nps

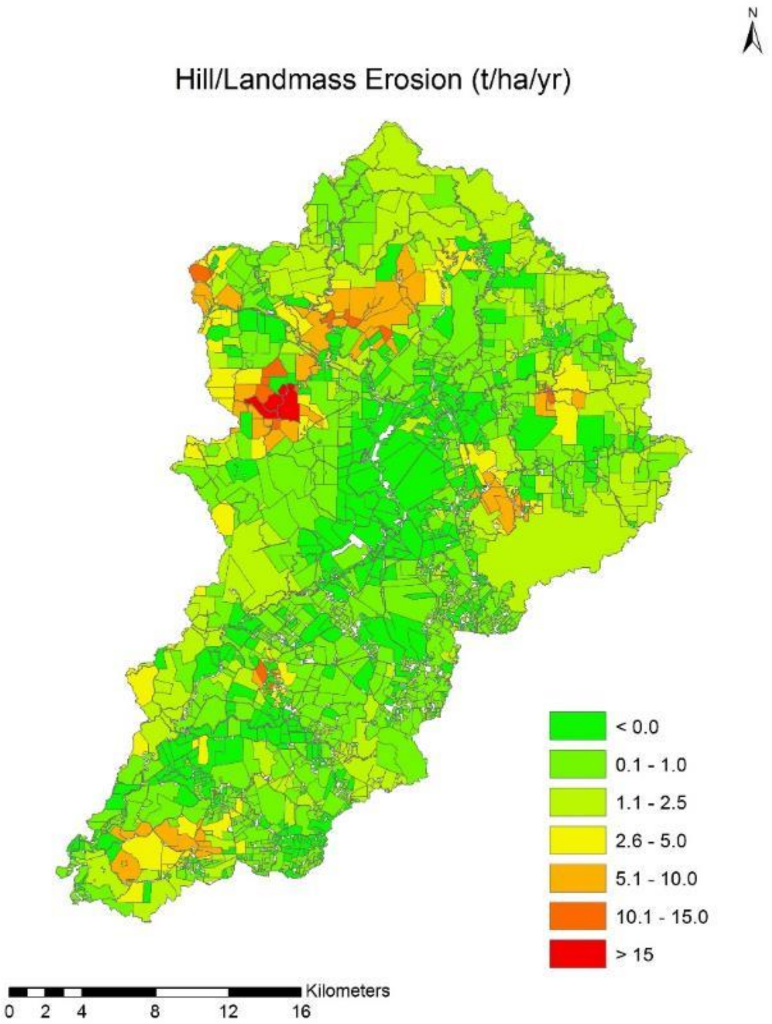

Figure 6 Total sediment load in the Upper Wairua Catchment.

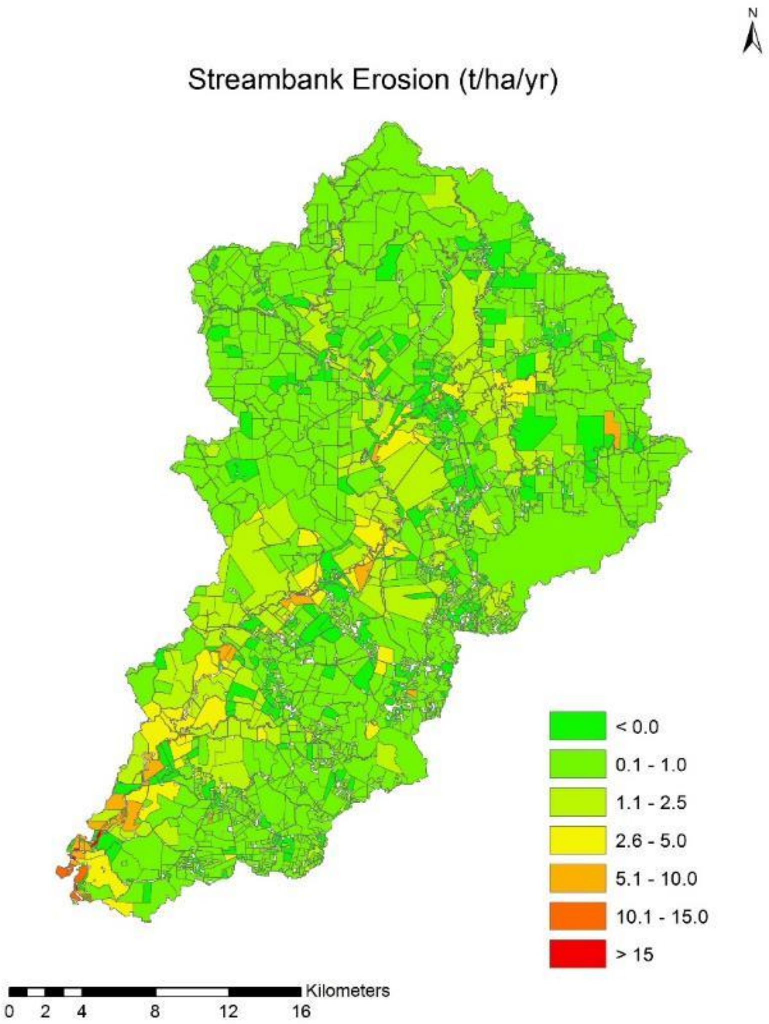

Figure 7 Total sediment load in the Upper Wairua Catchment.

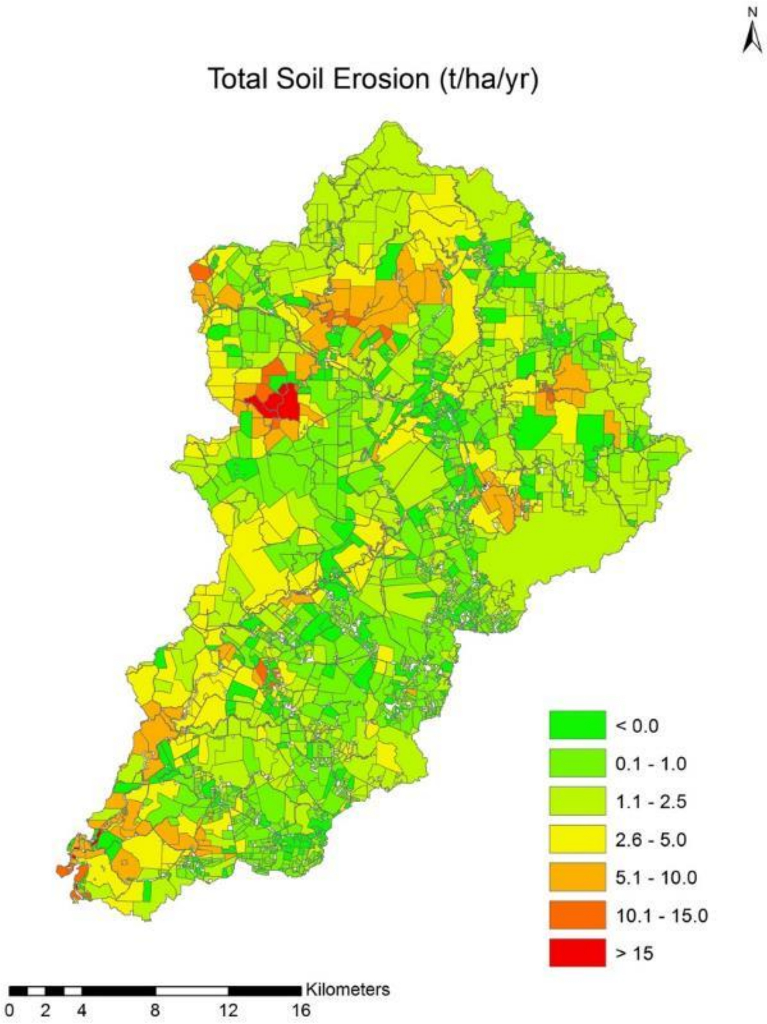

Figure 8 Total sediment load in the Upper Wairua Catchment.

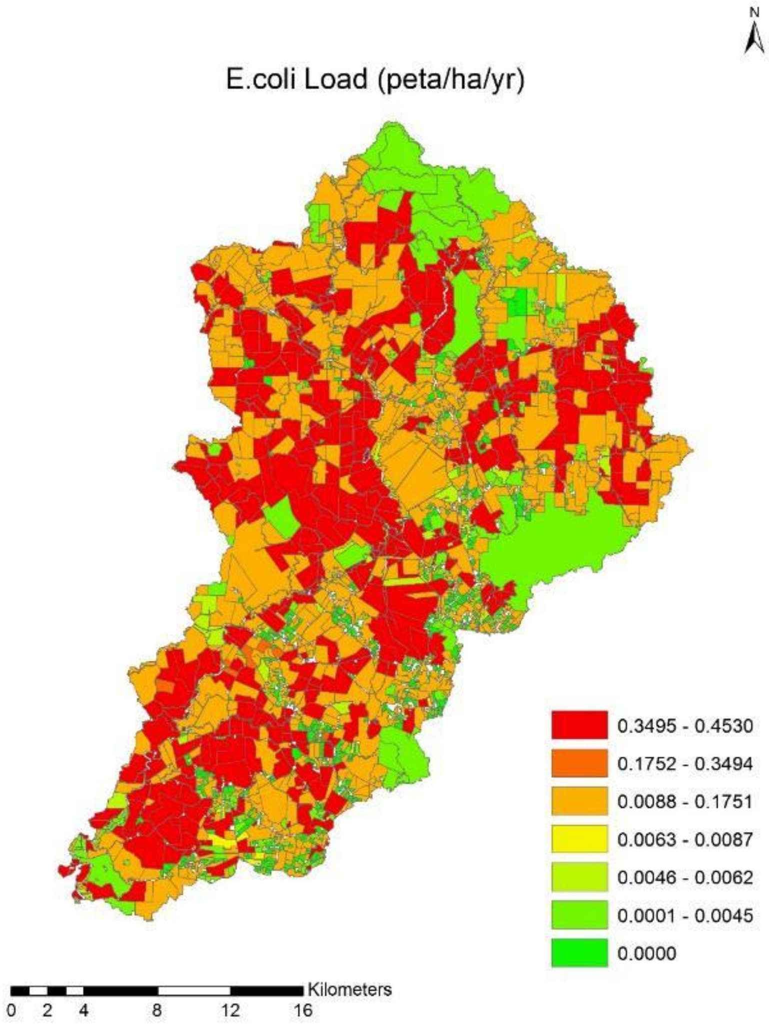

Figure 9 Estimated *E. coli* loads (peta *E. coli*/ha) for Upper Wairua Catchment.

2.4.4 Nutrient loads

Nutrient (N and P) loads for the UWC are estimated using the OVERSEER v6.0 model for pastoral enterprises, and literature sources for all other land uses. As shown in Figure 10, dairy farms export about 25 kgN/ha/yr and contribute to 57% of total N loads in the catchment. In terms of P loss, dairy contributes to 43%, while sheep & beef contribute to 44% of catchment loads.

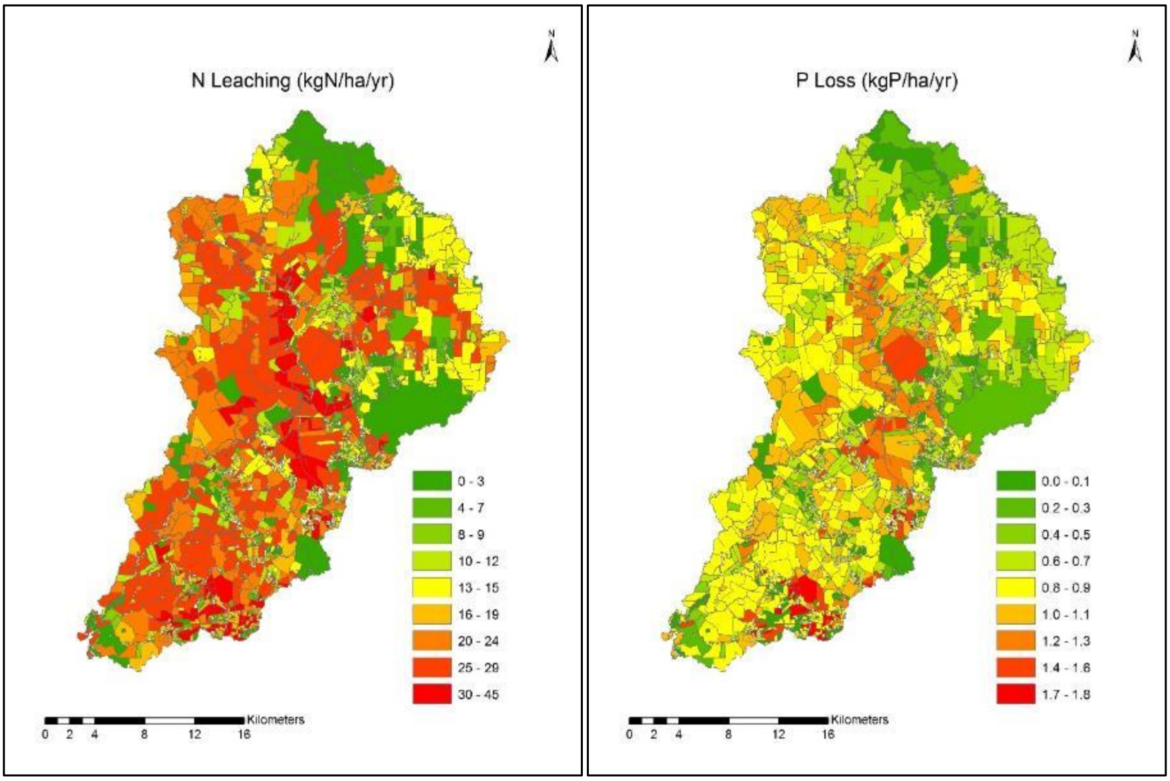

Figure 10 Estimated N and P losses for Upper Wairua Catchment.

2.4.5 GHG emissions

GHG emissions for the UWC were estimated using the MfE's GHG inventory accounting methods. Dairy averages about 7 tonnes of carbon dioxide equivalent per annum (CO2-e/ha/yr) and contributes to 67% of total gross GHG emissions in the catchment, followed by sheep & beef (31%). Forest carbon sequestration reduces net emissions to about 70% of gross emissions, with 12 tCO2-e/ha/yr (on average) coming from plantation forests, which contribute the bulk of the sequestration. The distribution of net emissions on a per hectare per year basis is shown in Figure 11. Note that estimates less than zero tCO2-e/ha/yr indicate there is net carbon sequestration from growing vegetation (i.e. plantations, mānuka or native bush) on that particular parcel of land.

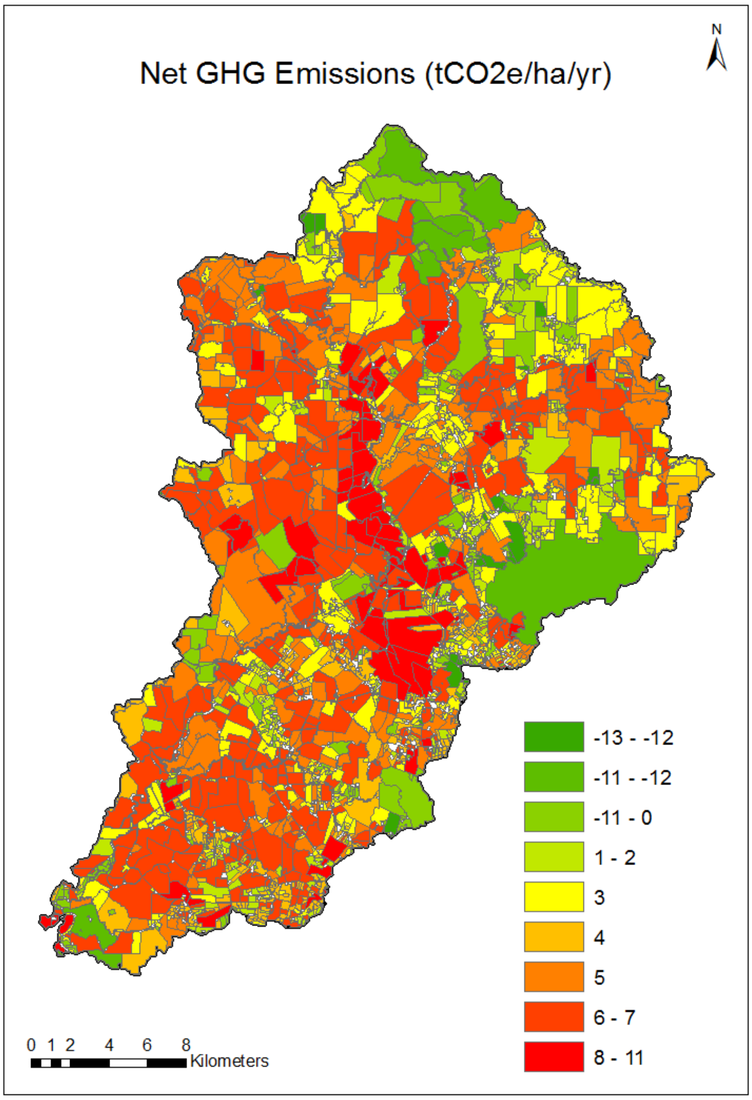

Figure 11 Estimated net GHG emissions (gross emission less sequestration) for the Upper Wairua Catchment. Negative values indicate there is annual carbon sequestration from growing vegetation.

2.5 Mitigation costs and effectiveness

Assumptions about mitigation costs and effectiveness in reducing sediment loads were primarily based on estimates from the Whangarei Harbour sediment and *E. coli* study (Daigneault & Samarasinghe 2015). The costs are broken down by fencing costs (if any), initial capital and implementation costs, and opportunity costs from taking land out of production. A summary of the costs of practices for reducing sediment loads and the relative effectiveness of each option (as a percentage change from the no-mitigation baseline practice) are outlined in Table 4. Additional details on the sources of many of these estimates are provided in Appendix 3.

It is important to note that two of the mitigation options − retention bunds and constructing wetlands − also have an effect on the amount of spill-over water released in the catchment, and hence can potentially reduce the impact of flooding. According to estimates by John Dymond (pers. comm.), in consultation with the Whangarei District Council, it is expected that constructing a retention bund in a REC 2-level catchment could hold 1,250 m^3 of water back from a flood (while constructing a wetland could hold about 250 m^3). Given there are about 2,000 REC 2 catchments in the UWC, this translates to the potential for 2.5 million m^3 of water to be held back from the design flood of 10 million m^3 by retention bunds. This equates to a 25% reduction in the design flood.

In addition to identifying practices that focus on reducing sediment, the study has also included practices that focus on reducing nutrients. Recent catchment-scale nutrient reduction modelling has focused on including a set of mitigations that are packaged as a 'bundle' of options that would probably be introduced on the farm at the same time (e.g. Everest 2014; Vibart et al. 2015). These bundles are typically defined as:

- M1: relatively cost-effective measures with minimal complexity to existing farm systems and management
- M2: mitigation that is less cost-effective than M1, and requires limited capital costs or systems change
- M3: management options with large capital costs and/or that are relatively unproven.

Bundled nutrient management practices are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes practices from M1 and M2. Running sheep, beef or deer assume both sides of a stream need to be fenced.

Table 5 shows the mean cost and effectiveness of each mitigation bundle for pastoral, arable and horticultural enterprises. Note that a bundle will not necessarily include all these practices, but rather a mix that achieves a similar reduction in contaminants for a given annualised cost per hectare. In addition, adjusting the set of mitigation options included in each bundle could have an influence on the effectiveness of both freshwater contaminant load and GHG emissions. More details on how these estimates were derived are found in Daigneault et al. 2016.

Costs can accrue at different times and magnitudes. As a result, they are converted to an annual figure so that they can be directly comparable 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%. Opportunity costs are assumed to accrue on a yearly basis and so are directly subtracted from the base net farm revenue figure. Recall that due to lack of data clearly identifying the spatial distribution, we make a broad assumption that none of the mitigation practices have been implemented in the catchment. This is, of course, an oversimplification as practices such as stream fencing have been undertaken in dairy farms.

Table 4 Annualised mitigation cost and effectiveness, sediment mitigation practices

Mitigation option	Annualised mitigation costs			Mitigation effectiveness (% reduction from baseline)						
	Fence cost ($/m)*	**Implementation cost ($/ha)**	**Opportunity cost (% net revenue)**	**N leaching**	**P loss**	**Landmass sediment**	**Streambank sediment**	**Stream *E.coli***	**Net GHG emissions**	**Gross GHG emissions**
Dairy										
Fence & riparian buffer	$0.87	$75	3%	28%	33%	50%	70%	60%	3%	2%
Fence stream bank	$0.87	$0	0%	13%	15%	0%	70%	60%	0%	0%
Construct wetland – flat	$0.00	$27	2%	10%	45%	65%	0%	55%	0%	0%
Retention bund	$0.00	$10	0%	0%	15%	50%	0%	30%	0%	0%
Soil management plan	$0.00	$26	0%	0%	20%	70%	0%	0%	5%	0%
Soil plan & fence	$0.87	$26	0%	13%	20%	70%	70%	60%	5%	0%
Wetland – steep	$0.00	$35	2%	10%	45%	65%	0%	55%	0%	0%
Soil plan & wetland	$0.00	$53	2%	10%	45%	70%	0%	55%	5%	0%
Soil plan, wetland & fence	$0.87	$53	2%	10%	45%	70%	70%	55%	5%	0%
Riparian, bund & soil plan	$0.87	$111	3%	28%	33%	70%	0%	60%	5%	2%
Riparian & bund	$0.87	$85	3%	28%	33%	50%	0%	60%	3%	2%
Fence, bund, & soil plan	$0.87	$36	0%	13%	20%	70%	70%	60%	5%	0%
Fence & bund	$0.87	$10	0%	13%	15%	50%	70%	60%	0%	0%
Wetland & fence	$0.87	$27	2%	13%	45%	65%	70%	60%	0%	0%
Sheep, beef & deer										
Fence & riparian buffer	$3.04	$75	3%	28%	33%	50%	70%	60%	7%	2%
Fence stream bank	$3.04	$0	0%	13%	15%	70%	70%	60%	0%	0%
Construct wetland – flat	$0.00	$27	2%	10%	45%	65%	0%	55%	0%	0%

Mitigation option	Annualised mitigation costs			Mitigation effectiveness (% reduction from baseline)							
	Fence cost ($/m)*	Implementation cost ($/ha)	Opportunity cost (% net revenue)	N leaching	P loss	Landmass sediment	Streambank sediment	Stream *E.coli*	Net GHG emissions	Gross GHG emissions
Retention bund	$0.00	$10	0%	0%	15%	50%	0%	30%	0%	0%
Soil management plan	$0.00	$26	5%	0%	20%	70%	0%	0%	6%	0%
Soil plan & fence	$3.04	$26	0%	13%	20%	70%	70%	60%	6%	0%
Construct wetland – steep	$0.00	$35	2%	10%	45%	65%	0%	55%	0%	0%
Soil plan & wetland	$0.00	$53	2%	10%	45%	70%	0%	55%	6%	0%
Soil plan, wetland & fence	$3.04	$53	2%	10%	45%	70%	70%	55%	6%	0%
Riparian, bund & soil plan	$3.04	$111	8%	28%	33%	70%	0%	60%	7%	2%
Riparian & bund	$3.04	$85	3%	28%	33%	50%	0%	60%	7%	2%
Fence, bund, & soil plan	$3.04	$36	5%	13%	20%	70%	70%	60%	6%	0%
Fence & bund	$3.04	$10	0%	13%	15%	70%	70%	60%	0%	0%
Wetland & fence	$3.04	$27	2%	13%	45%	70%	70%	60%	0%	0%
Non-pastoral uses										
Construct wetland – flat	$0.00	$27	2%	10%	0%	65%	0%	55%	0%	0%
Construct wetland – steep	$0.00	$27	2%	10%	0%	65%	0%	55%	0%	0%
Retention bund	$0.00	$10	0%	0%	15%	50%	0%	30%	0%	0%
Riparian & bund	$0.00	$10	0%	0%	15%	50%	0%	30%	0%	0%

Table 5 Annualised mitigation cost and effectiveness, nutrient mitigation bundles

Mitigation option	Annualised mitigation costs		Mitigation effectiveness (% reduction from baseline)						
	Fence cost ($/m)*	Implementation + opportunity cost ($/ha)	N leaching	P loss	Landmass sediment	Streambank sediment	Stream *E.coli*	Net GHG emissions	Gross GHG emissions
Dairy									
Mitigation Bundle 1	$0.87	$20	23%	14%	50%	70%	50%	8%	8%
Mitigation Bundle 2	$0.87	$51	38%	30%	50%	70%	50%	8%	8%
Mitigation Bundle 3	$0.87	$662	60%	34%	50%	70%	50%	12%	12%
Sheep & beef									
Mitigation Bundle 1	$3.04	$28	19%	35%	50%	70%	50%	0%	0%
Mitigation Bundle 2	$3.04	$34	25%	48%	50%	70%	50%	−1%	−1%
Mitigation Bundle 3	$3.04	$51	40%	58%	50%	70%	50%	4%	4%
Deer									
Mitigation Bundle 1	$3.04	$81	19%	35%	50%	70%	50%	0%	0%
Mitigation Bundle 2	$3.04	$105	25%	48%	50%	70%	50%	−1%	−1%
Mitigation Bundle 3	$3.04	$176	40%	58%	50%	70%	50%	4%	4%
Arable crops									
Mitigation Bundle 1	$0.00	$168	34%	56%	29%	35%	50%	13%	13%
Mitigation Bundle 2	$0.00	$385	37%	88%	30%	35%	50%	−24%	−24%
Mitigation Bundle 3	$0.00	$456	41%	88%	31%	35%	50%	−10%	−10%
Fruit and vegetables									
Mitigation Bundle 1	$0.00	$168	34%	56%	29%	35%	50%	13%	13%
Mitigation Bundle 2	$0.00	$385	37%	88%	30%	35%	50%	−24%	−24%
Mitigation Bundle 3	$0.00	$456	41%	88%	31%	35%	50%	−10%	−10%

* Sheep, beef, and deer assume both sides of stream need to be fenced.

3 Scenarios

The Living Water working group (i.e. Fonterra and the Department of Conservation), with input from Northland Regional Council and Whangarei District Council, has specified a range of mitigation scenarios to be analysed (Table 6). These primarily include practice-based approaches such as fencing streams for stock exclusion, but also some scenarios focusing on target-based approaches that include reducing erosion to reach a catchment-wide sedimentation target.

The practice-based or management action scenarios investigate the maximum amount of reductions that could be achieved when implementing certain mitigation options. The target-based or environmental outcome scenarios investigate the impact of setting a specific reduction target (i.e. percentage below baseline loads), but then allowing landowners to collectively select the set of mitigation options that will meet the target.

One potentially unique scenario that we have modelled here is the concept of purchasing land to set aside as a 'sacrificial pocket' to capture and hold flood water from the upper catchment. For this scenario, the Living Water working group has identified the entire area (approximately 1,250 ha) of the Otonga pocket being converted into sacrificial area for flood control, at a total land cost of $10 million[5].

As discussed above, the NZFARM model has the ability to track a number of environmental and economic outputs, ranging from production and net farm revenue to sediment and GHG emissions. For this study we present estimates for all of the environmental outputs as well as net farm revenue in order to identify the most cost-effective practices or options to meet environmental objectives in the catchment. However, the key environmental objectives we focus on in this study are sediment and flood spill-over, as these are the issues of most concern to stakeholders operating in the catchment.

[5] Whangarei District Council has indicated that the owner(s) of the land in the Otonga pocket have proposed an asking price of up to $40 million for this land. This significantly exceeds market values for land of similar quality in the area.

Table 6 Upper Wairua Catchment economic model scenarios

Scenario name	Description
Baseline	No explicit on-farm mitigation options implemented. Establishes the level of economic and environmental outputs (including ecosystem services) that all other scenarios are measured against
Designed flood control	
Flood retention bunds – all	One flood retention bund constructed in each of the 2,000 level-1 sub-catchments in the UWC
Wetlands – all	One wetland constructed/restored in each of the 2,000 level-1 sub-catchments in the UWC
Sacrificial pocket	Entire Otonga pocket converted into sacrificial area for flood control at total land cost of $10 million
Farm plan development and afforestation for land-based erosion control	
Min. soil conservation plan	10% of all farms have soil conservation plan implemented for erosion control
Worst 20% soil conservation plan	Worst 20% of sheep & beef farms (based on total erosion) implement farm plan for optimal erosion control
All soil conservation plan	All sheep & beef farms in the catchment implement farm plan for optimal erosion control
Afforestation – all hill farms	All upland (hill) pastoral farms converted to pine plantations. Represents upper bound of potential reductions in the upper catchment
Afforestation – all farms	All farms in the catchment converted to pine plantations. Represents upper bound of potential reductions in the entire catchment
Fencing streams	
Current fencing	75% of all dairy and 25% of all other pastoral farm streams along ‘permanent’ waterways are fenced
Fence all streams	All pastoral streams along permanent waterways in the catchment are fenced
Passive riparian buffers – all	All pastoral streams along permanent waterways in the catchment are fenced 5 m out with passively (naturally) regenerated riparian buffers
Active riparian buffers – all	All pastoral streams along permanent waterways in the catchment are fenced 5 m out with actively planted riparian buffers
Mitigation combination: sediment focused	
Current fencing and farm plan combo	10% of all farms have plan implemented for erosion control; 75% of all dairy and 25% of all other pastoral farm streams along ‘permanent’ waterways are fenced
Bunds, farm plans, and riparian planting − all	All eligible land implements bunds, farm plans and active riparian planting along all permanent streams. Likely to be the upper bound of mitigation potential
All bunds and fencing; worst 20% farm plan	All land in catchment construct bunds; all pastoral farms fence permanent waterways; worst 20% of sheep − beef farms (based on total erosion) implement farm plan for optimal erosion control
Mitigation combination: nutrient focused	
Low mitigation bundle	All farms implement relatively cost-effective measures with minimal complexity to farm systems and management, including bund construction
Medium mitigation bundle	Include low bundle, but also implement mitigation that is somewhat costlier, although requires limited capital or systems change
High mitigation bundle	Include low and medium bundle, but also implement management options with large capital costs
Outcome-based: sediment reduction targets	
20% sediment reduction	Catchment-wide 20% annual reduction in total sediment
40% sediment reduction	Catchment-wide 40% annual reduction in total sediment
60% sediment reduction	Catchment-wide 60% annual reduction in total sediment

4 Baseline

NZFARM first establishes a no-policy baseline for the catchment before conducting any scenario analysis. Here we specify that the distribution of enterprise areas match the land-use map presented in section 2 of this report (i.e. the baseline area is the same as the map). The baseline also assumes no sediment or other mitigation practices or policies have been implemented (including existing farm plans or stream fencing).[6] The 'no mitigation' baseline is the same assumption that was used for sediment modelling in SedNetNZ, as there was no spatially explicit information on which farms in the catchment are currently fenced or how effective that fencing is. As a result, we opted not to incorporate this mitigation into the NZFARM baseline,[7] so the model's mitigation figures may be a slight overestimate of the actual reduction that could occur under the different model scenarios.

A summary of the key economic and environmental outputs is listed in Table 7. Total net farm income from land-based operations with the current land-use mix is estimated at $48.0 million/yr, or $651/ha for all land and $732/ha for land that is currently earning revenue from farming and forestry. Total sediment load is almost 156,000 tonnes, of which about two-thirds comes from landmass erosion. The total stream *E. coli* loads are 180 peta *E.coli*, and nearly all of this is generated from pastoral land use. N and P losses are 1,205 and 51.7 t/yr, and gross GHG emissions total 285,500 tCO2-e/yr. However, more than 82,000 tCO2-e of forest carbon sequestration results in net emissions of about 203,000 tCO2-e/yr. Finally, it is estimated that the baseline amount of water spilled from a designed flood across all 2,000 sub-catchments in the UWC is about 10 million m^3.

These baseline figures represent the values to which all other scenario estimates are compared.

Table 7 Baseline area, farm earnings and environmental outputs, by land use

Land use	Area (ha)	Net revenue (mil $)	Total erosion (t)	Stream *E.coli* (peta)	N leach (t)	P loss (t)	Net GHG (tCO2e)
Dairy	27,914	34,357,569	68,982	126.4	691	25.4	190,652
Sheep & beef	29,839	4,033,616	54,627	52.3	448	22.7	87,517
Other pastoral	236	240,758	469	0.8	1	0.1	225
Arable & hort	1,028	5,309,653	1,394	0.1	16	0.2	1,216
Forestry	6,538	4,038,550	13,372	0.3	13	1.3	−79,555
Lifestyle	2,515	2,515	3,378	0.0	31	1.6	5,930
Native bush	4,475	4,475	10,611	0.2	5	0.4	−2,685
Other	1,180	1,180	2,911	0.1	0	0.0	0
Total	**73,725**	**47,988,316**	**155,745**	**180.0**	**1,205**	**51.7**	**203,300**

[6] In reality some mitigation practices such as fencing streams have been implemented by some landowners in the catchment. As a result, the baseline used for this study is likely to overestimate the impact of mitigation.

[7] We model current fencing in one of the scenarios, which presents a possible sensitivity of our no mitigation assumption.

5 Scenario analysis

This section reports the economic and environmental impacts of the more than 20 scenarios described in section 3 of this report. The key results reported for each policy scenario include net farm revenue, total annual cost, landmass and streambank sediment loads, stream *E. coli* loads, nutrient losses, GHG emissions, and flood spill-over volume. The estimates in this section compare the 'no policy' baseline to the policy scenario after it has been fully implemented.[8] That is, the baseline assumes that no implementation has been implemented in the UWC at all, while the results below quantify the difference in estimates from that base assumption. All values are listed as mean annual figures.

5.1 Catchment-wide results

The total estimated impacts for the entire UWC are listed in Table 8. The table shows that the impacts vary widely across scenarios. More insight on each scenario is provided in the following paragraphs.

In terms of flood control, constructing retention bunds was found to be the most cost-effective measure. This is because not only are they relatively cheap, at an annual cost of about \$10/ha/yr, but also because each one is effective at removing 1,250 m^3/yr. Wetlands still provide some flood control benefit, as well as many other benefits related to reducing freshwater contaminants, but at a much higher cost.

Sacrificing the entire Otonga pocket for flood control measures would reduce water spilled in a design flood by 17%, but the cost would be about 35% more than the flood retention bunds option. While it would ultimately require implementing mitigation on much less land than constructing bunds or wetlands in all 2,000 sub-catchments in the UWC, this also means that there is little impact on other ecosystem services in the catchment that may not benefit by reduced flooding.

Implementing farm plans for the main purpose of erosion control (e.g. pole planting) could reduce total erosion in the UWC by up to 25% if they were implemented on all sheep & beef farms in the catchment at a cost of almost \$1.0 million/yr. If the plans focused on just the 20% worst farms in terms of total erosion, annual sediment could be reduced by about 18% and only cost about a third as much as the scenario where all pastoral farms implement soil conservation plans.

Afforesting large amounts of the catchment would result in significant reductions in all freshwater contaminants as well as increase the level of forest carbon sequestration, thereby reducing GHG emissions in the catchment as well.[9] Mass conversion could occur in the uplands at a relatively low cost, because pine plantations are potentially more profitable

---

[8] For this analysis we assume that the policy is fully implemented over a relatively long timeframe of 10 years or more to allow landowners adequate time to adopt new mitigation practices

[9] Water yield from sub-catchments has been modelled using the hydrological model WATYIELD. The difference in design flood between pasture and forest is small because the interception capacity of the forest is small in comparison to the total rainfall expected in a design storm.

than existing pastoral farms located on marginal land. However, when higher-earning dairy and horticultural land is also afforested, costs escalate significantly ($30 million/yr).

Fencing streams can reduce streambank erosion by up to 80%, but it does not have any effect on landmass erosion and hence constructing them along all permanent waterways only reduces sediment by about 20%. Expanding this option to include 5 m riparian buffers has the potential to intercept some land-based erosion and hence can reduce sediment by up to 45% while also reducing other freshwater contaminants by 27% or more. This does come at a higher cost, though: potentially between $6.8 and 8.2 million/yr depending on whether the strips are left to regenerate naturally or are actively planted with native shrubs.

Combining several mitigation options such as farm plans, fencing and bunds also results in a wide range of impacts in the catchment, depending on how much management change is implemented. If all the eligible farms in the catchment constructed bunds, implemented farm plans for erosion control and included riparian buffers, both freshwater contaminants and GHG emissions could be reduced significantly. However, this could cost upwards of $10.5 million/yr to implement. On the other hand, if all landowners focused on just fencing and bunds, and the 20% of hill country S&B farms with the highest erosion rates implemented farm plans, similar figures could be achieved, but at a cost of $4.2 million/year.

If landowners focused on implementing bundles of nutrient mitigation practices that also have a positive effect on other ecosystem services, significant reductions could be achieved at a cost of $4.7 to 6.0 million/yr. Implementing a more effective bundle of practices that also involve significant capital improvements and systems change could reduce freshwater contaminants by 43% or more. However, the high-cost mitigation bundle could reduce net farm income by as much as 49% per annum, and so is not likely to be a viable option for most landowners in the catchment, particularly because nutrients have not been flagged as a major issue in the UWC.

The model scenarios focusing on outcome-based objectives (where landowners collectively choose a suite of mitigation options to meet catchment objectives) suggest that sediment can be reduced by up to 60% at a relatively low cost. For example, a 20% reduction target for the UWC could be achieved at a cost of less than $1/ha/yr, as NZFARM estimates that constructing bunds and fencing streams for about 10% of the total area in the catchment is all that would be required (Table 8). To get a 60% reduction, mitigation would have to be implemented on about 75% of the land in the catchment, particularly in the form of constructing retention bunds, fencing waterways, and implementing soil conservation plans for erosion control.

Table 8 Key model scenario estimates, entire Upper Wairua Catchment

Scenario	Total annual cost ($)	Net Rrevenue (mil $)	Total erosion (kt)	Stream *E.coli* (peta)	N leach (t)	P loss (t)	Net GHG (ktCO2e)	Water spilled design flood (mil m3)
Baseline	**$0**	**$48.0**	**155.7**	**180.0**	**1,205**	**51.7**	**203.3**	**10.0**
% change from no mitigation baseline								
Flood retention bunds – all	$688,505	-1%	-31%	-30%	0%	-14%	0%	-25%
Wetlands – all	$2,714,539	-6%	-34%	-55%	-10%	-42%	0%	-5%
Sacrificial Pocket	$928,283	-2%	-1%	-1%	-2%	-3%	-3%	-17%
Min soil conservation plan	$171,337	0%	-4%	0%	0%	-2%	-1%	0%
Worst 20% soil conservation plan	$376,099	-1%	-18%	0%	0%	-4%	-1%	0%
All S&B soil conservation plan	$993,132	-2%	-25%	0%	0%	-9%	-3%	0%
Afforestation –- all hill farms	$41,403	0%	-28%	-28%	-25%	-40%	-43%	0%
Afforestation –- all farms	$29,637,585	-62%	-80%	-98%	-92%	-88%	-139%	0%
Current fencing	$1,789,121	-4%	-11%	-36%	-8%	-10%	-4%	0%
Fence all streams	$4,608,436	-10%	-20%	-60%	-12%	-19%	-7%	0%
Passive riparian buffers – all	$6,792,746	-14%	-45%	-60%	-27%	-31%	-3%	0%
Active riparian buffers – all	$8,241,830	-17%	-45%	-60%	-27%	-31%	-6%	0%
Current fencing and farm plan combo	$1,154,462	-2%	-18%	-36%	-8%	-8%	0%	0%
Bunds, farm plans, and riparian planting – all	$10,530,506	-22%	-56%	-60%	-27%	-31%	-8%	-25%
All bunds and fencing; worst 20% farm plan	$4,164,578	-9%	-56%	-60%	-12%	-16%	-1%	-25%
Low mitigation bundle	$4,681,213	-10%	-46%	-50%	-21%	-22%	-8%	-20%
Medium mitigation bundle	$5,958,188	-12%	-46%	-50%	-34%	-36%	-7%	-20%
High mitigation bundle	$23,622,545	-49%	-46%	-50%	-53%	-43%	-13%	-20%
20% sediment reduction	$82,740	0%	-20%	-6%	-1%	-2%	0%	-2%
40% sediment reduction	$375,355	-1%	-40%	-16%	-2%	-7%	-1%	-5%
60% sediment reduction	$1,129,560	-2%	-60%	-29%	-5%	-14%	-2%	-6%

The total costs for all the scenarios (besides catchment-wide afforestation) range from $41,000/yr for afforesting all hill country sheep & beef farms, to about $23.6 million/yr for implementing the high-cost bundle of nutrient mitigation practices on all land in the catchment (Figure 12). Sheep & beef farms face the largest costs for nearly all scenarios. This is to be expected, as this enterprise comprises the largest area of productive land and pasture in the catchment, is often located on land with high erosion rates, and these properties have the greatest length of streams running through them. Note that the total costs for scenarios that include fencing as a mitigation options may be overstated by as much as $1.8 million/yr as some dairy and sheep & beef farmers have already fenced some or all of their streams (see current fencing scenario).

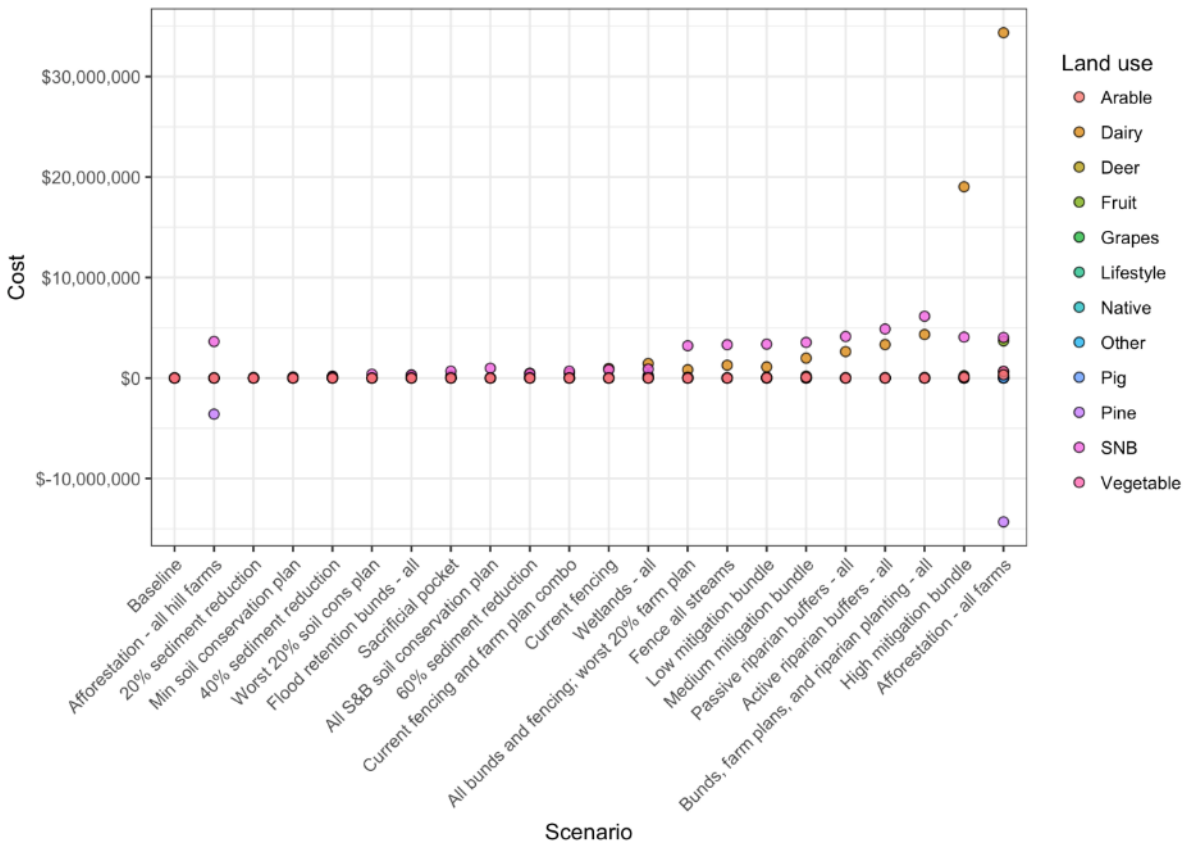

Figure 12 Total annual cost ($/yr), by land use. The mean annual mitigation costs for each scenario are broken down into per hectare values in Table 9.

The mitigation cost estimates illustrate that there is a wide distribution of impacts across both land use and scenario. Per hectare costs are generally higher for the scenarios that include riparian planting because they account for opportunity costs from taking some land out of production. Estimates from the outcome-based sediment reduction scenarios are typically cheaper than the practice-based scenarios because mitigation is not necessarily implemented on every parcel of land in the catchment, and only the most cost-effective options are applied.

Table 9 Mean annual mitigation cost ($/ha/yr)*

Scenario	Dairy	Sheep & beef	Other pastoral	Arable & hort.	Forestry	Total
Flood retention bunds – all	$10	$10	$9	$0	$10	$9
Wetlands – all	$52	$30	$43	$0	$39	$37
Sacrificial pocket	$8	$23	$0	$0	$0	$13
Min. soil conservation plan	$3	$3	$7	$0	$0	$2
Worst 20% soil conservation plan	$0	$13	$0	$0	$0	$5
All S&B soil conservation plan	$0	$33	$69	$0	$0	$13
Afforestation – all hill farms	$0	$122	$0	$0	$0	$1
Afforestation – all	$1,231	$135	$1,020	$5,164	$0	$402
Current fencing	$34	$28	$21	$0	$0	$24
Fence all streams	$46	$111	$84	$0	$0	$63
Passive riparian buffers - all	$94	$138	$129	$0	$0	$92
Active riparian buffers – all	$119	$163	$152	$0	$0	$112
Current fencing and farm plan combo	$16	$23	$0	$0	$0	$16
Bunds, farm plans, and riparian planting − all	$155	$206	$230	$0	$0	$143
All bunds and fencing; worst 20% farm plan	$30	$108	$70	$0	$10	$56
Low mitigation bundle	$40	$113	$135	$167	$0	$63
Medium mitigation bundle	$71	$119	$157	$385	$0	$81
High mitigation bundle	$682	$136	$221	$456	$0	$320
20% sediment reduction	$2	$1	$0	$0	$0	$1
40% sediment reduction	$7	$5	$5	$0	$4	$5
60% sediment reduction	$17	$14	$12	$0	$19	$15

* Estimated as total mitigation cost divided by total area for each land

The modelled scenarios estimate a wide range of impacts, not only to total sediment (1–80%), but also to the distribution across the two main sources of sediment. In most cases, sediment from hill and landmass erosion is reduced more than that from streambanks (Figure 13). By design, scenarios that include soil conservation plans, wetlands and bunds capture more landmass erosion, while those with fencing and riparian planting mitigate more streambank erosion. As about two-thirds of the total erosion in the catchment is landmass erosion, and soil conservation plans and sediment bunds are relatively cost-effective options, the three outcome-based scenarios show that it is more efficient to focus on reducing landmass erosion more than streambank erosion.

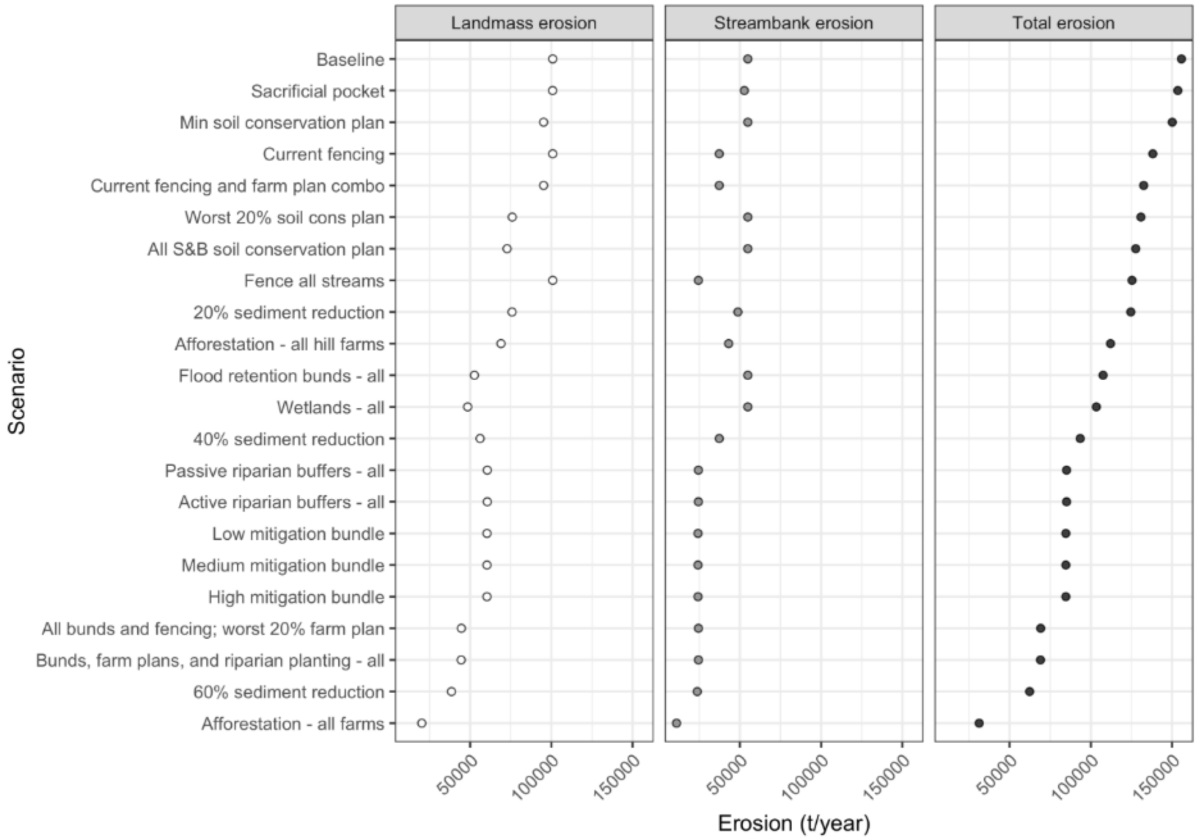

Figure 13 Catchment sources of total sediment (t/yr), by scenario.

5.2 Qualitative assessment of biodiversity-focused ecosystem services derived from bunds, pocket and baseline scenarios

The differences between the 'baseline' (as-now), all bunds (with fencing and worst 20% farm plans), and sacrificial pocket (with fencing and worst 20% farm plans) scenarios in terms of ecosystem service change are illustrated in Figure 14. In the absence of data sufficient for a quantitative analysis, service provisions are based on expert opinion. The importance of a service is denoted by the background colour: dark green denotes high importance, light green denotes medium–high importance, cream denotes medium–low importance, and grey denotes low importance. Scenarios differ most in the 'natural' ecosystem types – wetlands and rivers.

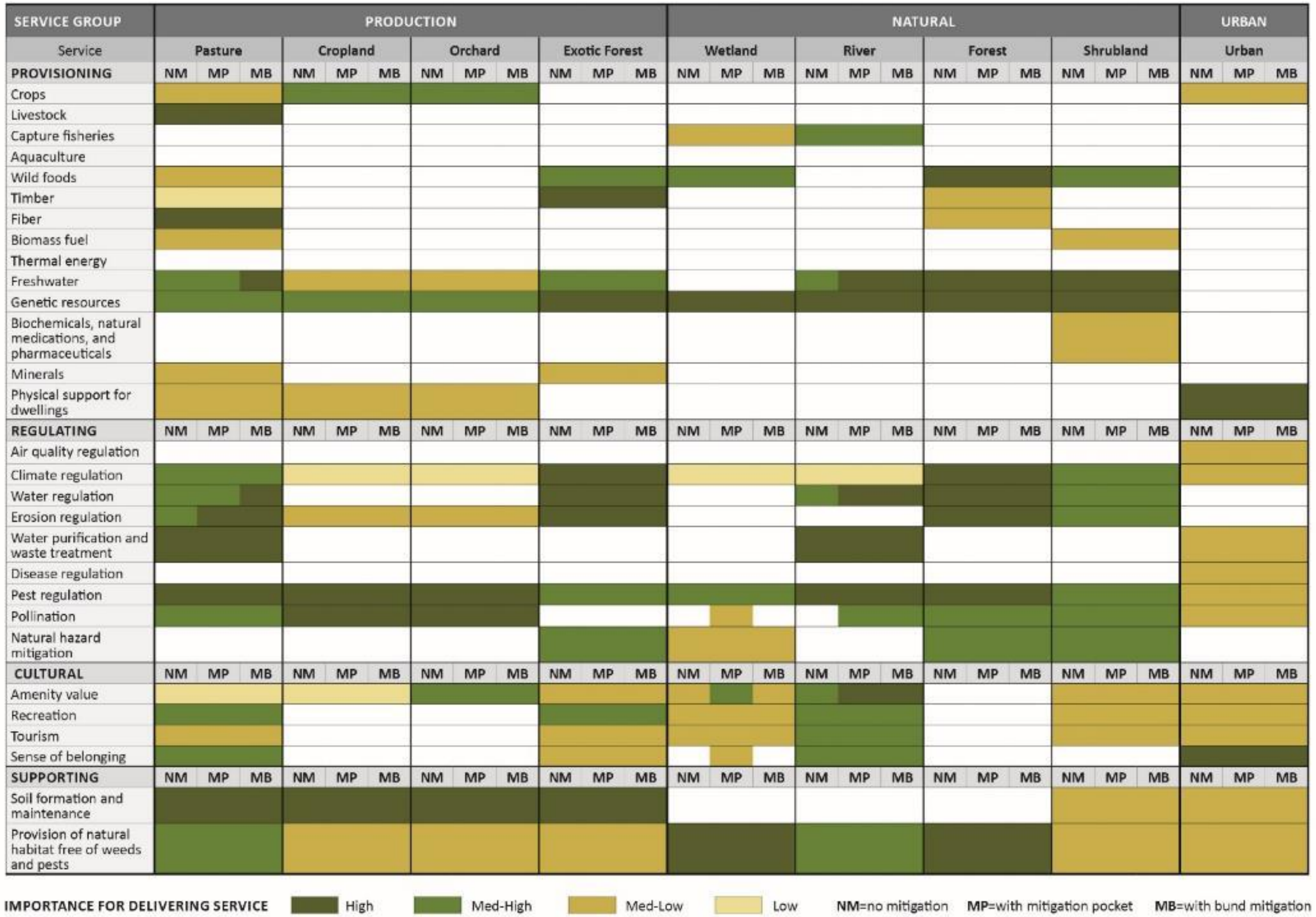

Figure 14 Qualitative analysis of changes in provisioning, regulating, cultural, and supporting ecosystem services under baseline (NM), the Otonga pocket (MP), and the upland bunds (MB). In this analysis MP and MB also have fencing of all streams and soil conservation implemented on the 20% worst farms for soil erosion.

6 Maximising biodiversity and ecosystem services within the UWC

Options for biodiversity enhancement in the catchment were considered in order to complement the UWC economic model described in this report. Options were assessed quantitatively using carbon gain and restored significance (Carswell et al. 2015), and qualitatively in relation to implications for habitat quality and threatened biodiversity (Figure 15). From a biodiversity perspective, the options are not mutually exclusive and a combination of habitat creation and enhancement would increase habitat quality and quantity within the catchment.

6.1 Scenario descriptions and rationale for inclusion

The upland bunds and Otonga wetland creation were included because they were the most effective options for flood mitigation and ecosystem service delivery under the economic model. Stream revegetation and wetland enhancement are biodiversity-focused options that were provided to complement the existing scenarios.

Upland bunds

Each sub-catchment would have a bund appropriate to the catchment size. Bunds were costed in the economic model at an average of one per 40 hectares at an annualised cost of $10 per hectare. The retention bunds were to be constructed with a bottom drain; minimal pasture would be lost below the bund. Benefits for biodiversity could be enhanced by fencing and planting native species for habitat in the immediate vicinity of the bund. Under this ‘enhanced bund’ scenario, planting of native species that tolerate occasional inundation and provide habitat would be recommended, such as *Carex secta*, *Carex virgata* and harakeke *(Phormium tenax).* Tree and shrub plantings around the bunds of cabbage tree (*Cordyline australis),* swamp coprosma (*Coprosma tenuicaulis)*, mānuka (*Leptospermum scoparium)*, kānuka (*Kunzea robusta)* and tōtara (*Podocarpus totara)* would increase habitat and food resources for invertebrates, and fauna in general (Gibbons & Boak 2002; Manning et al. 2006; Watts & Mason 2015).

Otonga pocket wetland creation

Under the UWC economic model, the Otonga pocket (approximately 1,250 ha) was modelled as a sacrificial area for flood control but to be left as pasture in between floods. In this analysis, we consider the effect of two possible scenarios:

a) creating an integrated constructed wetland (ICW, described further below in the Methods) to manage the area for biodiversity, flood management and water quality
b) allowing the pocket to naturally regenerate to forest, which would provide biodiversity benefits but reduce flood capacity.

An ICW in the Otonga pocket is estimated to provide the same flood attenuation as if the pocket were left in pasture, provided the constructed wetlands were not permanently deep.

Suitable native species for the ICW include raupō (*Typha orientalis*), *Carex virgata, Eleocharis acuta* and *Juncus edgariae*, with drier areas incorporating taller herbs, shrubs and small trees, such as harakeke, swamp coprosma, mingimingi (*Coprosma propinqua)*, mānuka, cabbage tree and small-leaved māhoe (*Melicytus micranthus*).

The ICW would be a swamp wetland: re-constructing a peat bog is not possible. However, at a national level swamps have suffered the greatest diminution from pre-human estimates of cover: Ausseil et al (2008) estimate that only 6% of the historical extent of swamps remain in New Zealand.

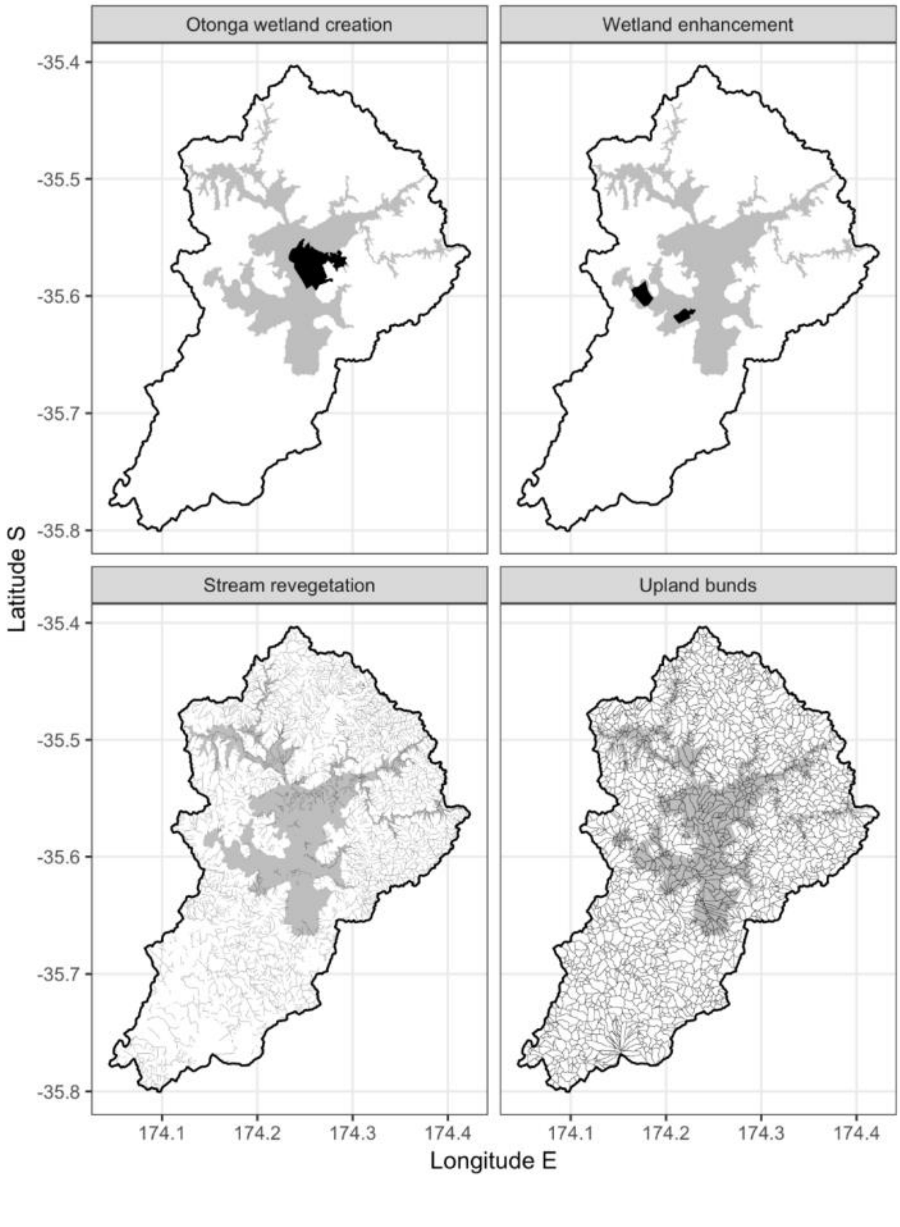

Figure 15 Location of restoration scenarios considered for the Upper Wairua Catchment. The Hikurangi floodplain is delineated in grey.

Stream revegetation

Stream revegetation is an extension of the ‘stream bank fencing’ option described in the UWC economic model and is intended to simulate realistic best case riparian fencing and planting. The UWC economic model was limited to fencing streams running through pastoral land; the stream revegetation considered here assumes 10 m-wide buffers around all streams on primary production land in the catchment (Daigneault, Eppink & Lee 2017). The buffers would take up an area of approximately 3,600 ha, or 4.8% of the catchment. A range of regionally common native species, appropriate for the riparian zone, could be used, such as lowland ribbonwood (*Plagianthus regius)*, kōwhai (*Sophora microphylla),* kaikōmako (*Pennantia corymbosa)*, mataī *(Prumnopitys taxifolia*), mingimingi, *Coprosma parviflora*, *Coprosma rigida* and *C. rotundifolia.*

Wetland enhancement

The wetland enhancement option examines the benefits of improving the condition of two wetlands on public conservation land, Otakairangi and the Wairua River reserve. Options for wetland enhancement have been described in a report commissioned on restoration opportunities within the Hikurangi floodplain (Clarkson et al. 2015); we propose a modified version here.

The Wairua River reserve is a large swamp remnant (153 ha) on the true right of the Wairua River. Major threats are considered to be invasive weeds and further modification of an already-modified hydrological regime, meaning priorities for this area include invasive weed control, particularly for *Tradescantia*, and avoiding further drainage around the wetland. *Tradescantia* is considered to be a priority for control because it takes over drier areas in which *Pittosporum obcordatum*, a nationally vulnerable species, otherwise resides.

The Otakairangi swamp is the largest natural area remaining on the Hikurangi floodplain (266 ha) and is a peat bog. *Sporadanthus ferrugineus*, a peat-forming species, was historically present. It is considered likely to have been extirpated by fire following European settlement of the area (Clarkson et al. 2015) and is now locally extinct in Northland. The bog is subject to ongoing human modification by a drain bisecting the wetland. Exotic species are found along the drain and the edges of the bog. Key threats to the bog are therefore ongoing drainage, weed invasion and fire. Habitat enhancement within Otakairangi would include: careful retirement of the drain bisecting the area, planting to re-introduce *Sporadanthus ferrugineus*, and weed control, particularly of royal fern (*Osmunda regalis*), an aggressive peatland invasive.

6.2 Methods

Integrated constructed wetlands

ICWs typically consist of several shallow wetland cells containing emergent vegetation. They have a greater land requirement than conventional constructed wetlands, but the larger footprint provides richer habitat diversity (Scholz et al. 2007; Jurado et al. 2010). ICWs have also been used successfully for water quality improvement (Kayranli et al. 2010).

Analysis of scenarios

Carbon gain and restored significance were calculated, as set out in Carswell et al. 2015. Briefly, carbon gain was predicted using the Generalised Regression and Spatial Prediction package (Lehman et al. 2002) as the difference between total current carbon and potential carbon stocks, as influenced by key environmental variables and human disturbance. Ecological representation was quantified in the form of restored significance (Carswell et al. 2015). Restored significance is quantified at the hectare scale and has units of parts per billion (ppb), one billion representing completely undisturbed condition. It is quantified as the difference between current and potential future condition. At the landscape scale, increases in restored significance can be thought of as increasing ecological integrity. Carbon gain and restored significance are assessed in relation to forest land cover types. As a result, we were unable to assess the wetland pocket scenario for carbon gain and restored significance quantitatively.

Habitat gain was assessed qualitatively on the basis of size and type of habitat restored. Threatened species gains are assessed according to the opportunity to address the priorities set out in Clarkson et al. 2015.

We used long term change in macroinvertebrate community index (MCI) as an indicator of shifts in freshwater ecosystem health in response to land use change scenarios. MCI change was modelled by comparing the relationships between changes in N, P, *E. coli* and land cover to changes in MCI at sites around New Zealand (MFE 2014c). A boosted regression tree model implemented in R statistical software was used to model the MCI change. Boosted regression trees draw from both machine learning and traditional statistical methods. Unlike traditional regression methods that produce one 'best' model, however, boosted regression trees combine numerous simple tree models to optimise performance (Elith et al. 2008).

Although predictors of nitrate change, ammonia change, P change, *E.coli* change and land cover type were included in the initial model, model simplification indicated the most parsimonious model included only land cover and P change (Figure 16). We used the parsimonious model to predict MCI change for four scenarios: the sacrificial pocket, upland bunds, stream revegetation, and baseline. The MCI results for stream revegetation can be considered conservative because it was modelled in the MCI analysis with a buffer width of 5 m, for consistency with the economic modelling. MCI declines were observed in the majority of sites within the raw data; relationships for all land cover types predicted declines in MCI, the magnitude of which were strongly influenced by changes in P. Within the range of P change and without any land cover change predicted under the scenarios, very little change was predicted at the catchment scale.

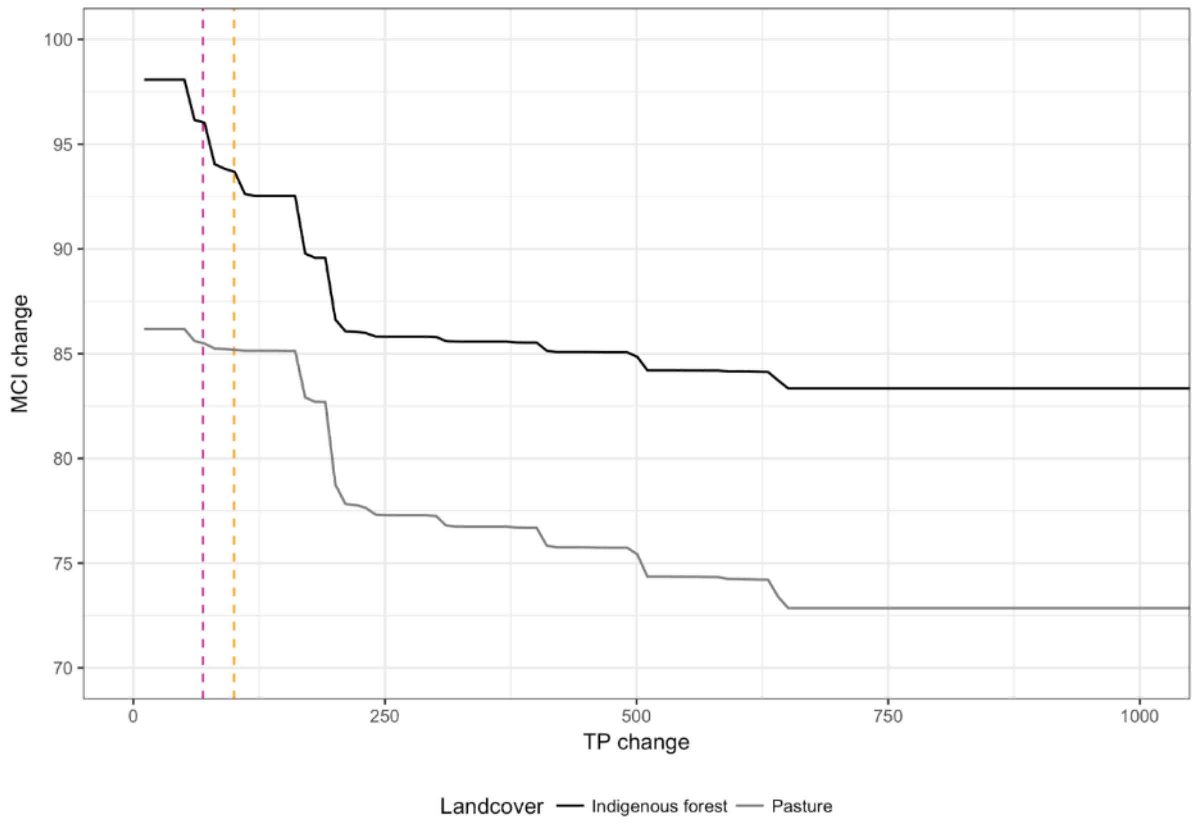

Figure 16 Modelled relationship between total P change (%) and MCI change expressed as change from baseline of 100%. MCI change of less than 100% indicates a decline in MCI. The pink dashed line indicates change under the best case mitigation scenario, which was stream revegetation; the orange dashed line indicates the baseline scenario. All scenarios modelled have a dominant land cover of pasture.

6.3 Quantitative and qualitative results

Upland bunds

Upland bunds would not materially change carbon gain or restored significance at the scale at which changes were modelled (1 ha; Figure 17; Figure 18). Water quality change in terms of MCI change was estimated to be <1%. Native invertebrate habitat would be enhanced by small-scale plantings around the bunds. The vegetated bunds would provide refuges and ‘stepping stones’ of native habitat for enhanced dispersal of flora and fauna across an exotic-dominated landscape. The bunds may also provide the opportunity for appropriate plantings of nationally threatened wetland-tolerant species such as the ‘nationally critical’ swamp hebe (*Hebe* aff. *bishopiana* Hikurangi Swamp) and the ‘nationally vulnerable’ heart-leaved kōhūhū (*Pittosporum obcordatum*), as well as regionally uncommon species such as mingimingi, swamp coprosma, *Coprosma rotundifolia*, *Neomyrtus pedunculata* and *Myrsine* *divaricata.* Appropriate plantings of threatened and uncommon species (see Clarkson et al. 2015) would increase biodiversity benefits in the catchment.

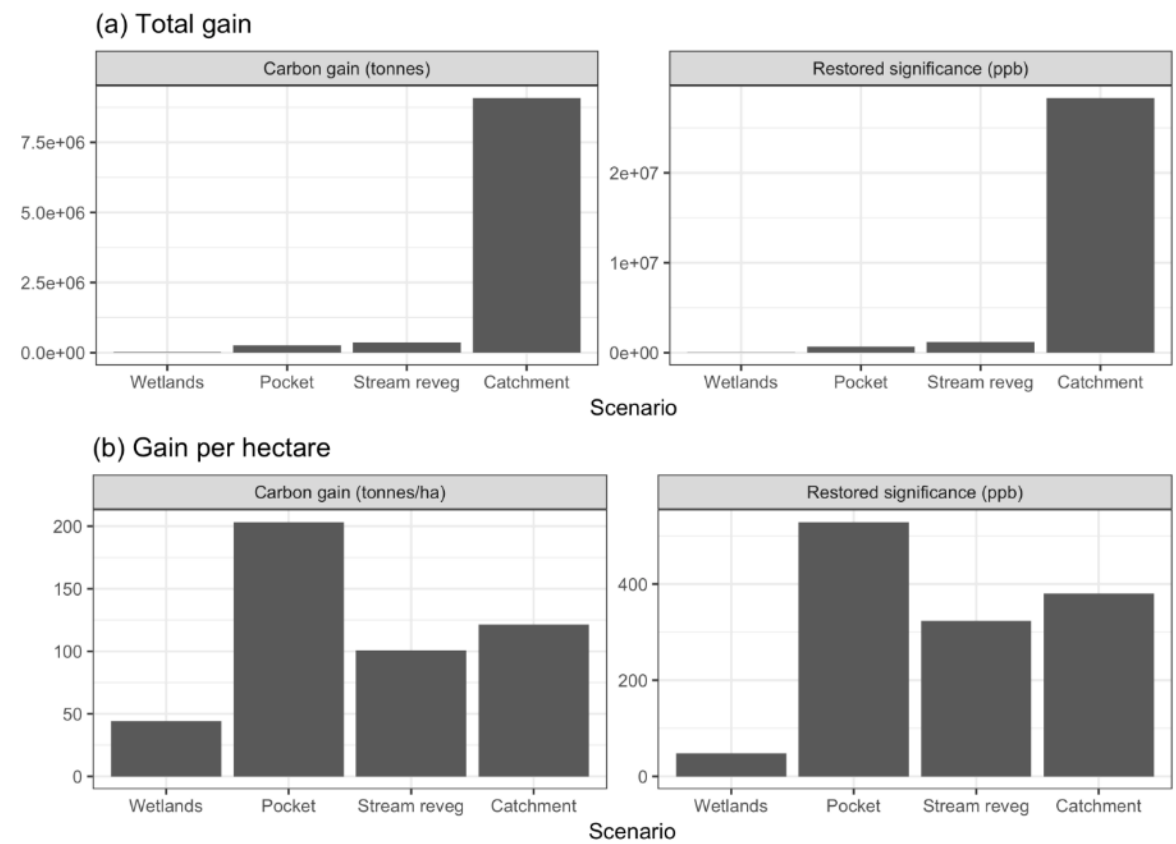

Figure 17 Carbon gain and restored significance in the UWC for (a) the entire area of each scenario and (b) the average per hectare for each scenario. The pocket was assessed for the natural forest regeneration scenario only; modelling for wetland creation is not available.

Otonga pocket wetland creation

Creation of an Otonga wetland would increase wetland coverage in the catchment from 0.6% currently to 2.3%, and would provide equivalent flood attenuation to a pasture-clad pocket. Water quality change in terms of MCI change was estimated to be <1% (Figure 16. An ICW would provide increased habitat for native bird species such as Australasian bittern, North Island fernbird, bellbird and tūī, and native invertebrates, as well as for threatened and uncommon plant species, as described above. In addition, the Otonga wetland would provide a sizeable increase in swamp habitat, a regionally and nationally threatened wetland type.

Were the pocket left to regenerate to forest, sizeable gains in carbon storage and restored significance could be expected, as could substantially lower flood attenuation. Natural regeneration of forest provides a total carbon gain of 266,093 tonnes and total restored significance gain equivalent to 690,152 ppb (Figure 17; Figure 18).

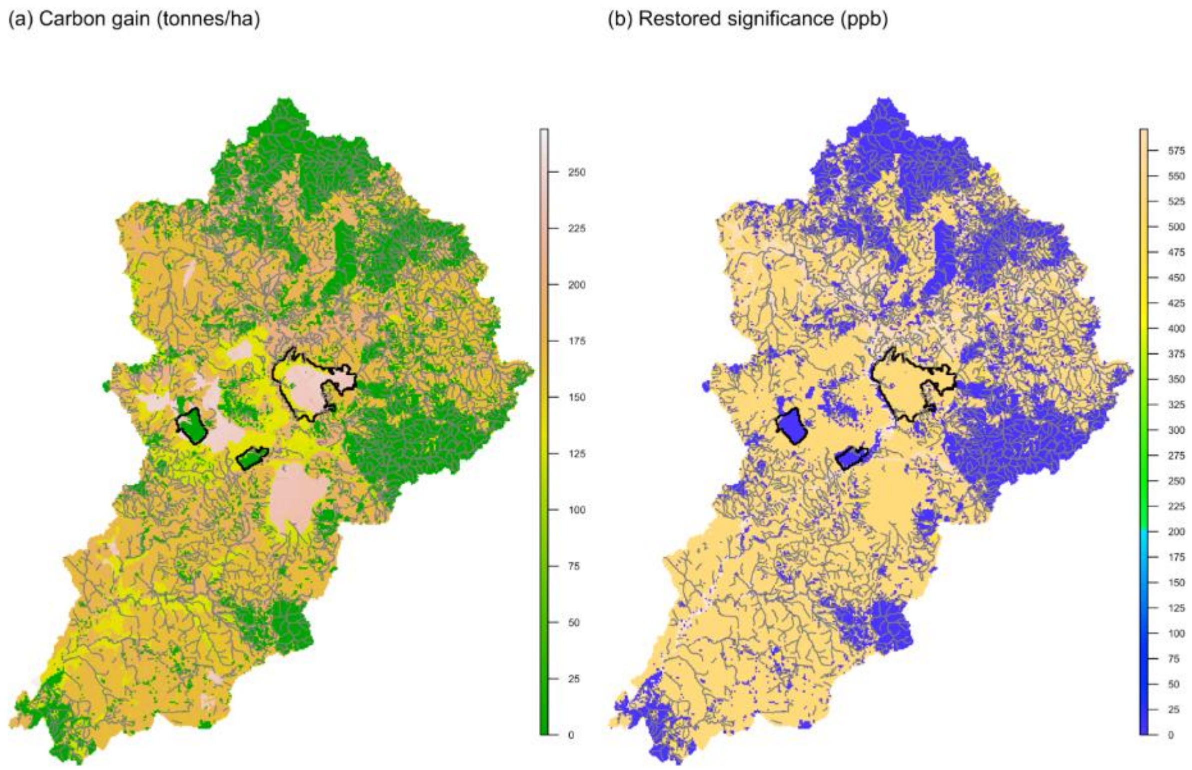

Figure 18 Carbon gain and restored significance for the UWC. The two existing wetlands (Wairua River reserve and Otakairangi, south-west), and the Otonga pocket (north-east) are delineated in black; streams are in dark grey. The modelled data assesses all areas mapped for gains under forest regeneration.

Wetland enhancement

Less change in carbon storage (19,046 tonnes) and restored significance (20,548 ppb) was detected for the existing wetlands compared to other scenarios (Figure 17; Figure 18). Water quality change in terms of MCI change was estimated to be <1% (Figure 16). Enhancing habitat through planting around wetland edges would take advantage of areas in which relatively large gains per hectare in carbon storage and restored significance can be made (Figure 17). Weed control and fire prevention would help to maintain existing habitat values. Rewilding the hydrology of Otakairangi would prevent future losses of habitat and carbon storage. Benefits to threatened biodiversity would be high following the re-introduction of *S. ferrugineus*, now locally extinct, and weed control to allow the continued presence of species such as the nationally vulnerable heart-leaved kohuhu *P. obcordatum*.

Stream revegetation

Total carbon gain (367,680 tonnes) and total restored significance gain (equivalent to 1,178,071 ppb) were the highest among all the scenarios (Figure 17; Figure 18. Water quality change in terms of MCI change was estimated to be <1% (Figure 16). Revegetation of 3,600 ha of riparian strips would provide little further wetland habitat but would increase native woody habitat over the entire area. The geographical extent of streams within the catchment would enhance connectivity between existing remnants in the district. In addition to the suggested riparian species above, threatened biodiversity would be enhanced by plantings of swamp hebe, which prefers river banks and riparian zone habitats, as well as heart-leaved kōhūhū, and the 'at risk – nationally uncommon' kawaka (*Libocedrus plumose).*

6.4 Discussion

Although upland bunds were the most cost-effective option for ecosystem service optimisation under the UWC economic model, they provide few opportunities for habitat enhancement within the UWC. In this section we discuss the best option under carbon storage potential, ecological representation, threatened biodiversity implications and enhanced habitat quality criteria, and conclude with an overall assessment.

Carbon gain

Carbon storage is maximised under the stream revegetation scenario. However, the Otonga pocket under forest regeneration provides the highest gains on a per hectare return. This is due to its spatial location in the catchment coinciding with high potential carbon gains. Quantitative gain for Otonga pocket wetland creation could not be assessed. Wetland enhancement had limited carbon storage gains under the existing assessment methodology, due to limited gains over and above values already present. Peat wetlands store large amounts of carbon (Gorham 1991), but peat degradation caused by drains can induce loss of such carbon (Holden et al. 2004). Therefore, averting peat degradation through managing the hydrological regime around Otakairangi wetland would have a positive effect on the carbon fluxes in the catchment. Averted loss has not been captured under the current modelling.

Ecological representation

Total gains were highest under the stream revegetation scenario, but, as for carbon, restored significance gain per hectare was highest in the Otonga pocket forest regeneration scenario. Quantitative gain for Otonga pocket wetland creation could not be assessed. Lesser gains were seen for wetland enhancement, as for carbon gain. The modelling indicates opportunities that will have a high rate of return (per hectare) for native forest regeneration/restoration around the edges of both existing wetlands.

Water quality

Little change in MCI declines was predicted by the model across any of the scenarios (Figure 16). Changes in land cover at a finer resolution than the catchment level are likely to have effects on MCI change; however, techniques to model these changes are currently lacking. Landcare Research is seeking funding to improve the model by including finer-scale predictors, such as the presence of riparian plantings. Until this is resolved, MCI change is not a reliable indicator of water biodiversity gains at this scale of management.

Enhanced habitat

Wetland habitat would be created under the Otonga pocket scenario and maintained – or improved – under the wetland enhancement scenario. These options are not mutually exclusive and together would improve wetland bog and swamp habitat in the catchment. Adding 3,600 ha of native planting would address historical forest loss within the catchment and increase food sources and connectivity for native fauna, but would not address the historical loss of wetland systems in the district. Upland bunds without planting would provide minimal habitat benefits; planting would provide some benefits for invertebrates, and food sources for birds that can travel across pasture to access them.

Threatened biodiversity

Threatened plant species and ecosystems would reap the greatest benefits under the Otonga wetland and wetland enhancement scenarios. Stream revegetation and upland lands would provide some opportunities for threatened plants to be planted.

Overall assessment

The most cost-effective method for achieving the key goals of the UWC working group – reduced sediment and increased flood mitigation – is upland bunds. However, this scenario provides the least scope for biodiversity enhancement within the catchment. This is a common result, with many previous authors concluding that biodiversity needs to be considered in its own right (Maron & Cockfield 2008; Carswell et al. 2015). Biodiversity gains only very rarely accrue in proportion to other ecosystem service gains, such as carbon.

Wetland scenarios and stream revegetation scenarios provided complementary gains (or averted loss) of wetland and forest habitat. If the sacrificial pocket were to be favoured as a flood mitigation option, the flood attenuation of a pasture-clad pocket could be provided by an ICW, which would increase wetland habitat and opportunities for threatened conservation within the catchment.

7 Model limitations

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 into the relative impacts and trade-offs across a range of policy scenarios (e.g. practice versus outcome-based targets), rather than to explicitly model the absolute impacts of a single policy scenario.

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 flood control, and other land-use policies in the UWC. Following are some of the modelling limitations of this study.

1. **Input data.** The quality and depth of the economic analysis depends on the data sets and estimates provided by biophysical models like SedNetNZ and CLUES, farm budgeting data based on information published by MPI and industry groups, and spatial data sets such as maps depicting current land use and sub-catchments. Estimates derived from other data sources or models not included in this analysis may provide different results for the same catchment. Thus, the analysis presented here should be used in conjunction with other information (e.g. input from key stakeholders affected by policy, a study of the health and recreational benefits from water quality improvements) during any decision-making process.

2. **Representative farms.** The model only includes data and mitigation practices for representative farms for the UWC that were parameterised based on their physical characteristics (land-use capability, slope, etc.). 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.

3. **Baseline conditions.** The NZFARM baseline assumed that (1) land use in the catchment was the same as a 2011 land-use map, (2) net farm revenue was based on a 5-year average of input costs and output prices, and (3) no landowners were implementing management practices intended to reduce sediment and other freshwater contaminants in the catchment. This assumption is likely to have the greatest impact on model estimates, as Northland Regional Council 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. One exception may be the effect of current fencing along streams running through the dairy platform, as indicated by the results of the 'current fencing' scenario.

4. **Management practices.** The model only includes some management practices deemed feasible and likely to be implemented in a catchment as a result of policies to mitigate flooding and freshwater contaminants, given the current state of knowledge and technology available. It does not account for new and innovative mitigation options that might be developed in the future as a result of incentives created as the result of a policy or plan change. Although not all possible mitigation options are likely to be included in the model, the suite of management practices is large enough to account for a wide range of mitigation costs (e.g. change in farm profit) and effectiveness (e.g. change in sediment or nutrient loads). Therefore, the average cost of the modelled scenarios should be within the range of what the actual average costs are likely to be as a result of the policy scenario analysed.

5. **Mitigation effectiveness.** Each management practice included in the model is assumed to have a fixed relative rate of effectiveness for reducing environmental outputs (e.g.

50% 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.

6. **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 environmental outputs in the UWC. This is assumed to occur over a period of at least 10 years, as landowners typically need adequate time to make significant changes to their operation. In reality, not all landowners will select the option that is considered most optimal, and thus the actual effectiveness of the policy may be overstated.

7. **Regional economic impacts.** NZFARM does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the scenarios investigated in this report could produce some change in regional employment and GDP due to reductions in farm outputs for taking land out of production (e.g. in the case of afforestation with native bush or constructing wetlands). There could also be social and cultural impacts. The estimates produced by NZFARM provide just a subset of possible metrics that could be used to determine the best option to manage ecosystem services in the UWC.

8 Acknowledgements

We would like to thank the following for contributing to this report: Ben Tait and Duncan Kervell of Northland Regional Council for providing data and information; Adam Twose of Whangarei District Council for providing data and information; Tim Brandenburg of Fonterra for providing data and information and coordinating the stakeholder meetings and input; Helen Moodie of DairyNZ for providing data and information; Marga Martens of DOC for coordinating stakeholder input; and Fonterra farmers, Geoff Crawford, Ken Finlayson, Jared Going, Jenny Vuglar, Steve Brown, Royce Kocich, Rosemary Lister, Mark Benton, Terence Brocx for input and 'ground trothing' of the proposed scenarios.

Appendix 1 Sediment bund and wetland mitigation assumptions

Table A1.1 Assumptions about wetland applicability and effectiveness

Mitigation	Description	Hydrological flow path	Proportional areal applicability (% of area)	Proportion of load intercepted (% of load)	Efficacy Sediment (% load reduction)	Efficacy *E.coli* (% load reduction)	Volume retained in design flood	Density of mitigation (no. or area per ha)
Flood retention bund (with drain)	Formed by retention bund with bottom drain. Minimal loss of pasture above bund.	Ephemeral channels/1st order catchments @ 1 per 40ha	80%	100%	50%	30%	1,250 m^3 per sub-catchment	1 per 40 ha = 0.025 systems/ha
Upland wetland	Formed by retention bund but without bottom drain. Managed as wetland with planting and fencing to exclude stock access.	Ephemeral channels/1st order catchments @ 1 per 40ha	80%	100%	70%	50%	250 m^3 per sub-catchment	1 per 40 ha = 0.025 systems/ha

Table A1.2 Cost of wetland construction (all costs assume activities are permitted and do not incur a resource consent charges)

Mitigation	Construction cost	Planting cost	Fencing cost	Opportunity cost	Maintenance cost
Flood retention bund (with drain)	$2,000 each	No planting	No fencing	No land lost to grazing (<0.2%)	$2,000 after 25 yr
Upland wetland	$0	0.02 ha wetland planting per system @ $20,000/ha = $400/system =$20/ha of land mitigated	0.02 ha fenced per system, assume need 80 m fencing/system @ $6/m installed and materials = $480 plus gate and hinges @$220= $700/system = $35/ha of land mitigated	Loss of lower value grazing, in 0.02 ha permanent wetland/system or 0.01 ha/ha of mitigated land with estimated 40% of average farm income/ha	General maintenance = $0.30/ha of land mitigated/yr, plus pipework replacement and some sediment removal @ $2,000 after 25 yr

Appendix 2 Detailed NZFARM methodology

Simulating endogenous land management is an integral part of the model, which can differentiate between business as usual farm practices and less-typical options that can change levels of environmental and agricultural outputs. Key land management options in the NZFARM version used for the UWC include implementing soil management plans, fencing streams, and constructing wetlands. Including a range of management options allows us to assess what levels of regulation might be needed to bring new technologies into general practice. Landowner responses to sediment load restrictions in NZFARM are parameterised using estimates from biophysical and farm budgeting models.

The model's objective function maximises the net revenue[10] of agricultural production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as slope, water available for irrigation, and any regulated environmental outputs (e.g. sediment load limits) imposed on the catchment. Catchments can be disaggregated into sub-regions (i.e. zones) based on different criteria (e.g. land-use capability, irrigation schemes), such that all land in the same zone will yield similar levels of productivity for a given enterprise and land management option.

The objective function, total catchment net revenue (π), is specified as:

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{matrix} PA_{r,s,l,e,m} + Y_{r,s,l,e,m} - \\ X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Z_{r,s,l} \end{matrix} \right\} \qquad (1)$$

where

- P is the product output price
- A is the product output
- Y is other gross income earned by landowners (e.g. grazing leases)
- X is the farm-based activity
- ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable and fixed input costs
- τ is an environmental tax (if applicable)
- γ^{env} is an environmental output coefficient
- ω^{land} is a land-use conversion cost
- Z is the area of land-use change from the initial (baseline) allocation.

[10] Net revenue (farm profit) is measured as annual earnings before interest and taxes (EBIT), or the net revenue earned from output sales less fixed and variable farm expenses. It also includes the additional capital costs of implementing new land management practices.

Summing the revenue and costs of production across all reporting zones (*r*), sub-catchments (*s*), land covers (*l*), enterprises (*e*), and management options (*m*) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production but also by a number of production, land, technology, and environmental constraints. The production in the catchment is constrained by the product balance equation and a processing coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

$$A_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \qquad (2)$$

Landowners are allocated a certain amount of irrigation (γ^{water}) for their farming activities, provided there is sufficient water (W) available in the catchment:[11]

$$\sum_{s,l,e,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq W_r \qquad (3)$$

Land cover in the catchment is constrained by the amount of land available (L) on a particular sub-catchment in a given zone:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \qquad (4)$$

Landowners are constrained by their initial land allocation (L^{init}) and the area of land they can feasibly change:

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Z_{r,s,l} \qquad (5)$$

The level of land cover change in a given zone and sub-catchment is constrained to be the difference in the area of the initial land-based activity (X^{init}) and the new activity:

$$Z_{r,s,l} \leq \sum_{e,m} \left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m} \right) \qquad (6)$$

We can also assume that it is feasible for all managed land cover to change (e.g. convert from pasture to forest). Exceptions include urban, native bush and tussock grassland under conservation land protection, which are fixed across all model scenarios:

$$L_{r,s,fixed} = L^{init}_{r,s,fixed} \qquad (7)$$

The model also includes a constraint on changes to enterprise area (E), if desired[12]:

$$E_{r,s,l,fixed} = E^{init}_{r,s,l,fixed} \qquad (8)$$

[11] For this analysis we assume there are no irrigated land uses.

[12] The UWC analysis was primarily focused on the effects of land management on sediment and *E.coli* loads. As a result, all the scenarios in this report assume all enterprises are fixed at baseline levels, with the exception of the ones that focus on the potential impacts of afforestation.

In addition to estimating economic output from the agriculture and forest sectors, the model also tracks a series of environmental factors, and in this study focuses on sediment and *E. coli* loads. In the case where farm-based loads (γ^{env}) are regulated by placing a cap on a given environmental output from land-based activities (*ENV*), landowners could also face an environmental constraint[13]:

$$\sum_{s,l,e,m} \gamma^{env}_{r,s,l,e,m} X_{r,s,l,e,m} \leq ENV_r \qquad (9)$$

Finally, the variables in the model are constrained to be greater or equal to zero, such that landowners cannot feasibly use negative inputs such as land and fertiliser to produce negative levels of goods:

$$Y, X, L \geq 0 \qquad (10)$$

The 'optimal' distribution of land-based activities based on sub-catchment $s_{1\ldots i}$, land cover $l_{1\ldots j}$, enterprise $e_{1\ldots k}$, land management $m_{1\ldots l}$, and agricultural output $a_{1\ldots m}$ are simultaneously determined in a nested framework that is calibrated based on the shares of initial enterprise areas for each of the zones. Detailed land-use maps of the catchment are used to derive the initial (baseline) enterprise areas, and a mix of farm surveys and expert opinion is used to generate the share of specific management systems within these broad sectoral allocations.

The main endogenous variable is the physical area for each of the feasible farm-based activities in a catchment ($X_{r,s,l,e,m}$). In the model, landowners have a degree of flexibility to adjust the share of the land-use, enterprise and land management components of their farm-based activities to meet an objective (e.g. achieve a nutrient reduction target at least cost). Commodity prices, environmental constraints (e.g. nutrient cap), water available for irrigation, and technological change are the important exogenous variables, and, unless specified, these exogenous variables are assumed to be constant across policy scenarios.

NZFARM has been programmed to simulate the allocation of farm activity area through constant elasticity of transformation (CET) functions. The CET function specifies the rate at which regional land inputs, enterprises and outputs produced can be transformed across the array of available options. This approach is well suited for models that impose resource and policy constraints, as it allows the representation of a 'smooth' transition across production activities while avoiding unrealistic discontinuities and corner solutions in the simulation solutions (de Frahan et al*.* 2007).

At the highest levels of the CET nest, land use is distributed over the zone based on the fixed area of each sub-catchment. Land cover is then allocated between several enterprises such as arable crops (e.g. process crops or small seeds), livestock (e.g. dairy or sheep and beef), or forestry plantations that will yield the maximum net return. A set of land management options (e.g. fencing streams, reduced fertiliser regime) are then applied to an enterprise, which then determines the level of agricultural outputs produced in the final nest.

---

[13] This constraint can be placed at the farm, sub-catchment or catchment level, depending on the focus of the policy or environmental target.

The CET functions are calibrated using the share of total baseline area for each element of the nest and a CET elasticity parameter, σ_i, where $i \in \{s, l, e, m, a\}$ for the respective sub-catchment, land cover, enterprise, land management and agricultural output. These CET elasticity parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes (i.e. there is no implicit cost in switching from one land use or enterprise activity to another).

The CET elasticity parameters in NZFARM typically ascend with each level of the nest between land cover, enterprise and land management. This is because landowners have more flexibility to change their mix of management and enterprise activities than to alter their share of land cover. For this analysis, the CET elasticities are specified to focus on the impact of holding land cover and enterprise area fixed, which allows us to focus on the impacts of imposing mitigation practices on existing farms.

Thus, the elasticities are as follows: land cover ($\sigma_L = 0$), enterprise ($\sigma_E = 0$), and land management ($\sigma_M = \infty$). An infinite CET elasticity value was used in the land management nest to simulate that landowners are 100% likely over the long-run to employ the most cost-effective practices on their existing farm to meet environmental constraints rather than change land use. The CET elasticity parameter for each sub-catchment (σ_S) is set at 0, as the area of a particular sub-catchment in a zone is fixed.[14] In addition, the parameter for agricultural production (σ_A) is also assumed to be 0, implying that a given activity produces a fixed set of outputs.

We note that this specification, along with equation (7), essentially re-specifies NZFARM to solve with additional levels of constraints. In this case, the only thing that is allowed to change is land management, which is now assumed to be completely substitutable over the long run. That is, the landowner will choose whatever land management option is most profitable for the farm, without any reservation. However, this approach also constrains changes in land use, and thus although a farm may be more profitable if it switches from sheep & beef to forestry, this specification prohibits it from doing so. As a result, the simulated costs of the policy are the same as those estimated using catchment economic modelling methods (discussed in Doole 2015).

The economic land-use model is programmed in the modelling General Algebraic Modelling System (GAMS) software package. The baseline calibration and scenario analysis are derived using the non-linear programming version of the CONOPT solver (GAMS 2015).

A schematic of the flow of inputs and outputs of NZFARM is given in Figure A1.1.

[14] Recall that other NZFARM-based catchment models have specified *S* as soil type and *R* as the zone or sub-catchment. In this study, we assume that there is just a single soil type and many reporting zones and sub-catchments. As both *R* and *S* are fixed in area, we can keep the same structure and simply replace soil type with sub-catchment.

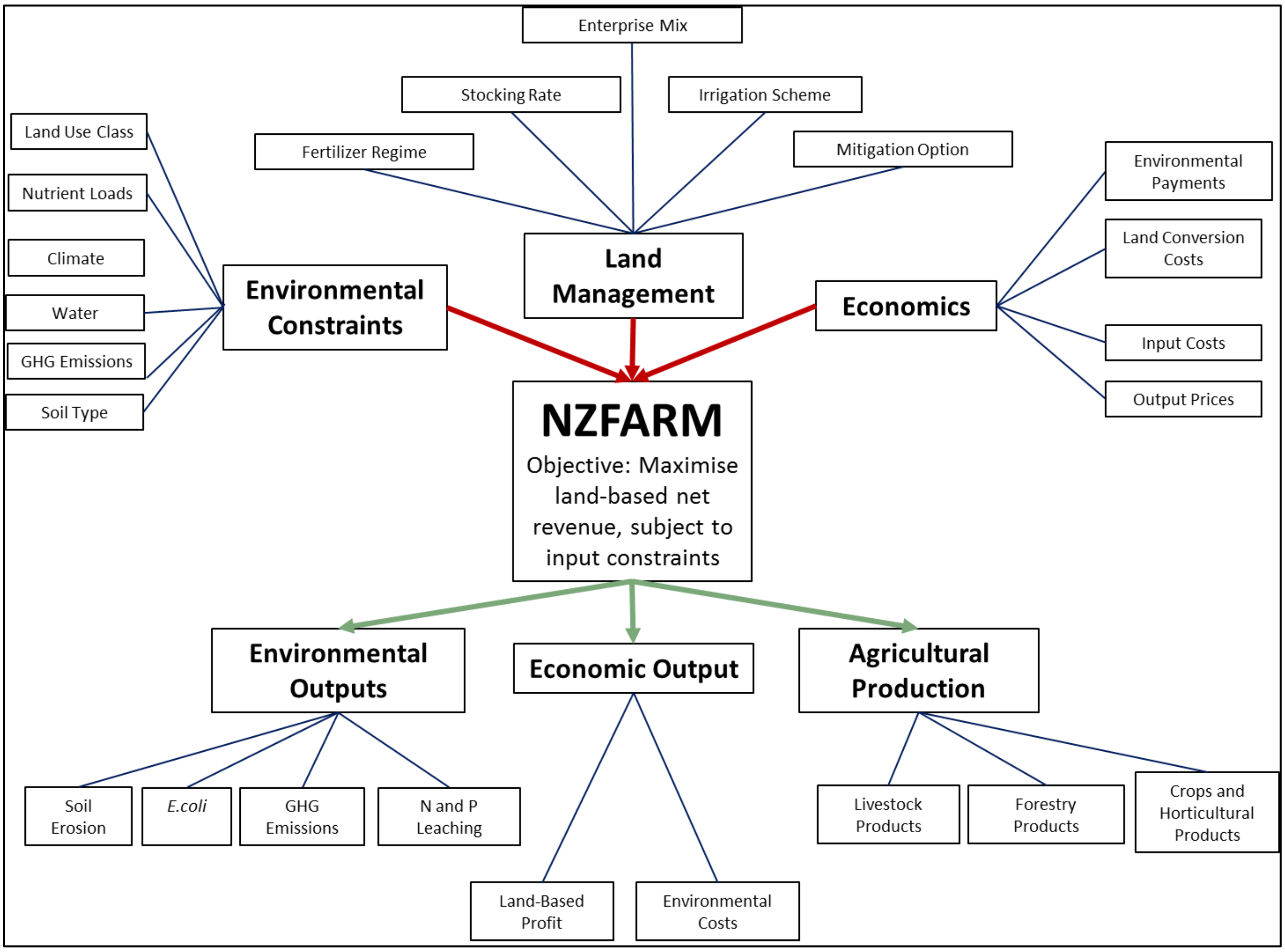

Figure A1.1 New Zealand Forest and Agriculture Regional Model (NZFARM).

Appendix 3 Details of mitigation cost estimates

Overview

A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water and the atmosphere, as well as to identify strategies to mitigate contaminant losses to fresh water (e.g. Monaghan et al. 2007; McDowell & Nash 2012; McDowell et al. 2014). This study has focused on incorporating research that has quantified mitigation cost and effectiveness from implementing technology (e.g. feed pads), as well as conducting better management practices (e.g. reduced fertiliser application).

For this project we reviewed and collected data on the cost and effectiveness for a wide range of options to mitigate nitrogen (N), phosphorus (P), sediment (S), *E.coli* (E), and greenhouse gas emission (GHG) from a range of land uses. These include dairy, sheep & beef (S&B), deer, arable cropping, and horticulture. Mitigation options were quantified as an individual practice or technology, or as a set of options referred to as mitigation bundles. Cost figures are reported as both annualised costs ($/ha/yr) as well as relative change in net farm returns, while reductions in diffuse pollution from the contaminants/emissions are listed in relative terms due to the wide variance in baseline rates that can vary through factors such as stocking rate, slope, and fertiliser rate.

We have typically focused on mitigation estimates that came from models, the literature or research programmes that originated in New Zealand. The relative effectiveness of N and P mitigation options were often reported in the literature as being estimated using the OVERSEER model, while S, E and GHG mitigation estimates were reported as using a variety of methods.

Although we have incorporated a wide range of studies into our mitigation estimates, most of the research has been conducted outside of the Northland region and thus will not precisely reflect the cost and effectiveness of implementing the same mitigation practices in the UWC. That said, this exercise is still very useful in identifying the potential range of costs and benefits of implementing some collection of mitigation practices in the catchment.

Methods

In this report we construct mitigation cost figures to help estimate the impacts of implementing mitigation options in the UWC. These curves were then incorporated into a spatial economic land-use model (NZFARM) that has been designed to estimate the effects of potential policies and pathways on meeting an agri-environmental policy objective by estimating cost-effective ways to implement land-use and land management change (Daigneault et al. 2017). The model is parameterised to track GHG emissions and several contaminants that can affect the quality of freshwater from a wide range of land uses, as well as a few land management options such as fencing streams, planting riparian buffers and reducing stock.

We collected several mitigation options for reducing N, P, S and *E. coli* loads in New Zealand. Additional details on some of the wetland mitigation were provided by expert option. The specific costs include initial capital, ongoing and periodic maintenance, and opportunity costs from taking land out of production. An overview of the individual mitigation options considered for NZFARM is listed in Table A3.1. See McDowell et al. 2013 for more details on each option, including factors limiting uptake and co-benefits.

Table A3.1 Summary of individual mitigation options considered for NZFARM

Option	Description	Cost component		
		Opp.	**Capital**	**Maint.**
Stream bank fencing	Construct fences to exclude stock from permanent waterways		X	X
Riparian buffers	Fence streams with 5 m buffer that is planted with grass and native vegetation	X	X	X
Wetland construction	Modification of landscape features such as depressions and gullies to form wetlands and retention bunds	X	X	X
Alum	Apply to pasture and cropland to decrease P loss in run-off			X
Low solubility P	Apply low-water-soluble fertiliser to reduce P loss in run-off			X
Sediment traps	Stock pond or earth reservoir constructed at natural outlet of zero-order catchment	X	X	X
Variable rate irrigation	Optimise water and nutrient application according to local pasture and crop requirements		X	X
Feed pads	Constructed area to keep animals off paddock for specified time	X	X	X
Restrictive grazing	Remove animals from pasture at certain times and/or extend housing period.	X	X	X
Nitrification inhibitors	Apply dicyandiamide (DCD) or alternative inhibitor to reduce nitrate		X	X
Space-planted trees	Trees planted on slopes to retain soil and prevent erosion	X	X	
Reduce fertiliser	Lower fertiliser application rates and/or adjust timing	X		
Reduced tillage	Adjust tilling practices and timing to reduce the time land is bare during the growing cycle	X		
Zero tillage	Eliminate crop disturbance from tilling	X		
Cover crops	Plough crops into soil between harvest and sowing periods		X	X
Full afforestation	Convert part or all of farm to pine plantation or native bush	X	X	X
Mitigation bundle	Includes a combination of the practices listed above. Often more effective, albeit at a higher cost	X	X	X

Costs are likely to vary over time and practice, particularly for mitigation options that include high capital costs. In response, we converted these costs to an annual figure so that they can be directly comparable with 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%. 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. These base figures are discussed in the next section.

For the NZFARM baseline, production yields, input costs and output prices come from several sources (MPI 2013a,b; Lincoln University 2013), and have been verified with agricultural consultants and enterprise experts. All figures are listed in 2012 New Zealand Dollars (NZD). Nutrient losses for pastoral enterprises are estimated using the OVERSEERv6 nutrient budgeting tool, while estimates for other enterprises are derived from the literature (e.g. Parfitt et al 1997; Lilburne et al. 2010). GHG emissions are derived using national GHG inventory methodologies (MfE 2014b). Erosion figures are based on methods from Dymond 2016, while *E.coli* figures were estimated using the CLUES model (Elliot et al. 2016). Note that many of the figures for the freshwater contaminants will change once we update the model with new load estimates from the CLUES model, which is currently being updated with a land-use map that was developed as part of this project.

Baseline practices

We use baseline or no mitigation estimates from the national-level NZFARM model as a basis from which to estimate opportunity costs and relative impacts of each mitigation practice. These baseline practices assume 'typical' management practices for a given land use (e.g. dairy farms already have a nutrient management plan). The mean estimates for each major land use are reported in Table A3.2. As these are listed as national averages, each figure actually has a distribution around it due to variances in factors such production, financial returns, land-use capability class, climate, region and more.

Table A3.2 Mean NZFARM estimates for UWC by land use (per ha per yr)

Land use	Net farm revenue ($)	GHG (kg)	Nitrogen (kg)	Phosphorus (kg)	Sediment (t)	*E. coli* (tera)
Dairy	1,231	6.8	24.8	0.9	2.5	4.5
Sheep & beef	135	2.9	15.0	0.8	1.8	1.8
Other pastoral	1,020	1.0	4.2	0.4	2.0	3.4
Arable & hort.	5,165	1.2	15.6	0.2	1.4	0.1
Forestry	618	-12.2	2.0	0.2	2.0	0.0
Lifestyle	1	2.4	12.3	0.6	1.3	0.0
Native bush	1	-0.6	1.1	0.1	2.4	0.0
Other	1	0.0	0.0	0.0	2.5	0.1
All land	**651**	**2.8**	**16.3**	**0.7**	**2.1**	**2.4**

Individual mitigation options

In this section we report the findings from the main set of individual mitigation options reported in the literature. These are presented by key land use: dairy, S&B, deer, arable cropping, and horticulture. A list of the sources consulted to develop these estimates is listed below.

Table A3.3 Individual mitigation options cost and effectiveness (% from no baseline)

Mitigation option	Annualised cost ($/ha/yr)	EBIT	N loss	P loss	Sediment	*E. coli*	GHG
Dairy							
Effluent management	$24	–0.7%	–4%	–30%	0%	0%	0%
Riparian planting	$71	–2.1%	–56%	–66%	–75%	–60%	–3%
Fencing streams	$137	–4.0%	–13%	–15%	–70%	–60%	0%
Wetlands	$68	–2.0%	–10%	–45%	–65%	–55%	0%
Alum	$34	–1.0%	0%	–26%	0%	0%	0%
Low solubility P	$48	–1.4%	0%	–10%	0%	0%	0%
Sediment traps	$68	–2.0%	0%	–15%	–80%	–50%	0%
Variable rate irrigation	$58	–1.7%	–10%	0%	0%	0%	0%
Feed pads	$171	–5.0%	–15%	–15%	0%	–10%	0%
Restrictive grazing	$513	–15%	–36%	–30%	–40%	–10%	–10%
Nitrification inhibitors	$137	–4.0%	–25%	0%	0%	0%	–17%
Space-planted trees	$34	–1.0%	0%	–20%	–70%	0%	–5%
Sheep & beef							
Riparian planting	$26	–21%	–56%	–50%	–75%	–60%	–10%
Fencing streams	$32	–25%	–13%	–15%	–70%	–60%	0%
Wetlands	$25	–20%	–10%	–45%	–65%	–55%	0%
Alum	$64	–50%	0%	–26%	0%	0%	0%
Sediment traps	$25	–20%	0%	–15%	–80%	–50%	0%
Low solubility P	$25	–19.4%	0%	–10%	0%	0%	0%
Nitrification inhibitors	$0	0.0%	–25%	0%	0%	0%	–15%
Restrictive grazing	$14	–11%	–16%	–20%	–10%	–10%	–6%
Space-planted trees	$6	–5%	0%	–20%	–70%	0%	–6%
Deer							
Riparian planting	$37	–3.7%	–51%	–50%	–82%	–60%	–13%
Fencing streams	$40	–4.0%	–13%	–15%	–70%	–60%	0%
Wetlands	$30	–3.0%	–10%	–45%	–65%	–55%	0%
Space-planted trees	$20	–2.0%	0%	–20%	–70%	0%	–6%
Nitrification inhibitors	$0	0.0%	–7%	–9%	0%	0%	–3%

Arable Cropping							
Riparian planting	$11	–0.7%	–51%	–50%	–75%	–60%	–4%
Reduce fertiliser by 15%	$22	–1.3%	–7%	0%	0%	0%	–5%
Reduced tillage	$141	–8.6%	–2%	–25%	–25%	0%	–4%
Zero tillage	$171	–10%	–10%	–50%	–25%	0%	–20%
Cover crops	$409	–25%	–60%	–25%	–10%	0%	–20%
Horticulture							
Riparian planting	$62	–1.1%	–51%	–50%	–75%	–60%	–4%
Limit N per application	$90	–1.6%	–4%	0%	0%	0%	0%
10% reduction in N	$1,679	–30%	–10%	0%	0%	0%	–3%
Cover crops	$347	–6.2%	–5%	–25%	–25%	0%	–10%
Altering tillage practice	$0	0.0%	–5%	–25%	–25%	0%	–4%

Mitigation bundles

In recent years catchment-scale modelling of the effect of management practices to reduce diffuse-source pollution has focused on including a set of mitigations that are packaged as a 'bundle' of options that would be likely to be introduced on the farm at the same time (e.g. Everest 2014; Vibart et al. 2015). These bundles are typically defined as:

- M1: relatively cost-effective measures with minimal complexity to existing farm systems & management
- M2: mitigation that is less cost-effective than M1, but with capital costs and/or large system change
- M3: management options with large capital costs and/or are relatively unproven

These bundles are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes practices from M1 and M2. Examples of practices that are included in each of these bundles are listed in Table A3.4. Note that a bundle will not necessarily include all of these practices, but rather a mix that achieves a similar reduction in contaminants for a given annualised cost per hectare.

Table A3.4 Mitigation bundle practices (not always applicable on all land types)

Mitigation bundle	Management option
M1	Installation of soil moisture monitoring gear and variable rate irrigation (VRI) on existing centre pivots.
	Adjust cropping fertiliser rates and types to best suit plant requirements and timings
	Limit each urea application
	Variable rate fertiliser
	Gibberellic acid to substitute some spring and autumn nitrogen on pastures
	Apply nitrate inhibitors
	Optimise stocking rates
	Implement best management practices for infrastructure use and maintenance
	Optimum Olsen P
	Low solubility P fertiliser
	Laneway run-off diversion
	Effluent management
	Stock exclusion/fencing
M2	Modify irrigated area to include centre pivots/laterals fitted with variable rate irrigation technology
	Variable rate application of liquid urea
	Wetlands and/or sediment traps
	Tile drain amendments
	Reduce nitrogen fertiliser applications
	Riparian planting
	Enhance animal productivity via introducing cows with greater genetic merit
	Dairy farms to install covered feed pads and required effluent systems
M3	Further reduce nitrogen fertiliser applications
	Reduce stocking rates
	All cows wintered off paddock, possibly in barns
	Restricted grazing of pasture and cropland
	Apply alum to pastures and crops
	Increase effluent area
	No winter feed crop yields over 14 t/ha.

Figure A3.1 shows scatter plots indicating the relative cost and effectiveness of mitigation bundles taken from the following studies:

- Parsons et al. 2015: Rotorua Lakes catchment, Bay of Plenty
- Everest 2014: Hinds catchment, Canterbury
- Vibart et al. 2015: Southland region
- Monaghan et al. 2016: New Zealand.

In all cases, the effectiveness of each bundle was tracked for most – but not all – of the five types of contaminants/emissions (N, P, S, E, GHG) we are interested in. As a result, we estimated the relative effectiveness for the 'missing' contaminants by using the figures from the individual practices discussed in the previous section of this report. For example, Vibart et al. (2015) did not estimate the effects of practices on mitigating S and E, but as their bundles included options such as stock exclusion and constructing wetlands, we were able to use that information to fill in the blanks. To the best of our knowledge, no studies have been conducted to develop mitigation bundles for horticultural crops (see Agribusiness Group 2014a,b).

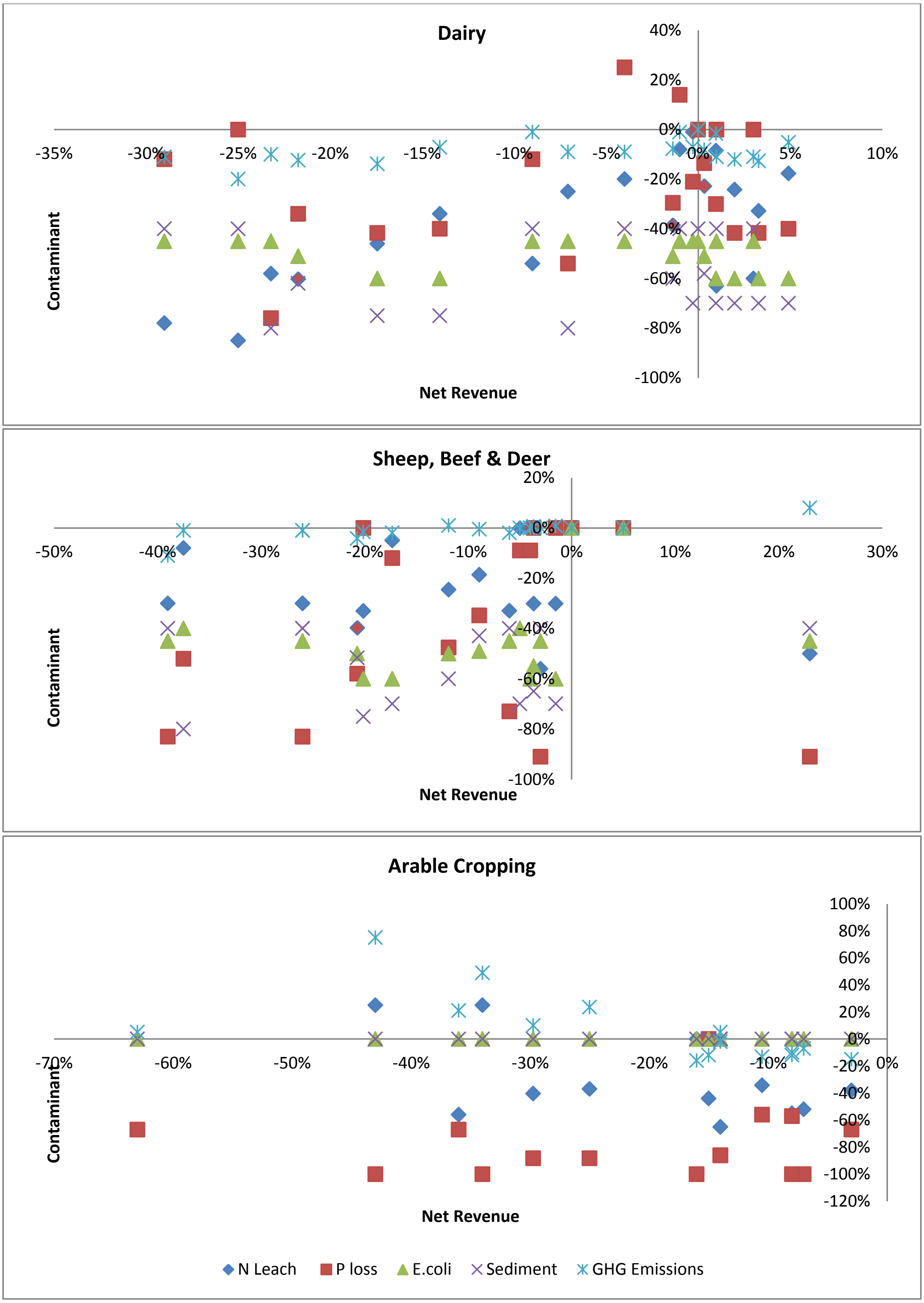

Figure A3.1 Relative change in net revenue versus contaminant (% change from baseline) for modelled mitigation bundles.

The mean, maximum and minimum values for impacts to net revenue, and the different contaminants and emissions of the mitigation bundles for each land use, are listed in Table A3.5. The mean values are the figures that were included in the economic land-use model for the estimates presented in the main report.

Here are a few things to note from the mitigation bundle figures.

- The M1 bundles are indeed relatively low-cost (mean of 0–11% reduction in net farm revenue) but present a wide range of effectiveness for the different contaminants.
- The arable cropping bundles did not include any mitigation that could reduce S or E. This may not be huge issue for the UWC.
- Many of these mitigation bundles were developed to focus on N and/or P, so they often do not have a large effect on GHG emissions.
- The figures that do have a larger effect on GHGs include de-stocking, additional trees, or vegetation.
- Implementing some mitigation bundles could actually lead to an increase in GHGs. This is particularly the case for more advanced mitigation for sheep, beef and deer, and arable cropping.

Table A3.5 Cost and effectiveness of mitigation bundles, by land use

		Dairy			**Sheep, beef & deer**			**Arable cropping**		
		M1	**M2**	**M3**	**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
Net revenue	Min	–4%	–9%	–29%	–26%	–38%	–39%	–16%	–43%	–63%
	Mean	0%	–1%	–22%	–9%	–12%	–21%	–11%	–25%	–30%
	Max	3%	5%	–14%	–4%	23%	–3%	–3%	–7%	–8%
N	Min	–60%	–63%	–85%	–33%	–50%	–56%	–55%	–65%	–67%
	Mean	–23%	–38%	–60%	–19%	–25%	–40%	–34%	–37%	–41%
	Max	–1%	–18%	–34%	0%	–5%	–30%	0%	25%	25%
P	Min	–42%	–54%	–76%	–83%	–91%	–91%	–100%	–100%	–100%
	Mean	–14%	–30%	–34%	–35%	–48%	–58%	–56%	–88%	–88%
	Max	25%	0%	0%	0%	0%	0%	0%	–67%	–67%
E.coli	Min	–60%	–60%	–60%	–60%	–60%	–60%	0%	0%	0%
	Mean	–51%	–51%	–51%	–49%	–50%	–50%	0%	0%	0%
	Max	–45%	-45%	–45%	–40%	–40%	–45%	0%	0%	0%
Sediment	Min	–70%	–80%	–80%	–70%	-80%	–75%	0%	0%	0%
	Mean	–58%	–60%	–62%	–43%	–60%	–52%	0%	0%	0%
	Max	–40%	–40%	–40%	0%	–40%	–40%	0%	0%	0%
GHG	Min	–12%	–13%	-20%	–2%	–2%	–11%	–16%	–7%	–12%
	Mean	–8%	-8%	–12%	0%	1%	–4%	–13%	24%	10%
	Max	–2%	–1%	–7%	1%	8%	0%	–10%	75%	49%

References

Agribusiness Group 2014a. Nutrient performance and financial analysis of horticultural systems in the Horizons Region. Report prepared for Horticulture NZ. 32 p.

Agribusiness Group 2014b. Nutrient performance and financial analysis of Lower Waikato horticulture growers. Report prepared for Waikato Regional Council, Ministry of Primary Industries and Horticulture NZ. 32 p.

Allen R, Platt K, Wiser S 1995. Biodiversity in New Zealand plantations. New Zealand Forestry 39: 26–29.

Armstrong-Read A 2016. Te Huarahi hei whakahokia te Māuri o nga Awa. Unpublished report.

Ausseil A-GE, Gerbeaux P, Chadderton WL, Stephens RTT, Brown D, Leathwick JR 2008. Wetland ecosystems of national importance for biodiversity: criteria, methods and candidate list of nationally important inland wetlands. Landcare Research Contract Report: LC0708/158, Wellington. Pp 171.

Borkin KM, Parsons S 2010. The importance of exotic plantation forest for the New Zealand long-tailed bat (Chalinolobus tuberculatus). New Zealand Journal of Zoology 37: 35–51.

Brockerhoff EG, Jactel H, Parrotta JA, Quine CP, Sayer J 2008. Plantation forests and biodiversity: oxymoron or opportunity? Biodiversity and Conservation 17: 925–951.

Carswell FE, Mason NWH, Overton JM, Price R, Burrows LE, Allen RB 2015. Restricting new forests to conservation lands severely constrains carbon and biodiversity gains in New Zealand. Biological Conservation 181: 206–218.

Chan KMA, Guerry AD, Balvanera P, Klain S, Satterfield T, Basurto X, Bostrom A, Chuenpagdee R, Gould R, Halpern BS, Hannahs N, Levine J, Norton B, Ruckelshaus M, Russell R, Tam J, Woodside U 2012. Where are cultural and social in ecosystem services?: a framework for constructive engagement. BioScience 62: 744–756.

Cieraad E, Walker S, Price R, Barringer J 2015. An updated assessment of indigenous remaining and legal protection in New Zealand's land environments. New Zealand Journal of Ecology 39: 309–315.

Clapcott J, Goodwin E, Snelder T 2013. Predictive models of benthic macroinvertebrate metrics (No. 2301). Nelson, New Zealand, Cawthron Institute. 55 p.

Clarkson BR, Ausseil A-GE, Gerbeaux P 2013. Wetland ecosystem services In: Dymond JR ed. Ecosystem services in New Zealand. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 192–202.

Clarkson BR, Bartlam S, Price R 2015. Living Water: opportunities for restoration: Hikurangi floodplain. Landcare Research Contract Report LC2383.

Clout MN, Karl BJ, Gaze PD 1991. Seasonal movements of New Zealand pigeons from a lowland forest reserve. Notornis 38: 37–47.

Daigneault A, Elliott S, Greenhalgh S, Kerr S, Lou E, Murphy L, Timar L, Wadhwa S 2016. Modelling the potential impact of New Zealand's freshwater reforms on land-based greenhouse gas emissions. Report prepared for Ministry for Primary Industries.163 p.

Daigneault A, Greenhalgh S, Samarasinghe O 2017. Economic impacts of multiple agro-environmental policies on New Zealand land use. Environmental and Resource Economics [early online]. DOI: 10.1007/s10640-016-0103-6.

Daigneault A, Greenhalgh S, Samarasinghe O, Jhunjhnuwala K, Walcroft J, de Oca Munguia OM 2012. Sustainable land management and climate change – catchment analysis of climate change: final report. MPI Technical Paper No. 2012/X.

Daigneault A, Samarasinghe O 2015. Whangarei Harbour sediment and E. coli study: catchment economic modelling. Landcare Research Contract Report LC2421 prepared for NZ Ministry for Primary Industries. 97 p.

Daigneault A, Samarasinghe O, Lilburne L 2013. Modelling economic impacts of nutrient allocation policies in Canterbury – Hinds Catchment. Final report. Landcare Research Contract Report LC1490 for Ministry for the Environment.

Daigneault AJ, Eppink FV, Lee WG 2017. A national riparian restoration programme in New Zealand: is it value for money? Journal of Environmental Management 187: 166–177.

de Frahan BH, Buysse J, Polomé P, Fernagut B, Harmignie O, Lauwers L, Van Huylenbroeck G, Van Meensel J 2007. Positive Mathematical Programming for Agricultural and Environmental Policy Analysis: Review and Practice. In: Weintraub A, Romero C, Bjørndal T, Epstein R, Miranda J ed. Handbook Of Operations Research In Natural Resources. Springer US, Boston, MA. Pp. 129–154.

Doole GJ 2015. A flexible framework for environmental policy assessment at the catchment level. Computers and Electronics in Agriculture 114: 221–230.

Dymond JR, Betts HD, Schierlitz CS 2010. An erosion model for evaluating regional land-use scenarios. Environmental Modelling & Software 25: 289–298.

Dymond JR, Herzig A, Basher L, Betts HD, Marden M, Phillips C, Ausseil A-G, Clark M, Roygard J 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. Geomorphology 257: 85−93.

Elith J, Leathwick JR, Hastie T 2008. A working guide to boosted regression trees. Journal of Animal Ecology 77: 802–813.

Elliott AH, Semadeni-Davies AF, Shankar U, Zeldis JR, Wheeler DM, Plew DR, Rys GJ, Harris SR 2016. A national-scale GIS-based system for modelling impacts of land use on water quality. Environmental Modelling & Software 86: 131–144.

Everest M 2014. Hinds catchment nutrient and on-farm economic modelling. Macfarlane Rural Business report for Environment Canterbury. 278 p.

GAMS 2015. GAMS – the solver manuals. Washington DC, GAMS Corporation. http://www.gams.com/dd/docs/solvers/allsolvers.pdf.

Gibbons P, Boak M 2002. The value of paddock trees for regional conservation in an agricultural landscape. Ecological Management & Restoration 3: 205–210.

Gorham E 1991. Northern peatlands: role in the carbon cycle and probable responses to climatic warming. Ecological Applications 1: 182–195.

Harmsworth G, Awatere S 2013. Indigenous Māori knowledge and perspectives of ecosystems. In: Ecosystem services in New Zealand: conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press.

Hein L, van Koppen K, de Groot RS, van Ierland EC 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57: 209–228.

Holden J, Chapman PJ, Labadz JC 2004. Artificial drainage of peatlands: hydrological and hydrochemical process and wetland restoration. Progress in Physical Geography 28: 95–123.

Jurado GB, Johnson J, Feeley H, Harrington R, Kelly-Quinn M 2010. The potential of integrated constructed wetlands (ICWs) to enhance macroinvertebrate diversity in agricultural landscapes. Wetlands 30: 393–404.

Kayranli B, Scholz M, Mustafa A, Hofmann O, Harrington R 2010. Performance evaluation of integrated constructed wetlands treating domestic wastewater. Water, Air and Soil Pollution 210: 435–451.

Lehmann A, Overton JM, Leathwick JR 2002. GRASP: generalized regression analysis and spatial prediction. Ecological Modelling 157: 189–207.

Lilburne L, Webb T, Ford R, Bidwell V 2010. Estimating nitrate-nitrogen leaching under rural land uses in Canterbury. Environment Canterbury Report No. R10/127.

Lincoln University 2013. Financial budget manual 2012/13. Christchurch, Lincoln University Press.

Mace GM, Norris K, Fitter AH 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology & Evolution 27: 19–26.

Manning AD, Fischer J, Lindenmayer DB 2006. Scattered trees are keystone structures: implications for conservation. Biological Conservation 132: 311–321.

Maron M, Cockfield G 2008. Managing trade-offs in landscape restoration and revegetation projects. Ecological Applications 18: 2041–2049.

McDowell RW, Nash D 2012. A Review of the Cost-Effectiveness and Suitability of Mitigation Strategies to Prevent Phosphorus Loss from Dairy Farms in New Zealand and Australia. Journal of Environmental Quality 41: 680–693.

McDowell RW, Snelder TH, Cox N, Booker DJ, Wilcock RJ 2013. Establishment of reference or baseline conditions of chemical indicators in New Zealand streams and rivers relative to present conditions. Marine Freshwater Research 64: 387–400.

McDowell RW, Cosgrove GP, Orchiston T, Chrystal J 2014. A Cost-Effective Management Practice to Decrease Phosphorus Loss from Dairy Farms. Journal of Environmental Quality 43: 2044–2052.

Millennium Ecosystem Assessment 2005. Ecosystems and human well-being: biodiversity synthesis. Washington, DC, World Resources Institute.

Millennium Ecosystem Assessment (MEA) 2003. Ecosystems and human well-being: a framework for assessment. Washington, DC, Island Press.

Millennium Ecosystem Assessment (MEA) 2005. Ecosystems and human well-being: synthesis. Washington, DC, Island Press.

Ministry for the Environment (MfE) 2014a. National Policy Statement – Freshwater Management. http://www.mfe.govt.nz/fresh-water/freshwater-management-nps

Ministry for the Environment (MfE) 2014b. New Zealand's Greenhouse Gas Inventory 1990–2011. http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2014-snapshot/index.html

Ministry for the Environment (MfE) 2014c. Environmental indicator for freshwater: River Condition. Archived data and report. http://ndhadeliver.natlib.govt.nz/ArcAggregator//arcView/resource/IE26112861//http://www.mfe.govt.nz/more/environmental-reporting/fresh-water/river-condition-indicator. Accessed 30 June 2017.

Ministry for Primary Industries (MPI) 2013a. Farm monitoring report. Wellington, New Zealand, MPI Publication. http://www.mpi.govt.nz/news-resources/publications?title=Farm%20Monitoring%20Report

Ministry for Primary Industries (MPI) 2013b. Situation and outlook for primary industries. Policy publication. Wellington, New Zealand, Ministry for Primary Industries.

Mitsch WJ, Gosselink JG 2000. The value of wetlands: importance of scale and landscape setting. Ecological Economics 35: 25–33.

Monaghan R, McDowell R, Muirhead R 2016. Generalised estimation of mitigation performance and costs. AgResearch Brief for Ministry for the Environment to support the 'Modelling national land use capacity' project. 5 p.

Norton BDA, Miller CJ 2000. Some issues and options for the conservation of native biodiversity in rural New Zealand. Ecological Management & Restoration 1: 26–34.

Ogden J, Braggins J, Stretton K, Anderson S 1997. Plant species richness under Pinus radiata stands on the central North Island Volcanic Plateau, New Zealand. New Zealand Journal of Ecology 21: 17–29.

Parfitt RL, Percival HJ, Dahlgren RA, Hill LF 1997. Soil and solution chemistry under pasture and radiata pine in New Zealand. Plant and Soil 191(2): 279–290.

Parsons O, Doole G, Romera A 2015. Economic effects of diverse allocation mechanisms in the Lake Rotorua catchment. Unpublished report.

Patterson MG, Cole AO 2013. 'Total economic value' of New Zealand's land-based ecosystems and their services. In: Dymond JR ed. Ecosystem services in New Zealand: conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 496–510.

Potschin MB, Primmer E, Furman E, Haines-Young RH 2016. Have ecosystem services been oversold?: a response to Silvertown. Trends in Ecology & Evolution 31: 334–335.

Scholz M, Harrington R, Carroll P, Mustafa A 2007. The integrated constructed wetlands (ICW) concept. Wetlands 27: 337–354.

Schröter M, van Oudenhoven APE 2016. Ecosystem services go beyond money and markets: reply to Silvertown. Trends in Ecology & Evolution 31: 333–334.

Seaton R, Holland JD, Minot EO, Springett BP 2009. Breeding success of New Zealand falcons (Falco novaeseelandiae) in a pine plantation. New Zealand Journal of Ecology 33: 32–39.

Semadeni-Davies A, Elliott S, Shankar U 2011. The CLUES Project: tutorial manual for CLUES 3.0 prepared for Ministry of Agriculture and Forestry. NIWA Client Report HAM2011-003.

Silvertown J 2015. Have ecosystem services been oversold? Trends in Ecology & Evolution 30: 641–648.

Vibart R, Vogeler I, Dennis S, Kaye-Blake W, Monaghan R, Burggraaf V, Beautrais J, Mackay A 2015. A regional assessment of the cost and effectiveness of mitigation measures for reducing nutrient losses to water and greenhouse gas emissions to air from pastoral farms. Journal of Environmental Management 156: 276–289.

Watts CH, Mason NWH 2015. If we build – they mostly come: partial functional recovery but persistent compositional differences in wetland beetle community restoration. Restoration Ecology 23: 555–565.

Zedler JB, Kercher S 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources 30: 39–74.