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Land use modelling report: Wairoa catchment in Northland / Te Tai Tokerau

21 August 2023

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1	Draft for client comment
2	Update based on client comments
3	Added Appendix 12 of additional model scenario run
4	Additional appendices added - final

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Glossary

Agricultural emissions levy

In June 2022, the He Waka Eke Noa partnership recommended to Government that a farm-level, split-gas levy be used to price emissions from 2025 instead of the ETS. The emissions levy refers to the price farm businesses will have to pay per kilogram of methane, nitrous oxide and carbon dioxide gas emitted from their farm systems. A pricing pathway has been provided in the Appendices.

Agricultural utilisation

Within the Nature Braid model, a measure of how the land is being used for agriculture, relative to its capacity to support agriculture based on soil and topography characteristics.

Agricultural utilisation – optimal / not optimal

If land is predicted by the model to be highly suitable for agriculture, and is also being used for agriculture, then the Nature Braid model will consider this optimal. However, if land is predicted to be marginal or less suitable for agriculture, and it is currently being used for agriculture, then the model will consider this not optimal.

Agricultural utilisation status

This output combines the current and predicted optimal output but in a different way to the relative agricultural utilisation output category. Rather than being concerned with direction of change (under or over utilisation), it considers whether the current agricultural utilisation may be worthy of preservation or change. For more information, see Appendix A.2.

Average flow class

This output is a classified version of average water flow, in cumecs (m^3/s). Flow delivery to all points in the river and lake networks are classified into five categories: <1 m^3/s, 0.1-1 m^3/s, 1-10 m^3/s, 10-100 m^3/s, >100 m^3/s.

Baseline 2025

The ‘current’ year of 2025, to which the five modelled policy scenarios are compared. We assume that land use remains similar to current/recent conditions until 2025, when levies are introduced, providing a 2025 environmental baseline for all scenarios.

C-factor

The ratio of soil loss expected from a landscape under a particular land use/cover (e.g., cropping, forest, etc) to what is expected from land under clean-tilled continuous fallow. The C-factor is unitless, ranging from 0 for land cover with no soil (e.g., water bodies, bare rock) to 1.0 for bare soil. This is used within the RUSLE model.

Carbon dioxide equivalent (CO_2-eq) emission

This is defined by the IPCC (2022) as “The amount of carbon dioxide (CO2) emission that would have an equivalent effect on a specified key measure of climate change, over a specified time horizon, as an emitted amount of another greenhouse gas (GHG) or a mixture of other GHGs. For a mix of GHGs, it is obtained by summing the CO2-equivalent emissions of each gas. There are various ways and time horizons to compute such equivalent emissions (see greenhouse gas emission metric). CO2-equivalent emissions are commonly used to compare emissions of different GHGs but should not be taken to imply that these emissions have an equivalent effect across all key measures of climate change”. For further information see https://www.ipcc.ch/

Clear-fell harvesting / clear-felling

A forestry practice which involves the cutting down/harvesting of an entire stand of trees within a commercial forest.

Classified Nitrogen accumulated load

This output combines the predictions of accumulated total N load with user specified thresholds, to categorise the nutrient loading into very low to very high categories.

Classified Nitrogen in-stream concentration

This output combines the predictions of N stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.

Classified Phosphorus accumulated load

This output combines the predictions of accumulated total P load with user specified thresholds, to categorise the nutrient loading into very low to very high categories.

Classified Phosphorus in-stream concentration

This output combines the predictions of P stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.

Current agricultural utilisation

This output shows utilisation according to current land cover/use, ignoring predicted production capacity. Uncertainty is reliant on the accuracy of land cover/land use data. Arable and improved grassland are considered to be highly productive, for example, while bare ground, or built infrastructure such as railways and roads, are considered to provide no agricultural utilisation

Discount rate

The percentage rate at which the present value of money is considered to decrease over time. For the purpose of this study a 5% discount rate has been assumed. However, this is further explored in a sensitivity analysis.

Economic Farm Surplus (EFS)

A measure of farm profitability considering revenue less farm expenses (including wages), but excluding any tax or investment costs (rent, lease, interest or return on capital).

Flood interception classification

This output shows the flood mitigation layer, which is influenced by soil, land use, topography, and climate. It identifies high-priority areas where land is not mitigated by any vegetation and where flow is either being generated or accumulated. Potential sources of error include inaccuracies in land use input data or Nature Braid classification of land cover as mitigating or not-mitigating. Failure to account for storage capacity of deep soils in non-wetland areas, or faster runoff in urban areas with paved surface may reduce accuracy of mapping of areas of high and low flood concentration.

Flood mitigation classification

This output shows the mitigation classification of the current soil/land use and areas. Potential sources of error include inaccuracies in land use input data or Nature Braid classification of land cover as mitigating or not-mitigating, as well as failure to account for soil permeability.

Habitat connectivity

This output highlights areas of ideal habitat based on land use/cover and user-defined thresholds of minimum habitat size. It uses information about species ability to travel through hostile terrain to highlight how far it can travel from patches of ideal habitat.

He Waka Eke Noa (HWEN)

He Waka Eke Noa – the Primary Sector Climate Action Partnership was formed in 2019 to design a practical, credible, and effective system for reducing emissions at farm level, as an alternative to government policy to bring agriculture into the New Zealand Emissions Trading Scheme (NZ ETS). Refer to https://hewakaekenoa.nz/ for more information.

High levy pathway

The high emissions pricing pathway starts in 2025 at $1.06 per kg CH_4 and $42.50 per tCO_2-eq from N_2O/CO_2. The levy rate starts with a 50% discount in 2025, which reduces by 7.1 percent per year (pp yr-1).

Low levy pathway

The low emissions levy pathway starts in 2025 at $0.11 per kg CH_4 and $4.25 per tCO_2-eq from N_2O/CO_2. The levy rate starts with a 95% discount in 2025, which reduces by 1 percent per year (pp yr-1).

Medium levy pathway

The medium levy was calculated using the low levy + 40% of the difference between the low levy and the high levy. This pathway starts in 2025 at $ 0.49 per kg CH_4 and $19.60 per tCO_2-eq from N_2O/CO_2

N fertiliser cap

A maximum limit on the amount of synthetic nitrogen (N) fertiliser that may be applied. For both the Wairoa and Mataura catchments the limits of 85 kg N/ha/yr have been applied for 2030, and 65 kg N/ha/yr for 2060.

N high-risk

Areas classified as “high” within the Nitrate-Nitrite-Nitrogen (NNN) output of Land and Water Science

Nitrogen accumulated load

This output shows the accumulated total N load (in kg/yr), considering the load not just at a point (depending on modified export coefficients which are influenced by rainfall, irrigation, fertiliser, effluent, and stock), but also that contributed from “uphill” sources. N accumulated load is estimated based on terrestrial nutrient loads combined with topographic routing and effective precipitation to route water through the landscape. High values are prime targets for mitigation or interception opportunities. Accuracy reflects that of the input data on land use and the relevant Nature Braid export coefficient, as well as the DEM and topographic routing approach used to model accumulation. The output can be used to extract total N accumulated load (kg/yr) at any point.

NZ ETS

The New Zealand Emissions Trading Scheme (NZ ETS), a key tool for meeting our domestic and international climate change targets, including the 2050 target set by the Climate Change Response Act 2002. Refer to https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/ets/ for more information.

Phosphorus accumulated load

This output shows the accumulated total P load (in g/yr), considering the load not just at a point (depending on modified export coefficients which are influenced by rainfall, irrigation, fertiliser, effluent, and stock), but also that contributed from “uphill” sources. P accumulated load is estimated based on terrestrial nutrient loads combined with topographic routing and effective precipitation to route water through the landscape. High values are prime targets for mitigation or interception opportunities. Accuracy reflects that of the input data on land use and the relevant Nature Braid export coefficient, as well as the DEM and topographic routing approach used to model accumulation.

Predicted optimal agricultural utilisation

This output ignores the input land cover and instead predicts a near-optimal utilisation based on soil water holding characteristics, fertility, elevation, slope, aspect. For more information, see Appendix A.2.

Productive land

Land identified by Nature Braid with “high or very high” productive capacity based on slope, fertility, aspect, and drainage.

Relative agricultural utilisation

This output is calculated from a comparison of predicted optimal agricultural utilisation and current agricultural utilisation outputs. It flags where land appears to be over or under-utilised. For more information, see Appendix A.2.

Riparian planting

Indigenous (New Zealand native) vegetation planted by streams and other waterways.

Risk of sediment delivery

This output shows sediment delivery vulnerability depending on whether the soil loss (using ‘Soil loss risk’) is occurring on non-mitigated land.

RUSLE

Revised Universal Soil Loss Equation

Sediment high-risk

Areas susceptible to erosion and sediment delivery based on either LWS (high Sediment and Pathogen Susceptibility) or NB (high sediment delivery)

Sequestration payment

In this report, “sequestration payment” refers to the financial payment for carbon sequestered from planting forestry, within the NZETS,

Soil loss risk

This output shows the risk of soil loss based on Terrestrial soil erosion and user-defined thresholds.

Stocking rate

An indicator of farm intensity measured in stock units per hectare (SU/ha). A stock unit in FARMAX is calculated by dividing the total intake in standard DM (10.8 MJME/kgDM) eaten by 550kgDM. This is the approximate annual feed requirement of a 55kg breeding ewe rearing a single lamb.

Terrestrial N loads

This output shows the total N load (kg/ha/yr) generated at any point within the landscape, considering the load at a point, depending on modified export coefficients which are influenced by rainfall, irrigation, fertiliser, effluent, and stock. Proportion of dissolved vs. particulate N needs to be defined by the user. The default value is 0.8. Nitrate and ammonium are treated separately as nitrate is more soluble while ammonium somewhat sorbed.

Terrestrial P loads

This output shows the total P load (g/ha/yr) generated at any point within the landscape, depending on modified export coefficients (which is influenced by rainfall, irrigation, fertiliser, effluent) together with Olsen P and topography. Proportion of dissolved vs particulate P needs to be defined. The default value is 0.3. Particulate and dissolved species are considered separately.

Terrestrial soil erosion by water

This output shows the annual soil loss by water using the RUSLE (Revised Universal Soil Loss Equation) which considers rainfall, soil, land use/cover, management, and topography. The rainfall factor uses the New Zealand constants formulated by Klik et al. (2015) and the user is referred to that article to find the constants for their study area.

Total Nitrogen in-stream concentration

This output shows total N concentration (in mg/L) at all points in-stream. High values suggest that the catchment of this point should be targeted for mitigation/interception opportunities. N in-stream concentration is influenced by N accumulated load and stream attenuation. This is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial nutrient concentration.

Total Phosphorus in-stream concentration

This output shows total P concentration (in mg/L) at all points in-stream. High values suggest catchment of this point should be targeted for mitigation/interception opportunities. P in-stream concentration is influenced by P accumulated load (below) and stream attenuation. This is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial nutrient concentration.

Untargeted revenue recycling

Recycling of agricultural emissions levy funds for the implementation of land management practices and farm system changes that improve freshwater quality, protect/enhance biodiversity and reduce emissions, using broad policy approaches that do not take into account the specific features of the catchment.

LAND USE TYPES

Agroforestry

A simple agroforestry system was created for Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing in the Wairoa catchments. The system assumes kawa poplar as the tree species at a final stocking rate of 280 trees per hectare, harvested at years 30 or 60 for timber, with livestock grazing underneath the forest canopy. The systems are built by adapting the baseline FARMAX models with the key assumptions of 50% stocking rate, 50% fertiliser incomes, 50% of the GHG levy and 50% of variable cost and income but full fixed costs.

Dairy

A modelled land use type within this study (using FARMAX and Nature Braid). This is modelled in FARMAX as a dairy cow system with peak 440 Kiwi cross cows milked on 165 ha with replacements grazed off-farm, 5% of the milking platform grows a summer crop, and 15% is conserved for pasture silage in spring. The farm produces 829 kgMS/ha with an EFS of $1857/ha.

Exotic Forestry

A modelled land use type within this study (using simple economics and Nature Braid). Productive forestry based on non-native tree species. The example used within this study is pine (*Pinus radiata*).

Hill Country Sheep and Beef

A modelled land use type within this study (using FARMAX and Nature Braid). This is modelled in FARMAX as 360 effective hectares running 9.3 stock units per hectare, sheep to beef ratio is 22:78. 400 mixed age ewes and 50 mixed age cows are wintered, finishing 89% of lambs. 80% of cattle sold are prime. 198.6 kg meat + wool/ha. EFS is $286/ha.

Indigenous Vegetation

A modelled land use type within this study (using simple economics and Nature Braid). Existing or new non-productive plantings of New Zealand native species, that is not predominantly trees but may include some trees.

Lowland Beef Finishing

A modelled land use type within this study (using FARMAX and Nature Braid). This is modelled in FARMAX as 235 effective hectares running 12.1 stock units per hectare at a sheep to beef ratio of 0:100. 85% of all beef sales are prime. EFS = $644/ha.

Mixed Cropping

A modelled land use type within this study (using FARMAX and Nature Braid). The example that has been modelled in FARMAX within this study is kumara cropping and lamb finishing as this is a common mixed cropping system within the Wairoa catchment. The Nature Braid model for Mixed Cropping represents general arable land and does not assume any specific crops.

Orchard (Avocado)

A modelled land use type within this study (using simple economics and Nature Braid). A commercial avocado orchard system.

Orchard (Macadamia)

A modelled land use type within this study (using simple economics and Nature Braid). A commercial macadamia nut orchard system.

Totara Forestry

A modelled land use type within this study Productive forestry with (*Podocarpus totara*). A specific example of indigenous forestry that has been used within this study.

Wetland

Areas on top of very poorly drained soils that become covered by shallow standing water, whether seasonally/ephemerally, and are able to support flora and fauna suitable for wet conditions or in the liminal spaces between terrestrial and aquatic ecosystems (Ausseil et al., 2008)

Disclaimers and Limitations

This report (‘**Report**’) has been prepared by WSP exclusively for the Parliamentary Commissioner for the Environment (PCE) (‘**Client**’) in relation to modelling potential land use change under different future policy scenarios (‘**Purpose**’) and in accordance with the contract titled ‘Consultancy Contract to Perform an Assignment for the Parliamentary Commissioner for the Environment’ with the Client dated 26th January 2022 (‘**Contract’**). The findings in this Report are based on and are subject to the assumptions specified in the Report and the Contract. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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Acknowledgements

It is important to acknowledge that this modelling exercise has taken place within the broader context of the overall Landscapes project, including wide-ranging conversations by the PCE with stakeholders around New Zealand, as well as other contracted work. This includes work by Land and Water Science (LWS) on physiographic layers; as well a study to explore Māori perspectives for the catchment. For the Wairoa, this work is being led by Nicki Wakefield, who also organised the workshops.

For the specific purpose of this modelling exercise, a range of expert discussions and stakeholder engagement activities were undertaken to ensure relevance, as well as informing stakeholders of progress with the project. A series of workshops were carried out, both online and in person, to share knowledge of the catchment, provide input, critique the modelled scenarios, provide lessons and promote discussion on the difference between an untargeted and a landscape approach. These workshops were invaluable and much gratitude is due to the participants who invested their time and knowledge in supporting this thought exercise.

While it is impossible to list here everyone who has contributed to this project to date, throughout the text we have indicated where specific advice was provided. It should also be emphasised that the kind provision of advice in no way indicates responsibility of the provider for the way in which that advice was incorporated into the modelling. In this, as in any modelling exercise, all models are wrong. However, we are extremely grateful to all those who helped us make this particular exercise more relevant and useful.

Executive Summary

The Parliamentary Commissioner for the Environment (PCE) is investigating what an integrated landscape approach looks like in Aotearoa New Zealand and its potential to improve freshwater quality, climate change and biodiversity outcomes. Scenarios are being explored in the Mataura catchment (Southland/Murihiku) and the Wairoa catchment (Northland/Te Tai Tokerau).

This report provides an overview of the modelling approach and results of the five modelled scenarios in the Wairoa catchment, intended to explore the research question:

Could an integrated landscape approach enable rural communities and tangata whenua to achieve better climate, water, soil and biodiversity outcomes than an untargeted approach?

By assessing potential land use change under different future policy scenarios, this project aims to shed light on how some of the major policy levers under consideration might impact on land use, and hence people and their environment.

As with any future modelling scenarios, there are significant limitations on the accuracy with which both the current and future landscape can be modelled. There are a wide range of variables and uncertainties beyond the scope of this work. Multiple assumptions, simplifications and subjective choices were required in order to bring together the different disciplines, scales, and models used for this work. In all such choices, the aim has been not to propose, recommend or predict the impacts of a specific future policy, but rather to highlight the trade-offs between different policy approaches as a thought exercise. The intent is to stimulate useful, science-based, and policy-focussed conversations about some of the future pathways under consideration.

Approach

To help answer the research question, five scenarios have been developed and assessed at three timesteps; 2025 (referred to as the ‘baseline’), 2030 and 2060. These were explored using an ensemble of models: the Nature Braid to explore spatial environmental impacts; Farmax to represent pastoral farming systems; and a broader economic analysis including a simple representation of other land use types, to explore land use change.

For each scenario, either a high or low agricultural emissions levy rate is represented. For scenarios 1A and 2A, using a low levy rate, the levy is considered to be used for national level research on reducing greenhouse gas emission, and is not directly recycled back into the catchment. For the other scenarios (1B, 2B and 2C), a Medium levy rate is used, as the high levy rate was considered to create too extreme an impact on land use change. As with the Mataura, funds are still recycled back to national level research. However, this amount varies by scenario as a significant fund is first made available for recycling back into the catchment in either an untargeted (1B) or targeted (2B and 2C) manner.

The methodology for scenario 1A is identical to the Mataura modelling, with a low levy rate and modelling the current suite of untargeted freshwater regulations. Scenario 1B models a Medium levy rate, with funds ‘recycled’ back into the catchment to support Riparian Planting. Scenario 2A differs from the Mataura; for Wairoa the model considers both nitrogen (N) and soil loss risk (instead of P-risk). Scenarios 2B and 2C explore a Medium levy, with targeted revenue recycling; and a Medium levy where forestry phased out from New Zealand Emissions Trading Scheme (NZ ETS); and an additional multipurpose fund is instead available, for environmentally beneficial activities.

As part of this process, engagement with stakeholders in the Wairoa catchment was undertaken, including a series of workshops as well as engagement with local landowners and industry professionals. The purpose of these workshops is to connect with local knowledge and expertise, share information on the project and obtain feedback on scenario development and mitigation approaches.

To explore these scenarios, four representative farm 'types' were set up in the model FARMAX based on the main pastoral land use types in the Wairoa catchment: Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping. Two further existing land uses, Exotic Forestry and Orchard (Avocado) were represented using a simple economic model. In addition, three example "future" land uses were represented using a simple economic model: Orchard (Macadamia); Agroforestry; and Totara Forestry. These modelled farms were drawn into a broader economic analysis to explore land use changes under the different scenarios.

Currently, Exotic Forestry is significantly more profitable than indigenous alternatives so it has been assumed that, without intervention, only pine would be planted. The broader economic analysis also included a cost for interventions (such as the cost per hectare for riparian planting or conversion to wetlands). The Nature Braid team have used the GIS information available to provide land areas available for, or affected by, each intervention. The economic assessment has provided non-spatial land use change tables, related to the "potential productivity" of the land based on categories identified in the Nature Braid model and existing land use. This information was then mapped onto the landscape and fed into the Nature Braid model to provide spatially explicit assessments of the environmental impacts of the different scenarios.

Results

Scenario 1A provides a "business as usual" scenario under the lower emissions levy. In this scenario, the most significant land use change is the loss of Hill Country Sheep and Beef farm area and a gain in Exotic Forestry by 2060. The emissions levy reduces, but does not eliminate profitability, until 2060 for any Hill Country Sheep and Beef that has moderate productive capacity. Marginal productive land in Dairy, Lowland Beef Finishing and Hill country Sheep and Beef is also unprofitable by 2060. For the purpose of this model, we have assumed the unprofitable land transitions to Exotic Forestry. The profitability of Exotic Forestry increases over time due to ETS payments. By 2060, Lowland Beef Finishing is barely profitable as a consequence of the emissions levy and Dairy profitability has decreased by 63% of the baseline year.

The large land transitions to Exotic Forestry by 2060 resulted in in-stream N concentration reducing by over half, to 0.3 mg/L and mean terrestrial N loading decreased by 38%. Mean terrestrial P loading also reduced by nearly half by 2060 over the catchment. Flow mitigation increased due to the increase in forested area, however clear fell harvesting increases vulnerability to erosion. Mean terrestrial soil loss in the catchment nearly doubles between the baseline and 2060. Forest establishment by 2060 improved biodiversity corridors shown as connectivity for Kererū.

Greenhouse gas (GHG) emissions for the Wairoa catchment are net negative in 2025, indicating sequestration from vegetation within the catchment exceeds emissions from farming land-uses. The increase of Exotic Forestry by 2060 is a key driver for whole catchment net emissions decreasing from 2025 levels of -350,303 tCO_2-eq, by 1286% to -4,854,811 tCO_2-eq.

Scenario 1B, for scenarios 1B, 2B and 2C it was necessary to adjust the original "high levy" rate used in the Mataura catchment down to a medium levy rate, in order to provide outcomes that would stimulate more nuanced discussions around land use change, rather than simply highlighting the impact of the levy by driving most pastoral farms out of business and leaving almost no levy to collect for recycling back into the catchment.

In scenario 1B, all Hill Country Sheep and Beef and Lowland Beef finishing and moderate, marginal, and negligible productivity classes of Dairy become unprofitable by 2060 and are transitioned to Exotic Forestry. The most significant change in land area is the increase in Exotic forestry by 171,502 ha or 311% from baseline. Very high and high productive capacity Dairy land remains profitable in 2060, which makes up the majority of Dairy area in the catchment. Although GHG emissions in 1B are net negative in 2025, the increase in Exotic Forestry by 2060 results in whole catchment net emissions decreasing by 1618% from the baseline to -6,020,866 tCO_2-eq.

The extensive transitions to Exotic Forestry by 2060 resulted in in-stream N concentration reducing by over half, to 0.3 mg/L and mean terrestrial N loading also decreasing by 46%. Mean terrestrial P loading also reduced by nearly half by 2060 over the catchment, with the mean in-stream P concentration dropping to 0.003mg/L compared to the 2025 estimate of 0.016mg/L.

The clear fell harvesting of Exotic Forestry increases vulnerability to erosion. Mean terrestrial soil loss in the catchment nearly doubles between the baseline and 2060. However, Exotic Forestry establishment by 2060 increased habitat for kererū, and improved habitat connectivity across the catchment.

Flow mitigation increased markedly between 2025 and 2030 due to the increase in forested area and Riparian Planting which directly changed ~21700ha of the catchment. This planting also mitigated/benefitted an additional ~91800ha of the catchment by slowing rapid water flow generated uphill of the planting and catching sediment and nutrients enroute to the streams.

In *Scenario 2A* under the low emissions levy, two levels of nutrient limits are applied to the identified high-risk areas for synthetic N fertiliser: For 2030 and 2060, the application limit is set at the same rate as the Mataura catchment: 85kg N/ha/yr and 65kg N/ha/yr, respectively. High risk areas for sediment loss have also been identified. A “100 stems per hectare” planting rule was established for high-risk sediment areas, resulting in the transition to Agroforestry systems.

As the levy rate increases over time, the profitability of agricultural uses decreases throughout the catchment. In the N risk areas, the effect is more pronounced due to changes in farm management to meet N caps. By 2060, all Hill Country Sheep and Beef becomes unprofitable and land transitions to the Agroforestry-Hill or Exotic Forestry. However, this is driven by the emissions levy rather than the N cap. Only high or very high productive capacity for Lowland Beef Finishing remains marginally profitable in 2060, and the unprofitable land transitions to the Agroforestry-Lowland system or to Exotic Forestry. Mixed Cropping remains under the N cap and remains profitable for all time steps. All Dairy remains marginally profitable by 2060, and the profitability for Dairy in N risk areas by 2060 has reduced by 80%. The largest land use change by area is the increase in Exotic forestry, however 7.9% of the whole catchment is in an Agroforestry system by 2060.

The shifts to Agroforestry farm systems presented positive outcomes to agricultural utilisation, nutrients, soil losses, and flow mitigation. However, their parameterisation within the Nature Braid model was very conservative and may be improved by further research and more specific parameterisation to better reflect the potential environmental outcomes from Agroforestry systems. For example, while the agroforestry system was not considered favourable for kererū in the model setup, at the Wairoa workshop it was noted that since kererū have had to adapt to exotic tree species due to habitat loss, they may also receive benefits from trees such as poplar.

GHG emissions in 2A are net negative in 2025, and the increase in Exotic Forestry and Agroforestry systems by 2060 results in whole catchment net emissions decreasing by 859% from the baseline to –3,360,828 tCO_2-eq.

Changes to stocking rates under the agroforestry systems, a reduction in N fertiliser input and an increase in Exotic Forestry area by 2060 resulted in in-stream N concentration reducing by over half, to 0.3 mg/L and mean terrestrial N loading also decreasing by 39%. Mean terrestrial P loading also reduced by 41% by 2060 catchment wide. The N fertiliser limits had a minor effect on mean N terrestrial loadings from each farm system, the largest difference observed was a 0.7 kg/ha/yr reduction in both the Dairy and Orchard (Avocado) systems.

Mean terrestrial soil loss in the catchment nearly doubles between the baseline and 2060 due to the consequences of clear fell harvesting, exposing vulnerable soils which may also interact with steep topography and rainfall that contributes to further erosion by water. Forest establishment by 2060 improved habitat connectivity for kererū by increasing biodiversity corridors across the catchment.

In *Scenario 2B*, a targeted “landscape” approach guides application of the funds generated by the medium emissions levy. The fund is applied to:

- Support national-level research
- Financial support as a progressive, no interest loan to assist farmer transition from eligible Dairy to Orchard (Macadamias).
- Wetland restoration of the Otonga land pocket
- Riparian Planting on farm and associated maintenance costs

The new land use, Macadamia orchards, was selected on the basis of its profitability as well as lower environmental impact and water use. There is a high transition cost to Macadamias but, once established, these are highly profitable. The loan scheme was intended to enable farmers to easily transition. There is a 5% interest rate on these loans, providing an extra return to the overall fund. This land use does already exist currently in the area, although concerns were raised during the second in-person workshop on its viability in the catchment. These issues would require further exploration – as discussed in the Mataura catchment report, buy in from landowners in the catchment and the creation of critical mass for any new or growing industry would be an essential element in its success.

In this scenario, all negligible and marginal productive capacity land for Dairy, Lowland Beef Finishing and Hill country Sheep and Beef land becomes unprofitable and transitions to Exotic Forestry by 2060. Moderate and high productive capacity Lowland Beef Finishing and Hill Country Sheep and Beef transition to the corresponding Agroforestry systems by 2060. All Dairy land that is feasible to transition to Orchard (Macadamias), does so by 2060. Restoration of the Otonga pocket of the Hikurangi Rep means wetland area increases by 126% from baseline by 2060, to 2250 ha.

The increase in area of Exotic Forestry, Agroforestry and Orchard by 2060 is a key driver of the results in whole catchment net emissions decreasing by 922% from the baseline to -3,581,132 tCO_2-eq. In-stream N concentration reduces by over half, to 0.3 mg/L and mean terrestrial N loading also decreasing by 53% by 2060. Mean terrestrial P loading also reduced by just over half by 2060 over the catchment. Flow mitigation increased markedly between 2025 and 2030 due to the increase in forested area and Riparian Planting which directly changed ~20900 ha of the catchment. This planting also mitigated/benefitted an additional ~92500 ha of the catchment, showing its capability to intercept flows of water, mass, sediments, nutrients, etc. coming from uphill sources.

In *Scenario 2C*, the funds generated by the medium emissions levy are recycled into the catchment and spent on targeted landscape mitigations as in 1B with the addition of the remaining 7 pockets of the Hikurangi Repo being retired from productive use and restored into wetlands.

In 2C the application of the ETS also changes, with any new forest not eligible to receive carbon credit payment through the ETS from 2030. Instead, a multi-benefit fund is established to facilitate targeted forest planting and other environmentally beneficial activities. This includes a subsidy to encourage a sustainable Totara Forestry system over transition to Exotic Forestry.

In this scenario, targeted mitigations and land use change occur as they do in Scenario 2B (funded by the levy) except that all land conversion to pine forestry is instead converted to totara forestry with the multi-benefit fund subsidy covering the difference between totara and pine, and the additional fund is used for wetland restoration of the entire Hikurangi Repo, increasing wetland area 8,145 ha.

Marginal productive capacity land in Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing becomes unprofitable and transition to Totara Forestry by 2060, totaling 70,883 ha. Hill Country Sheep and Beef and Lowland Beef Finishing land with moderate productive capacity or above, also become unprofitable by 2060 but transition to the respective Agroforestry systems as in 2B, no Hill Country Sheep and Beef or Lowland Beef Finishing remains in 2060. The increase in area of Exotic Forestry, Agroforestry and Orchard (Macadamia) area by 2060 is a key driver in whole catchment net emissions decreasing by 500% from the baseline to –2,101,853 tCO_2-eq.

In-stream N concentration reducing by over half, to 0.3 mg/L and mean terrestrial N loading also decreasing by 54% by 2060. Mean terrestrial P loading also reduced by more than half by 2060. Terrestrial Soil loss in the catchment increases between 2025 and 2030, but there is an overall decrease by 15%. The mitigations in 2C also provide significant benefits for flood mitigation and kererū habitat connectivity.

Similar to 1B and 2B, the interventions in 2C led to an increase in mitigating features by ~189km^2 from the baseline. This provided mitigation benefits to or was able to intercept flows from uphill sources from, ~93100 ha of the catchment. These added features were able to provide mitigation benefits to areas almost five times larger than their own extent. The ideal habitat for kererū increased by ~76000 ha, increasing connectivity across the catchment.

Scenario 2C had the most ideal environmental outcomes in 2060 for habitat due to the addition of totara, and high benefits to flow mitigation due to Riparian Planting, totara, and restoration of the Hikurangi repo. While all other scenarios had higher potential soil losses in 2060 due to conversions to pine plantation, 2C 2060 had the inverse.

In order to better understand the outcomes on specific species of N and P, relating to thresholds for ecological protection, health, and national bottom lines, the nutrient tools (see Appendix A.2) were used to compare the outcomes of 2C 2060 to the baseline: When compared to the national bottom lines for NO_3-N (Ministry for the Environment, 2020), the changes in 2C 2060 increased the percentage of stream reaches within the Wairoa catchment to a mean below 2.4 mg NO_3-N/L. The percentage of reaches within Band A ($\leq$1.0 mg NO3-N/L) increased to 96% in Scenario 2C 2060 compared to 15% in the baseline. For ammonia (NH4-N), percentage of reaches within Band A ($\leq$ 0.03 mg NH_4-N/L annual median) and Band B (>0.03 and $\leq$ 0.24 mg NH_4-N/L) increased to 84% in Scenario 2C 2060 compared to 83% in the baseline. It should be noted that the bands are set using medians from monthly sampling while the Nature Braid model uses daily hydrology and mean annual estimates of N and P load. However, the changes are still indicative of movement between the bands.

Although Scenario 2C had generally good environmental outcomes, there were questions raised during the results workshop regarding the interventions in this scenario and how they might be implemented. The complete restoration of the Hikurangi repo, for example, would mean the loss of productive land that has been farmed over multiple generations.

Following consultation in the Wairoa, an additional scenario was requested by the PCE after the completion of the first five scenarios, to explore the impact of converting marginal land to indigenous vegetation. This scenario, based on the original 1A scenario, is not discussed in the main report but has been included as a separate summary in Appendix A-12.

1 Introduction

The Parliamentary Commissioner for the Environment (PCE) is investigating what an integrated landscape approach looks like in Aotearoa New Zealand and its potential to improve freshwater quality, climate change and biodiversity outcomes. For this purpose, the PCE has engaged WSP, in partnership with Nature Braid, to conduct a modelling exercise in two case study catchments: the Mataura catchment in Southland/Murihiku and the Wairoa catchment in Northland/Te Tai Tokerau. This report focuses on the Wairoa catchment.

The primary research question guiding this thought experiment is:

Could an integrated landscape approach enable rural communities and tangata whenua to achieve better climate, water, soil, and biodiversity outcomes than an untargeted approach?

To help answer the research question, five scenarios have been developed and assessed at three timesteps; 2025 (referred to as the 'baseline'), 2030 and 2060. The methodology for scenario 1A is identical to the Mataura modelling. Scenario 2A differs from the Mataura; for Wairoa the model considers both nitrogen (N) and soil loss risk. Scenario's 1B, 2B and 2C follow the same rules as the Mataura modelling except a medium levy is used instead of a high levy. This is described in Section 2.1 and Appendix A.1.

- **Scenario 1A:** Low levy, untargeted freshwater regulations.
- **Scenario 1B:** Medium levy, funds 'recycled' back into the catchment though untargeted policies (support for Riparian Planting).
- **Scenario 2A:** Low levy, targeted limits on synthetic nitrogen fertilisers for high N-risk areas, and a requirement for targeted afforestation (minimum number of stems/ha) for high soil loss risk areas.
- **Scenario 2B:** Medium levy, targeted revenue recycling.
- **Scenario 2C:** Medium levy, forestry phased out from New Zealand Emissions Trading Scheme (NZ ETS).

As part of this process, engagement with stakeholders in the Wairoa catchment was undertaken, including a series of workshops as well as engagement with local landowners and industry professionals. The purpose of these workshops is to connect with local knowledge and expertise, share information on the project and obtain feedback on scenario development and mitigation approaches.

Through this modelling exercise, the objectives were to:

- Illustrate how land management practices and land uses in the two case study catchments might change in future in response to an untargeted approach to environmental policy;
- Estimate the associated changes in environmental and economic indicators that would be expected to result from these future changes in land management practices and land uses; and
- Consider how the results might differ if a targeted 'landscape' approach were taken to environmental policy interventions.

We note the following factors are beyond the scope of the modelling exercise:

- The impacts of climate change on productivity and land use suitability;
- Other land uses (than those specified under section 2), such as forest land planted exclusively for carbon credits (carbon forestry) have not been included;
- New technologies to reduce on-farm environmental impacts that could become available in the future (e.g., a methane vaccine);
- Non-forestry removals of greenhouse gases (e.g., by soils, marine plants); and
- Other environmental issues such as water quantity (droughts floods, etc) and heavy metals or synthetic chemical contaminants in the environment.

2 Approach & Methodology

To explore the research question, a hybrid approach has been developed. The approach we have taken integrates a set of modelling tools (FARMAX, Economic analysis and Nature Braid) that when combined, can provide insights into both the environmental and economic factors under analysis.

A high level explanation of the overall process is detailed in the subsequent Section 2.1, with each of the components described in Section 2.2 to Section 2.4. Detailed scenario descriptions and assumptions of these are described in Section 3.

2.1 Overview of process

A schematic of the modelling tools used to address the research question is shown in Figure 2-1.

The combination of these tools has been used to explore the 'untargeted' and 'targeted' landscape scenarios for the present (i.e., baseline, 2025), 2030 and 2060 time steps.

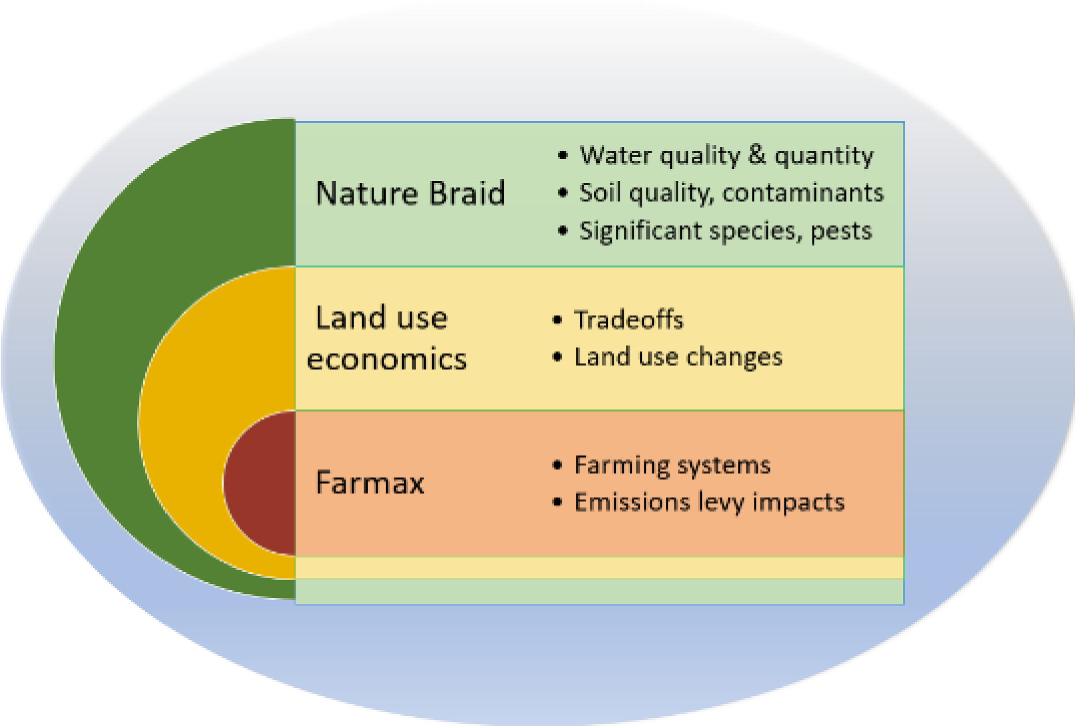

Figure 2-1. Schematic of the project approach. All three models work in conjunction to determine how policy impacts land use and subsequent economics and feasibility of a catchment.

The overall approach was similar to that taken for the Mataura catchment. However, there is significant variation in land use practice and economics, environmental issues and land use suitability, and social drivers between the two catchments. Therefore, the farm types, alternative land uses and environmental mitigations and economic analysis vary significantly between catchments.

A high-level summary of the approach taken is provided below.

FARMAX and economic analysis approach

To support the assessment of the economic impact and likely responses of landowners under the different scenarios, a set of land use “types” have been identified to represent the main economic land uses within the Wairoa catchment. The following farm ‘types’ have been modelled using the FARMAX farm systems model:

- Dairy (cow)
- Hill Country Sheep and Beef
- Lowland Finishing (beef only)
- Mixed Cropping (kumara and lamb finishing)

The outputs from the farm types modelled were then included with the land use economics process, along with those types that cannot be modelled in FARMAX. Additional land uses which were modelled outside of FARMAX in the broader economic analysis include:

- Orchards (Avocado)
- Orchards (Macadamia) *(future land use)*
- Exotic Forestry (Pine)
- Agroforestry *(future land use)*
- Indigenous Vegetation
- Totara Forestry *(future land use)*
- Wetlands

FARMAX also provided GHG emissions for each farm type, which have then been used to calculate the emissions levy at farm level. These figures were then extrapolated into a per hectare estimate (by farm type) to estimate catchment-level emissions. Profitability was then reassessed under the 2030 and 2060 levy scenarios. For those land use types outside of FARMAX, separate emission calculation analyses were undertaken to get similar outputs.

Within FARMAX, there are various libraries containing default values for production and economic parameters, which can be altered manually if required. The most significant in terms of this project are meat schedules and milk pay-outs, farm working expenses and pasture growth and quality. FARMAX financial data operates primarily on a “cash-in/cash-out” basis and does not include capital values or on-farm capital costs.

The primary financial unit of measurement for this project is **Economic Farm Surplus (EFS).** This measure excludes interest and rent, and this is appropriate as the cost of funding the farm business has not been analysed. Depreciation is included and this is considered as a proxy for the ongoing capital required to maintain the farming business. FARMAX generates economic outputs using a library of commodity prices and expenses. Estimated revenue is specific to the system established in FARMAX. Changes in commodity prices outside of the FARMAX model have not been forecasted.

The broader land use economic analysis is then used to project likely land use change resulting from different policy scenarios, based on the outputs of FARMAX and Nature Braid as well as consideration of transition costs.

The assumptions of the land use economics are discussed in Section 2.4 for each land use type.

Environmental analysis

To provide a spatially explicit assessment of ecosystem services and environmental indicators, the Nature Braid model (formerly Land Utilisation Capability Indicator, LUCI) is employed. For this purpose, the spatial distribution of the modelled farm types was identified and assessed against their relative productivity levels as predicted by the Nature Braid model. This provides a basis for a distributed economic assessment of land use change. The relative productivity levels also provided an additional layer of validation for pasture growth rates in the catchment for specific farm types. Further detail regarding how the Nature Braid model works can be found in Appendix A.2.

The outputs of the FARMAX models (i.e., monthly stock numbers and weights, cultivation practices, and fertiliser inputs) and outputs from the simple economic analysis modelling were fed into Nature Braid to represent the changes in land use, and the subsequent impacts to environmental indicators. It is assumed that land use remains similar to current conditions until 2025 when levies are introduced, providing a baseline for all scenarios.

Combined land use economic analysis and outputs

To assess potential land use change, the profitability of the modelled land use types have been assessed against each other, as well as additional 'future' land use options such as Totara Forestry or Orchards (Macadamia)

Using financial and physical parameters from the FARMAX 'base' models and feedback of spatial distribution and production capacity from Nature Braid, further economic analysis was conducted. The main purpose of the analysis is to determine how land use is likely to change in response to policy changes.

The land use change methodology is based primarily on profitability; if the revenue from the land in its current use is not covering the variable costs, it will change to another use. This represents an inertia to land change as some land will change use when it is not providing sufficient return on investment while other land will continue in its current use even when it is effectively making a loss. For the purpose of this thought exercise, land use change is assumed to occur for three main reasons:

1) Loss of profitability: If profitability drops to $0/ha, the land use will change to a more profitable use;

2) Highly profitable alternative land use with short-medium term returns: For example, once Agroforestry is a "known" alternative (from scenario 2A onwards).

3) Where land use change is promoted and subsidised for environmental benefit, as is the case with the Orchard (Macadamia) and Totara Forestry systems.

Currently Exotic Forestry (pine) is significantly more profitable than indigenous alternatives, so it has been assumed to be the preferred forestry option without intervention.

The broader economic analysis also included a cost for interventions (such as the cost per hectare for riparian and other native planting, or conversion to wetlands). The Nature Braid team have used the GIS information available to assess land areas available for, or affected by, each intervention. The economic assessment has provided non-spatial land use change tables, related to the "potential productivity" of the land based on categories identified in the Nature Braid model and existing land use. This information was then mapped onto the landscape and fed into the Nature Braid model to provide spatially explicit assessments of the environmental impacts of the different scenarios. Productive capacity ("utilisation"), as provided by Nature Braid, has also been taken into account in this assessment.

The final outputs from this modelling exercise from the combined Nature Braid, FARMAX and Economic analysis approach are spatial maps demonstrating how land use could change under the five different scenarios at different time periods and spreadsheets detailing the economic impact of land use change.

2.2 Emissions levy

2.2.1 Calculation approach – farm level

For consistency with the Mataura modelling approach, the agricultural emissions levy has been applied on a farm level for the Wairoa catchment.

This is an important modelling choice whether to calculate the emissions levy at farm level, by calculating emissions from stock and fertiliser inputs, or to calculate this at processor level, which would then be passed on to farmers via prices for meat and milk products. In practice, implementation and transaction costs may be simpler/lower at the processor level. However, the impact of this approach is less direct in terms of feedback in the modelled system. For example, calculated at processor level, no levy would then be applied directly to the Dairy Support farm type, as there is no direct product.

The He Waka Eke Noa (HWEN) proposal was a large driver of the levy design and pricing within the Mataura modelling. Following HWEN's recommendations for pricing agricultural emissions, submitted to the government in May 2022 (HWEN, 2022) and the release of the government's consultation document in October 2022 (MfE & MPI, 2022) there is still a lack of clarity surrounding the pricing mechanism and its implementation by 1st January 2025.[1] The government has stated it is prepared to implement an interim processor-level levy as a transitional step if a farm level levy cannot be implemented by 1st Jan 2025. Due to the lack of any template or available information to include in the Northern Wairoa economic modelling, the same HWEN farm level pricing as the Mataura catchment was used.

2.2.2 Emission levy calculation

To calculate the expected on-farm cost of the greenhouse gas (GHG) emissions levy, physical parameters and GHG outputs from the four 'base' FARMAX models have been used. FARMAX provides a range of GHG estimations in various formats. To calculate the levy generated from each farm type, estimates in kilograms of methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) on a per farmed hectare basis have been selected and are described in Appendix A.8.

Kilograms of CO_2-eq (carbon dioxide equivalent) on a per farmed hectare basis have also been used to determine emissions intensity (kg CO_2-eq/ha) for each farm system. Per hectare emissions have been calculated by multiplying the per kg cost of an individual gas, established by the PCE pricing pathway by per hectare emissions of each gas for a given farm system (see Appendix A.8). These are based on the price pathways published by the Climate Change Commission and agreed for the purpose of this modelling project in consultation with experts and industry representatives. The total provides the expected per hectare levy cost for each farm type in the current year. This

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[1] The model settings were finalised before the Government published its final report on pricing agricultural emissions in December 2022.

process was repeated from years 2025 to 2060 following the timesteps, discount rates and gas pricings in the PCE pricing pathway.

The total GHG levy for the low and high price pathway, over the whole catchment has been determined using the previously established on-farm levy, multiplied by the area of that land use found within the catchment. The total area of each land use within the Wairoa catchment has been determined by Nature Braid, utilising existing land use layers as described in Table 3-1. The crude assumption that every hectare of a particular land use, produces the same amount (kg gas/ha) of CH_4, N_2O and CO_2 was required to estimate the 'whole catchment' levy. This was used to estimate the funds to be recycled into the catchment.

For the high and low levy calculation, the methodology used was the same as the Mataura catchment. However, when the high levy pathway was tested in scenario 1B, it had the undesirable outcome of full-scale land transition to Exotic Forestry by 2060, due to negative profitability of current land-uses under the high levy. Rather than model such an extreme outcome, a medium levy pathway was adopted. For the economic analysis, scenarios 1A and 2A use the low levy pathway and scenarios 1B, 2B and 2C use the medium levy pathway (see Appendix A.7). The medium levy was calculated using the low levy + 40% of the difference between the low levy and the high levy. The medium levy has been tested to be appropriate in scenario 1B as it keeps the most productive Dairy lands profitable and in business until at least 2060.

For all scenarios except scenario 2C, no limits are assumed for the NZ ETS. Consequently, the economic value of the NZ ETS is incorporated into all eligible plantings including Exotic Forestry, Totara Forestry and Agroforestry.

Agricultural emissions source

For each of the farm systems modelled in FARMAX, the GHG emissions are calculated within the software. The sources include both enteric and manure methane (CH_4) from livestock digestion, nitrous oxide (N_2O) from animal manure and nitrogen fertiliser and carbon dioxide (CO_2) from urea hydrolysis. Any emissions from fuel use or non-agricultural waste are not covered. FARMAX implements calculations described in *Methodology for calculation of New Zealand's agricultural greenhouse gas emissions; Version 4*. (MPI, 2023)

Enteric CH_4 is calculated using animal dry matter intake, N_2O emissions are calculated using a range of emissions factors within the calculations, the specifics of these haven't been investigated. FARMAX also utilises the global warming potentials over a 100-year time span (GWP100) from the IPCC fourth assessment report (IPCC, 2007). The GWP figures of 1, 25 and 298 have been used for CO_2, CH_4 and N_2O respectively, throughout the project where manual calculations have taken place.

Where systems were modelled outside of FARMAX, other tools or manual calculations were used. The HortNZ Agricultural Emissions Calculator (HortNZ, 2021) was used for the Orchards (Avocado) and Orchards (Macadamia) systems to calculate emissions from nitrogen fertiliser and lime. Fuel and other sources are not included in the calculation. The same GWP100 estimate for N_2O of 298 is used within the calculator, specific emissions factors are also included within the spreadsheet.

2.3 Delineation of land use types

To delineate basic categories of land use within the catchment for representation within the model, the most recent Wairoa land use map produced by Northland Regional Council and Land and Water Science (Rissmann, Pearson, Robson, & Rahimi, 2022) was used as a basis (Figure 2-2). The original Wairoa land use classes were represented as four modelled (FARMAX) farm types:

Dairy (Cow), Hill Country Sheep and Beef, Lowland Finishing (Beef only), and Mixed Cropping (Kumara and Lamb Finishing) (Table 2-1). Exotic Forestry, Orchards (Avocado), and Indigenous Vegetation were also represented as land use types in the Nature Braid and economic modelling, although these were not modelled in FARMAX.

The classification of the "Land_Use" field in the original land use map within the attribute table was used to delineate the farm types. With input from professionals from the different sectors, and taking into account the area covered by each land use (Table 2-1), a representative modelled system was developed for each major land use: "Arable and Horticulture" land in the original map was represented as "Mixed Cropping"; "Orchard" as "Orchard (Avocado)"; "Dairy" as "Dairy"; "Lowland Livestock" as "Lowland Beef Finishing"; "Hill Country Livestock" and "Deer" categories were represented as "Hill Country Sheep and Beef" (see Figure 2-2).

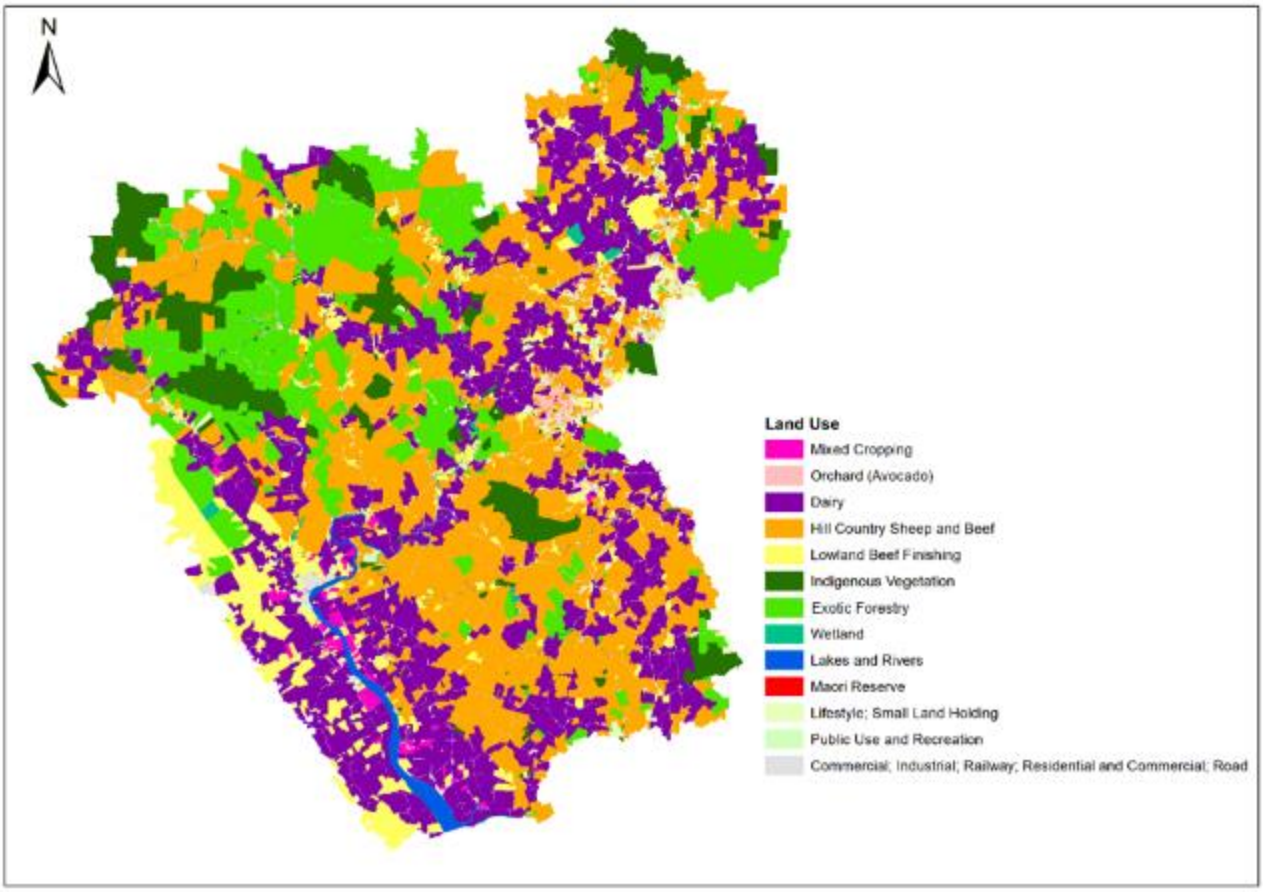


Figure 2-2: Reclassed land use map for the Wairoa catchment.

Table 2-1: Land area for each land use class within the Wairoa catchment. Shaded land use classes have been modelled in FARMAX.

No.	Land use class	Area (ha)	Percentage (%)
1	Hill Country Sheep and Beef	130,510	33.18
2	Dairy	111,536	28.35
3	Exotic Forestry	61,924	15.74
4	Indigenous Vegetation	33,206	8.44
5	Lowland Beef Finishing	26,564	6.75
6	Lifestyle	6,599	1.68
7	Road	6,328	1.61
8	Lakes and Rivers	5,811	1.48
9	Mixed Cropping	2,910	0.74
10	Small Land Holding	2,732	0.69
11	Orchard (Avocado)	1,427	0.36
12	Residential and Commercial	1,425	0.36
13	Wetland	1,102	0.28
14	Public Use and Recreation	523	0.13
15	Railway	476	0.12
16	Industrial	120	0.03
17	Commercial	97	0.02
18	Māori Reserve	75	0.02

2.4 Representing land use types

A brief overview and the key assumptions for each representing land use type that are modelled in the various scenarios are described in this Section.

It should be noted that no specific suggestions for land use changes were provided during the initial Wairoa workshop to help inform additional land use types to be represented. However, a range of concerns and considerations were identified, and these have been considered in the identification of potential land use changes suitable for the catchment. These concerns and considerations were taken into account in selecting a suitable alternative land use to model, and Orchards (Macadamias), Totara Forestry and Agroforestry systems were selected as future land use types.

For the Wairoa catchment, four hypothetical farm systems have been modelled using FARMAX Dairy 8.2.0.23 and Red Meat 8.2.0.16. These represent Dairy (cow), Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping (kumara and lamb finishing). For further information regarding FARMAX refer to Appendix A.3.

The base farm models were selected and developed with support and input from industry professionals, representatives, and farmers in the catchment. FARMAX model outputs were also sense checked with the same individuals to ensure farm inputs were as representative as possible. Parameters for the four FARMAX models are outlined in Appendix A.4.

For the land use types which could not be modelled in FARMAX i.e., Exotic Forestry and Orchards (Avocados); and future land use types of Orchards (Macadamias), Totara Forestry, and Agroforestry systems, have been represented in the economic models using a simple land profitability analysis. These were also developed with support and input from industry professionals, as well as available literature to verify that they were representative for modelling purposes.

2.4.1 Dairy (Cow)

For Dairy, one base model in FARMAX was created to represent a typical system for the Wairoa catchment. This was the subject of some discussion with industry professionals, as there is very significant variation between dairy farm systems in the catchment. However, data for these different systems is not available, and only one system could be modelled in this exercise. For the Dairy base model, Northland specific DairyNZ Dairybase data for the 2020-21 season were used in conjunction with discussion with DairyNZ and Fonterra representatives with knowledge of the region, as well as input from farmers within the catchment. This helped to refine the base models to be as representative of dairying in the catchment as practicable.

It is noted that in the Nature Braid, Dairy was assumed to have higher N and P exports than Lowland Beef Finishing and Hill Country Sheep and Beef. Dairy cattle are much larger than beef cattle therefore dairy farms use more inputs including fertiliser and brought-in feed. They also produce more solids than beef cattle (Fleming & Ford, 2001). From the literature on nutrient losses in New Zealand, total N losses and P losses from dairy pasture are higher than from sheep and beef pasture and deer (Trodahl, 2018). Elliott & Sorrell (2002) and McDowell & Wilcock (2008) also used higher N and P export coefficients for dairy.

2.4.2 Hill Country Sheep and Beef

For the red meat models (Hill Country Sheep and Beef and Lowland Beef Finishing (Beef only), the Beef + Lamb NZ ('B+L NZ') benchmarking data for Class 4 North Island Hill Country (specific Northland dataset) was used to create the hill country model in FARMAX. Personal communication from Sam Stewart, the B+L NZ Economic Service Manager for the catchment, supported this use of data for the model.

2.4.3 Lowland Beef Finishing (Beef only)

Due to the prevalence of beef-only finishing systems in Northland, a Lowland Beef Finishing system was modelled in FARMAX. To create this system, Class 5 North Island Finishing (Northland, Waikato, and BOP) survey analysis was used with sheep stock units replaced with cattle at an equal stocking rate. This was due to limited catchment specific farm system data. As for Hill Country Sheep and Beef, personal communication from Sam Stewart, the B+L NZ Economic Service Manager for the catchment, supported this use of data for the model.

2.4.4 Mixed Cropping (Kumara and Lamb Finishing)

For the Mixed Cropping system, a model with kumara cropping and lamb finishing was developed. Both red and orange kumara were modelled as a cash crop in the Mixed Cropping system. The fertiliser inputs, crop management, yields, production costs and per acre financial returns were determined with support from a grower in the Wairoa catchment (Luke Posthuma, pers. comm., 2022).

In the Wairoa case study, Mixed Cropping was modelled in FARMAX as kumara and lamb finishing system. However, the class within the Nature Braid model represents general arable land and does not assume any specific crops. Nature Braid has used general short rotation crop parameterisation which is non-mitigating for flood, good agricultural productivity, and not ideal habitat for kererū. This is a limitation of the modelling.

2.4.5 Wetlands and Indigenous Vegetation

Where land is restored or converted to Wetland (scenarios 2B and 2C) a capitalisation rate of 7% has been assumed. Landowners are compensated for their land use conversion to Wetland based on their lands current use type and their land production capacity adjusted by the capitalisation rate of 7% to reflect the perpetuity return of their current land use that they forgo. It has been assumed that a one-off fixed Wetland establishment cost of $80,000 per hectare and a recurring annual Wetland maintenance expense of $1100 per hectare for Dairy land conversion to Wetland and $258 per hectare for all other remaining land conversions to Wetland.

Indigenous vegetation is represented in the Nature Braid model as Riparian Planting, wetland planting, gully planting, and the additional planting of indigenous vegetation on farms in scenario 1B (indigenous reforestation). The planting of an 8m strip (4m each side) beside rivers and streams uses a mixed planting model costing $4.20 per m2 to establish and $1.47 per m2 each subsequent year for maintenance.

2.4.6 Orchards (Avocado)

This was not modelled in FARMAX. Therefore, an economic model using a simple land profitability analysis was undertaken.

Avocado orchards have been selected for this modelling exercise as an existing land use, as they are the predominant crop grown within the class of “Orchard” land mapped in the Northern Wairoa catchment (LWS, 2022 and HortNZ, 2022), accounting for approximately 50-60% of this land class area (Deloitte, 2022).

Avocados require access to high quantities of irrigation water. For example, an avocado orchard within the Poroti - Maungatapere area, the main avocado growing area within the catchment, uses approximately 2,070m^3/ha/yr (based on a total annual rainfall of 1,593 mm and a soil Profile Available Water value of 90mm; Aqualinc Research Ltd, 2020). This has been calculated by WSP to be 26 times more water use than dairy farming, based on reasonable stock water requirements guidelines (Horizons Regional Council, 2007).

Groundwater is over allocated in large areas of the Northern Wairoa catchment (Northland Regional Council, 2022a) particularly to the north and west of Whangārei (Hikurangi and Maungatapere areas). This area is also where the predominant area of avocados are grown in the catchment. Northland Regional Council (NRC) considers access to groundwater and consent to be the key limiting regulatory factor for further developing horticulture in Northland (Deloitte, 2022). Water consents for horticultural developments (particularly avocados) have been controversial in Northland. A recent example being the consents granted in the Far North from the Aupōuri aquifer. To further support horticultural development, a water storage scheme is in progress in Kaipara. The Kaipara Water Scheme is intended to provide irrigation for up to 1,100ha of land. There is approximately 50 ha of avocado orchard development already underway near the reservoir, and potential future developments of avocados or other horticultural crops will be supported by this scheme (pers. comm. Ben Craw, Te Tai Tokerau Water Trust, 2022). At the first Wairoa engagement workshop, concerns were voiced from a number of attendees which suggested local resistance to the idea of developing orchards within the catchment. This was due to the high-water usage, potential water allocation issues, and impacts on groundwater systems.

New plantings of avocados have predominantly been in the Far North, and plantings within the Mid North, including the Wairoa catchment, have remained relatively stable from 2010 – 2021 (only 12 ha of new plantings since 2016, compared with 521 ha in the Far North) (Deloitte, 2022). However, within the past year there has been an additional 111ha planted in the Mid-North (NZ Avocado, 2022). Based on the information outlined above, we assume that new plantings in the area will be restricted primarily due to access to water however other factors are also likely to come into play (e.g., access to affordable land with suitable soils, availability of skilled labour).

Although further developments of avocado orchards are possible for future land use in the Northern Wairoa catchment, most likely these will occur within the Kaipara due to the Kaipara Water Scheme. However, this area is likely to be small. We have decided to not expand the area of avocado orchards as a land use within our economic modelling for the reasons outlined above, particularly due to water availability and community concerns.

For the Wairoa catchment, it is assumed that water constraint remains constant and therefore orchard planting (predominantly avocados) cannot be expanded. Intensive water use is of significant political and economic concern. As orchard land uses are significantly more profitable than other land uses, no land will transition out of orchards. These assumptions hold for all modelled scenarios.

The key parameters have been summarised in Table 2-2 below.

Table 2-2: Orchard (Avocado) parameters assumed for this project. Values are per hectare.

	Orchard (Avocado)
Harvest	Year 5 onwards
Harvest profit	$43,500 from Year 5 onwards
Establishment cost	$200,000
Discount rate (real)	7% real cost of capital to discount future values back to present terms to inform current decision-making.
Long term growth rate	2%

2.4.7 *Exotic Forestry*

This was not modelled in FARMAX. Therefore, an economic model using a simple land profitability analysis was undertaken. The key parameters to characterise Exotic Forestry for modelling have been summarised in Table 2-3 below. An assumed real cost of capital of 5% was used to discount future values back to present terms and to inform current decision-making.

Table 2-3: Exotic Forestry parameters assumed for this project. Values are per hectare

	Exotic Forestry
Establishment cost	$1,250
Average annual maintenance costs in years 1-10	$181
End-of-life harvest value	$33,700
End-of-life harvest year	25
Capitalisation rate (pre-tax real)	5%
Sequestration rate	28.6 (tCO_2/ha/yr)
Return 2025	$1,519
Return 2030	$2,663
Return 2060	$7,668

The sequestration rate for Exotic Forestry in the catchment has been approximated by calculating the average annual sequestration from year 1 to year 25 (assumed harvest year) using the data for post-1989 Pinus radiata in the Auckland region, from the MPI Lookup tables (MPI, 2017). The mean annual sequestration rate on 28.6t/ha/yr was used.

Annual sequestration payments have been modelled starting in the planting year. As forests are harvested, they will no longer be eligible for sequestration credits hence the related sequestration payment ceases. It is assumed that sequestration payments are paid at the end of year to all eligible forestry hence no sequestration pay backs were required for harvesting during the year. It’s assumed that as soon as forests mature and are harvested, new forests are being replanted in the same year such that they could still be eligible to sequestration payments. As the majority of the return is practically expected to be realised when the forestry matures and are harvested, we had modelled returns as an effective annual annuity to reflect an equal return split across the modelled period such that catchment profitability could be assessed. For all scenarios expect 2C, forestry earns sequestration payments between 2025 to 2060. For scenario 2C, sequestration payments are phased out by 2030.

2.4.8 Agroforestry system

This system was not modelled in FARMAX, although the three systems defined were based on FARMAX outputs for the pastoral component. A basic Agroforestry system was designed to apply to each pastoral land use identified as having a high risk for sediment loss (‘sediment high-risk').

The model assumes Kawa poplar (*Populus deltoides x yunnanensis*) as the tree species due to its wide growing climatic and soil conditions, palatability to livestock, pest tolerance, existing timber market, availability of research and its use throughout the country for erosion control (Wilkinson, 2000; Northland Regional Council, 2022).

While research and expert opinion has been gathered to develop the poplar Agroforestry model described (Northland Regional Council 2022b, NZ Farm Forestry Association 2022a, 2022b, Satchell & Moore, 2023) Pers. Comm. D. Satchell, 2022), it is acknowledged that there are many potential alternative species which could be included in a Northland Agroforestry system. The production forestry component of the Agroforestry system is described in Table 2-4.

Table 2-4: Production forestry component of the Agroforestry system

Timeline (years)	Activities	Cost	Benefit
1-3	Temporary fencing, Planting 1120 wands/ha ($2.00/wand plus 80c for planting), Release spray (80c for labour plus cost of spray) Grazing stock off farm	Fencing: $0 Wands, planting, and release: $4032 Grazing: Lease	NZ ETS
4-10	Thinning at yr 5 and 10 (2*$2/tree – 560 trees) 3x pruning lifts of 280 trees @$1/tree	1st thin: $1120 2nd Thin: $560 Pruning $840	NZ ETS Fodder
10-30	No costs, harvest half i.e., 140 trees at 30 years Coppice at harvest, no replanting cost	Harvest cost: $ 15,000	Yield: 150 tonnes @ 50% timber yield, @ $800/cubic metre = $60k
31 -40	Off-farm grazing from years 1-3 (31-34)	Lease	
30-60	Prune coppiced trees (140 trees*3 @$2/tree) Harvest other half at year 60	Prune: $420 Harvest: $15,000	Fodder $800/cubic metre ($60k)
60-90	Prune coppiced trees (140) Second harvest of first crop (140 at year 90)	Pruning: $140 Harvest costs: $15,000	Fodder $800/cubic metre (60k)
90+	Replant 550 wands after harvest Off-farm grazing	Planting and release spraying: $1,980 Grazing: lease	

For the Agroforestry system, poplar trees are initially planted at a 3x3m spacing to encourage vertical trunk growth for timber quality, and root expansion for erosion control. The closer spacings encourage roots to touch in a shorter timeframe than wider spacing, which reduces erosion risk. The forest is thinned to a final stocking of 280 stems per hectare or a 6x6 spacing by age 10, when root diameter and canopy is further established. Poplar species sprout shoots from cut stumps, therefore replanting after wood harvest is not essential. It is assumed this process is not infinite therefore the model implies a replant is needed after an individual tree's second harvest.

Within the Agroforestry system it is assumed that pasture production would reduce by 50%. This is a conservative number and most New Zealand literature indicates there is variation in the reduction in total pasture growth. Further detail on this assumption is provided in Appendix A.5 along with base model specific assumptions relating to the Agroforestry system.

The information from the base FARMAX models were adjusted to create each of the Agroforestry systems (Agroforestry – Dairy, Agroforestry – Hill, Agroforestry – Lowland). A spreadsheet of physical and economic information was then utilised by the Nature Braid and economics teams to determine the impact on the environment and economic returns respectively. For simplicity, each farm system has been modelled as converting fully to an Agroforestry system. The outputs per hectare were then extrapolated to the sediment high-risk areas of the catchment for the required scenarios (Scenario 2A and 2B). It is assumed that the most common result will be that only sediment high-risk areas of farms will be converted to Agroforestry, with the remaining majority of farmland staying in pasture. Because of this, fixed costs have been kept at baseline levels.

Following the assumptions of the economic modelling, all the Agroforestry systems within Nature Braid assumed poplar as the tree species in combination with stock. Poplar has extensive root systems which are capable of rapidly stabilising large soil masses (Wilkinson, 1999). Therefore, Nature Braid modelling has assumed these areas to have high soil erosion retention capacity with the presence of poplar. Poplar is also suited for mitigating erosion due to its slow root decay rate compared to radiata pine and is suitable to be grown under continuous cover regimes (Satchell, 2018).

2.4.9 Orchards (Macadamia)

Macadamia orchards (referred to as 'Orchard (Macadamia)' as a land use within this report) have been selected as a representation of a high value, low environmental impact land use. Macadamias are currently grown in coastal areas of Northland with around 28% of the NZ planted area (around 40 ha) grown in Northland (Stats NZ, 2017). They are not available to be modelled in FARMAX, therefore a simple economic model was developed to include them.

Macadamia orchards can generate high returns (Te Puna Kōkiri, n.d.) and can be feasible where water availability is limited. Macadamia generally do not require irrigation once established if annual rainfall is above 1300 mm, only requiring irrigation during the first 4 years of establishment or in soils with a lower water holding capacity (Carr, 2013). Macadamias have low fertiliser requirements (63 kg N/ha and 26 kg P/ha annually; Ballance Agri-Nutrients, 2022), particularly if grown in richer soils, and mainly require the addition of micronutrients. Macadamias are well suited to Northland due to its high rainfall (>1300 mm; not requiring irrigation once established) and limited frost risk. Macadamias require well drained soil and protection from strong winds (Te Puna Kōkiri, n.d.). Due to requirements for mechanical harvesting and mowing, a maximum slope of 15 degrees is required.

Macadamias do not qualify for carbon sequestration under the NZ ETS as they are recognised as a commercial nut cropping tree (Ministry for Primary Industries, 2022), and regular pruning and management will reduce carbon uptake. However, calculated GHG emissions from macadamias are low based on the nitrogen fertiliser application recommendations from Balance (2022).

Currently the macadamia market in New Zealand is small, with only 200 growers producing 66 T of macadamia kernels for the domestic market (Hayes, 2018). However, demand for macadamias in New Zealand outstrips supply and there is opportunity for this market to expand, particularly the export market (Hayes, 2018).

Macadamia economic returns were calculated based on the information provided by Te Puni Kokōri (n.d.). A real discount rate of 5% was used as consistent with the rest of the study and with the Mataura catchment. This set the annualised return at $33,809/ha.

Table 2-5: Orchard (Macadamia) operating costs and returns utilised in the economic modelling.

Year	Yield (conventional NIS; tonne/ha)	Yield (organic kernels; tonne/ha)	Gross income (organic kernels; $/ha)	Operating Expenses – Fixed	Operating Expenses – Variable	Deshelling Expenses
1 – 3	0	0	$ -	$10,125	$ -	$ -
4	1	0.4	$18,000	$10,125	$844	$1,250
5	1.5	0.6	$27,000	$10,125	$1,266	$1,875
6	2	0.8	$36,000	$10,125	$1,688	$2,500
7	3	1.2	$54,000	$10,125	$2,531	$3,750
8	4	1.6	$72,000	$10,125	$3,375	$5,000
9	4	1.6	$72,000	$10,125	$3,375	$5,000
10+	4	1.6	$72,000	$10,125	$3,375	$5,000

2.4.10 *Totara Forestry*

The sustainable Totara Forestry system ('Totara Forestry') modelled includes totara (*Podocarpus totara*) under continuous cover forestry. This means that the forest canopy is maintained at a certain level without clear-felling (Mason 1999). As totara are not modelled in FARMAX, the economic analysis considered a selective harvesting regime of 60 years after the initial establishment and continuous maintenance and pest control Table 2-6).

It should be noted that the assumption for establishment costs are about eleven times those of Exotic Forestry. Establishment, maintenance, and pest control costs are highly variable and severely understudied for indigenous vegetation in New Zealand (Forbes 2021). While the assumption of (tree) stocking rates for the economic analysis was 2,000 stem/ha (New Zealand Farm Forestry Association n/d.), totara could be grown at lower stocking rates (see for example Satchell 2018). This choice of stocking rate is therefore a conservative one.

Table 2-6: Totara Forestry parameters assumed for this project.

	Totara Forestry
Establishment Cost	$14,750/ha
Average annual maintenance costs in years 1-10	$2,025/ha
End-of-life harvest value	$110,000/ha
End-of-life harvest year	60
Capitalisation rate (pre-tax real)	5%
Sequestration rate (tCO_2/ha/yr)	8.2
Return 2025	-$1,007
Return 2030	-$679
Return 2060	$756

The sequestration rate for Totara Forestry in the catchment has been approximated by calculating the average annual sequestration from year 1 to year 35 (tree age in 2060) using the data for indigenous forest from the MPI Lookup tables (MPI, 2017). The mean annual sequestration rate on 8.2tCO_2/ha/yr was used. However, as Totara Forestry is only included in scenario 2C, in which the

NZETS is phased out, no sequestration payments are made; this figure is only used to calculate overall sequestration for the catchment in scenario 2C.

The Nature Braid parameters for sustainable Totara Forestry implicitly assumed a continuous cover forestry system, for example, the C-factor in the RUSLE model used for totara was the same as the indicative C-factor for native forest (0.005). The Nature Braid model also assumes that the sustainable Totara system mitigates flow and is a good habitat for kererū (See Appendix A.2).

Nature Braid has assumed that Totara Forestry is high retention for soil losses and flood as it was recommended as suitable for production plantation forestry on erodible hill country (Satchell, 2018). It has an extensive lateral root system that often spreads and can produce new root systems after flooding and roots can develop from the trunk where silt has been deposited (Bergin, 2003).

Both the Mataura and Wairoa cases used the same parameters in Nature Braid and economic assumptions for Totara Forestry.

3 Scenarios and assumptions of modelling

For each scenario, a specific set of assumptions were required. This section outlines these assumptions and their rationale.

The same modelling methodology was used in the Wairoa catchment economic analysis as for the Mataura catchment. Financial and physical parameters from the FARMAX baseline models and feedback of spatial distribution and production capacity from the Nature Braid model were used. The focus of the economic analysis was then to determine how land use will likely change in response to policy changes and government interventions.

For specific use of the levy for each scenario, refer to Appendix A.1.

3.1 Scenario 1A: Low levy, untargeted freshwater regulations

For this scenario, the lower levy is introduced in 2025, increasing gradually over time. The impact of the lower-rate emissions levy was calculated for 2030 and 2060, and associated land use change was assessed. The revised proportions of land uses were then fed back into Nature Braid to assess the environmental impacts of the land use change. The option of Exotic Forestry represented a high-value alternative use for all four categories of negligible productivity and marginal productivity farming land uses which became unprofitable in 2030 and 2060.

The levy revenue, in this scenario, is small and is assumed to be channelled to national-level research on reducing emissions from agriculture (‘untargeted revenue recycling’).

3.2 Scenario 1B: Medium levy, untargeted revenue recycling

The revenue available in scenario 1B is calculated as the levy collected under the medium levy pathway. For the purpose of this scenario, this levy revenue available has been prioritised to be applied directly to a modelled intervention of funding to support Riparian Planting along river streams in the catchment. As NZ ETS eligible planting is not included in the funding for this scenario, Riparian Planting within the catchment is assumed to occur only under the assumption that this is funded by the levy revenue. Planting riparian areas can provide significant benefits for water quality and biodiversity as well as providing a carbon sink (McKergow et al., 2022). Riparian Plantings can occur on any land type and for the purpose of this study are assumed to have no impact on land use, with no associated land use change.

Between 2030 and 2060, there are levy funds left remaining after all expenses for Riparian Planting, but this has not been modelled to be used as a subsidy to reduce stocking rates like in the Mataura catchment because by 2060, only the moderate to very high production capacity Dairy farming lands will be profitable enough to remain in operation. All Hill Country Sheep and Beef and Lowland Beef Finishing would be unprofitable and would convert to a higher value land use.

For levy funds remaining each year after all riparian expenses, we have assumed this to be channelled to national-level research on reducing emissions from agriculture, similar to (but a lower overall amount than) scenario 1A.

3.3 Scenario 2A: Low levy, targeted freshwater regulations

Scenario 2A, as in the Mataura catchment, examines the use of a regulatory approach targeted to environmentally vulnerable land. The regulations modelled were 1) a cap on synthetic nitrogen as in Mataura; and 2) a requirement for planting on sediment/erosion susceptible (sediment high-risk) land. It has been assumed that the levy revenue generated from the low GHG pricing pathway will be channelled to fund for national level research at the same level as in scenario 1A.

For the Wairoa catchment, the loss of sediment to waterways is considered to be of particularly high importance. However, N loss remains an important issue. As a result, the freshwater regulations in this scenario are set to target N leaching, as well as sediment loss.

The policy under scenario 2A applies the same N fertiliser cap used for the Mataura scenario 2A (85 kg N/ha/yr for 2030, and 65 kg N/ha/yr for 2060), although the underpinning rationale is slightly different. In the Mataura catchment, the 2060 cap was approximately half the total amount applied by the highest input land use, while the 2030 cap aligned with a recent consent granted for future tulip growing. In the Wairoa catchment, it was considered reasonable to maintain these caps to provide some consistency in approach. The 2030 N cap (85 kg/ N/ha/y) corresponds quite closely to 50% of the highest synthetic N input of any farm system (this being Orchard (Avocado) at 180 kg N/ha/yr. The capped applications of 85 kg N/ha/yr for 2030, and 65 kg N/ha/yr for 2060 were therefore carried over to the Wairoa catchment.

Areas classified as “high” within the Nitrate-Nitrite-Nitrogen (NNN) output of Land and Water Science (LWS; Rissmann et al., 2022) were used to identify the N high-risk areas for modelling. The impact of N caps on farm profitability was calculated in FARMAX. These outputs were used to determine whether farming land under N caps remains profitable or whether certain areas would convert to a corresponding Agroforestry system. The FARMAX modelling assumptions are detailed in Appendix A.5.

For the purpose of this scenario, sediment high-risk areas were identified as the overlapping areas between the sediment high-risk areas as defined by LWS (the high “sediment and pathogen” class of LWS’s Susceptibility Typology map) and the Nature Braid model (the “high sediment delivery” class of Nature Braid’s sediment delivery output).

To address the sediment issue, the assumed policy response is to require tree planting in sediment high-risk areas. For example, to continue livestock grazing on a sediment high-risk area, a minimum of 100 stems per hectare are required to be planted, which is interpreted as an Agroforestry system. The Agroforestry system grows poplars for timber, combined with pastoral grazing i.e., it is no longer just a pure ‘grazing’ land type. However, if the land is identified as being marginal or negligible as well as is a sediment high-risk area, then it would not convert to Agroforestry, and instead to Exotic Forestry.

In N high-risk areas, farm systems will be restricted with an N cap, and it is assumed that Orchards (Avocado) will be unproductive with an 85 kg N/ha/yr limit. Therefore, any Orchard (Avocado) area in an N high-risk zone, will transition to an Agroforestry - Lowland system. In sediment high-risk areas, the existing pastoral system converts to the respective Agroforestry system (i.e., a sediment high-risk Lowland Beef Finishing area converts to Agroforestry - Lowland, or a sediment high-risk Dairy area converts to Agroforestry - Dairy). The exception is that any Mixed Cropping in a sediment high-risk area converts to Agroforestry – Lowland. When a given land use becomes unprofitable as a result of the N cap and/or emissions levy, a transition to the corresponding Agroforestry system for that land use has been adopted.

Scenario 2A utilises three spatial layers to identify areas within Wairoa where caps on synthetic nitrogen and planting (Agroforestry or Exotic Forestry) could be applied. These layers are explained in Table 3-1.

Table 3-1: Overview of each of the spatial layers used for scenario 2A.

Layer	Explanation
High sediment delivery (Nature Braid)	Areas of extreme soil loss susceptibility identified by the RUSLE (Revised Universal Soil Loss Equation) model and sediment delivery susceptibility is high because flows from these areas are not being intercepted/filtered/slowed prior to reaching water bodies
Erosion and pathogen susceptibility (LWS)	Susceptibility of the landscape to contaminant losses of NNN, soil from erosion, and pathogens given its climate, topography, hydrology, soils, geology, and land use (Rissmann et al., 2022)
Nitrate-Nitrite-Nitrogen (NNN) susceptibility (LWS)	

The sediment delivery of Nature Braid is based on the risk of soil loss from a particular pixel using the RUSLE (Revised Universal Soil Loss Equation) model and where flow from this pixel travels through the landscape. The RUSLE uses information about rainfall, topography, soil, and land cover to model soil losses by rill and interrill erosion, or erosion due to water action (Benavidez et al., 2018). Areas of extreme soil losses (>10 t/ha/yr) are then isolated and Nature Braid's spatially explicit hydrology algorithms identify if flow from these areas are being mitigated or not. If they are being mitigated, sediment-rich flows from these areas encounter features such as vegetation, Riparian Planting, wetlands, etc. prior to reaching water bodies (streams and rivers). If they are not being mitigated, these sediment-rich flows are not being intercepted and flow directly into water bodies, causing adverse impacts on water quality.

The susceptibility layers of LWS also utilise spatial information about the landscape (climate, topography, hydrology, geology, land use) and water quality records to identify areas prone to contaminant losses (Rissmann et al., 2022). Regression analysis was used to fit models and build equations relating water quality measures and landscape controlling factors, which were then applied spatially across the Wairoa catchment.

Although Nature Braid and LWS both use spatial information and models to estimate soil/nutrient losses based on landscape information, they do so in different ways. Nature Braid is spatially explicit in its hydrology, tracking movement of flows of mass, water, nutrients, and sediments across each pixel of the landscape, utilising a process-based approach. LWS uses complex regression analysis of very large records of water quality and spatial datasets to determine the landscape susceptibility to contaminant losses.

To identify areas that are susceptible to erosion and sediment delivery (Figure 3-1, orange circles), the areas of high Sediment and Pathogen Susceptibility from LWS were overlapped with the areas of high sediment delivery from Nature Braid. These overlapped areas were then further overlapped with the areas identified as having high susceptibility for NNN from LWS (Figure 3-1, red circles).

This produced three sets of areas to address, and each area received its own set of interventions (Table 3-2).

Table 3-2: Summary of what interventions are applied on different areas of N risk, erosion risk, and a combination of both.

Areas	Interventions
Areas of high susceptibility for NNN (LWS)	Set A: caps on synthetic nitrogen
Areas susceptible to erosion and sediment delivery	Set B: planting and Agroforestry; Exotic Forestry on areas of poorer productivity
Areas of high NNN and erosion susceptibility	Combination of Set A and Set B

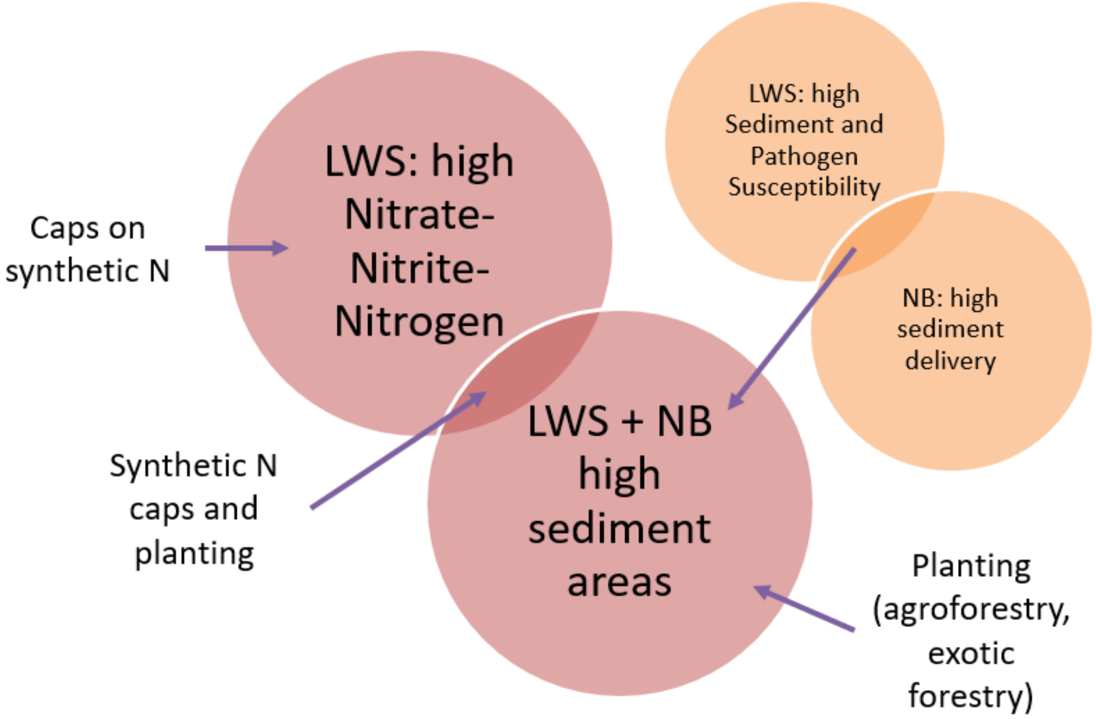


Figure 3-1: Overview of how LWS and Nature Braid (NB) layers were used to identify areas to apply interventions in scenario 2A.

3.4 Scenario 2B: Medium levy, targeted levy recycling

For scenario 2B, the levy available is calculated in the same approach as in 1B following the medium levy pathway. Similar to 1B, we have assumed this levy revenue to be recycled back into the catchment and prioritised to be spent towards Riparian Planting along the rivers and streams. The key modelling difference is that in scenario 2B, there are interest free loans to financially support productive farming land conversions to Orchard (Macadamia).

In detail, levy funds available each year are first directly applied to a modelled intervention of funding to support Riparian Planting in the catchment. After all expenses related to Riparian Plantings and maintenance are covered, the remaining levy fund available each year will be spent towards providing financial support (interest free loans) to Dairy farmers who meet the appropriate land criteria to convert to Orchard (Macadamia) - an example of a low environmental impact land use. Although macadamias are highly profitable and have a low environmental impact (see section 2.4.8), they have a long harvest life and require significant initial capital expenditure. It has been assumed that a loan amount equivalent to the initial capital requirements to be issued from the fund by central government to smoothen the Dairy conversion to Orchard (Macadamia). The number of loans issued each year are constrained by the levy fund left available after funding is supplied for Riparian Planting. It is assumed that the loan recipient will pay no interest on the loan over the course of the loan, but the loan will have a maturity of 9 years and a loan margin of 5% paid at maturity. As loan repayments plus loan margins comes in, they are recycled back into the catchment, adding to the fund available each year. This process will continue every year until all of the identified Dairy land has converted to Orchard (Macadamia).

After all the suitable Dairy land has converted to Orchard (Macadamia), remaining available levy funds, plus loan repayment and loan margin, would be spent on targeted restoration of the Otonga pocket of the Hikurangi Repo (Hikurangi Swamp) as wetland. The Wetland restoration process has been modelled to occur immediately as a lump sum payment when the cumulative funds available in the catchment are sufficient to cover the total wetland restoration cost.

The Riparian Planting areas, Orchard (Macadamia) planted areas and the restored Wetland areas are then fed back into the Nature Braid model to assess the environmental impacts of these land use changes.

The use of remaining funds left available after all activities described above are financed, including loan repayments and loan margins collected have been modelled to be channelled to fund for national level research. The cumulative funding towards national level research in this scenario is less than the cumulative channelled national level research funding in 1B.

3.5 Scenario 2C: Medium levy, forestry phased out from NZ ETS

Scenario 2C is similar to scenario 2B where it follows the same medium levy pricing pathway with the levy revenue assumed to be recycled back into the catchment through the central government funding programme and spent using a simple targeted approach. It repeats the same targeted mitigations such as Riparian Plantings along the river stream and financial support to smoothen the Dairy land transition to Orchard (Macadamia).

The key difference in this scenario is that the effect of removing new forests from the NZ ETS and increasing public funding for integrated landscape management in the catchment have been modelled, in addition to targeted revenue recycling. The levy revenue is supplemented by additional public funding to provide for activities that improve freshwater, biodiversity, and climate outcomes in the catchment. All eight pockets of the Hikurangi Repo, as identified by Nature Braid, are restored as wetlands and additional public funding to encourage a sustainable Totara Forestry system rather than Exotic Forestry (pine) is introduced after 2030.

4 Results

4.1 Baseline 2025 results description

4.1.3 Environmental analysis

Nature Braid uses the land cover data to assess both the current agricultural utilisation (i.e., potential productivity) and the environmental impact of not just the agricultural utilisation, but also the geoclimatic and topographic factors underpinning environmental outcomes. Very highly productive land which is under intensive agricultural activities (Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, Mixed Cropping, and Orchard (Avocado)) covers 69.4% of the catchment (Figure 4-1, top right). About 23% of the catchment is considered to have no/negligible agricultural production value, but it may be important for other non-agricultural uses.

The predicted optimal agricultural utilisation map is based on climate, soil water characteristics, fertility, slope, and aspect (Figure 4-1, top left). Areas that are flat with a slope less than 5 degrees and under soils with well-draining characteristics, and fertile are considered to have high agricultural production potential. In Wairoa, 20.3% of the catchment has high to very high agricultural potential. Areas that are susceptible to waterlogging or very hilly are considered to have low agricultural production potential, as these areas will require management interventions to become suitable for agricultural use. 72.9% of the catchment is considered to have moderate and marginal productivity; and 6.0% to have negligible production value, mostly found in the north of the catchment.

The relative agricultural utilisation uses the current land use and predicted agricultural productivity to identify whether existing current agricultural utilisation is appropriate given the landscape’s predicted agricultural productivity (Figure 4-1, bottom right). An area of 25.3 % of the catchment is flagged as significantly over-utilised (very high utilisation) while 29.6% is somewhat over-utilised (somewhat high utilisation). These areas are under Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing farms within the Wairoa catchment.

The utilisation status map (Figure 4-1, bottom left) provides an assessment of whether the current agricultural utilisation may be worthy of preservation or change. It is an assessment of both the landscape’s capacity to support agricultural production (e.g., topography, aspect, soil) and what uses currently exist on that landscape. If the current agricultural utilisation of land aligns with associated predicted optimal (the landscape’s capability to support agricultural production matches its usage) agricultural production, Nature Braid marks the land as typical/usual utilisation. Typical and near-typical agricultural production areas account for 33.1% of the catchment, extending across dairy farms on low slopes (<5 degrees). Agricultural production results highlight 35.8% of unusually utilised areas in Dairy and Mixed Cropping farms along the Wairoa and Wairua rivers. Land that is flagged as unusually utilised may indicate either (1) the area is being used for agricultural purposes when the underlying soil and landscape characteristics may not be able to support it, or (2) areas that may have high agricultural productivity potential are not currently being used for agricultural purposes.

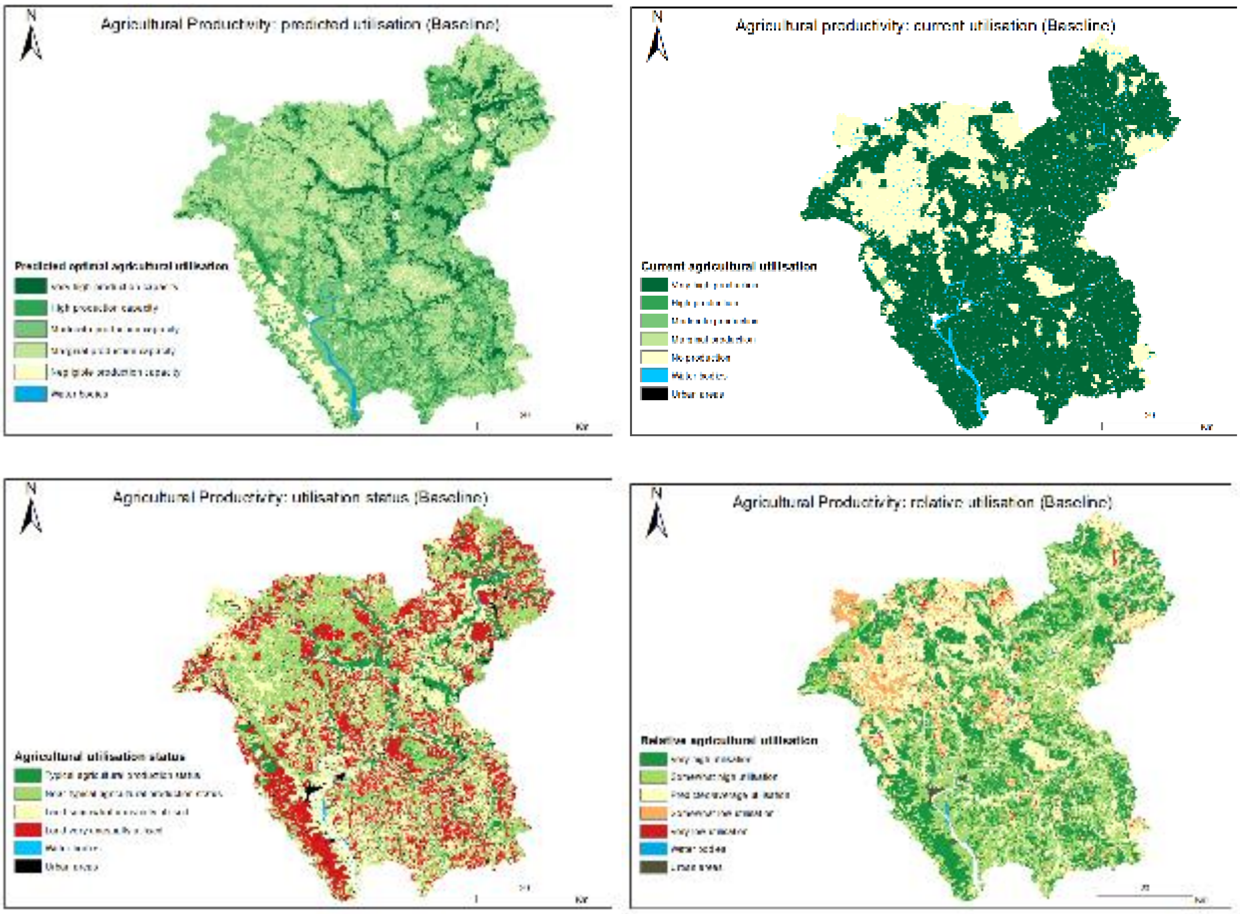


Figure 4-1: Results of agricultural productivity: predicted agricultural utilisation, current agricultural utilisation, agricultural utilisation status and relative agricultural utilisation.

In Wairoa, the mean N (total N) in-stream concentration is ~0.7 mg/L, reaching a maximum of ~191 mg/L (Table 4-1). The reaches with generally higher average in-stream N concentration are identified in Manganui River and Waipao Stream (Figure 4-2; bottom). The model estimations reasonably align with the high total nitrogen concentrations monitored at Manganui at Mititai Road the Waimea stream at Waipao at Draffin Road (measurement data published by Land, Air, Water Aotearoa: 'LAWA'; Appendix A.9).

Table 4-1: Summary statistics of in-stream nitrogen concentration for the baseline scenario.

Nitrogen stream concentration (mg/L)	Baseline 2025
Min	0
Mean	0.7
Max	191

Table 4-2: Classified in-stream N concentrations for the baseline scenario.

In-stream N concentration	Number of reaches	Percent of total (%)
<1 mg/L	27,096	76.1
1 to 3 mg/L	8,273	23.2
3 to 5 mg/L	194	0.54
5 to 10 mg/L	21	0.1
>10 mg/L	25	0.1

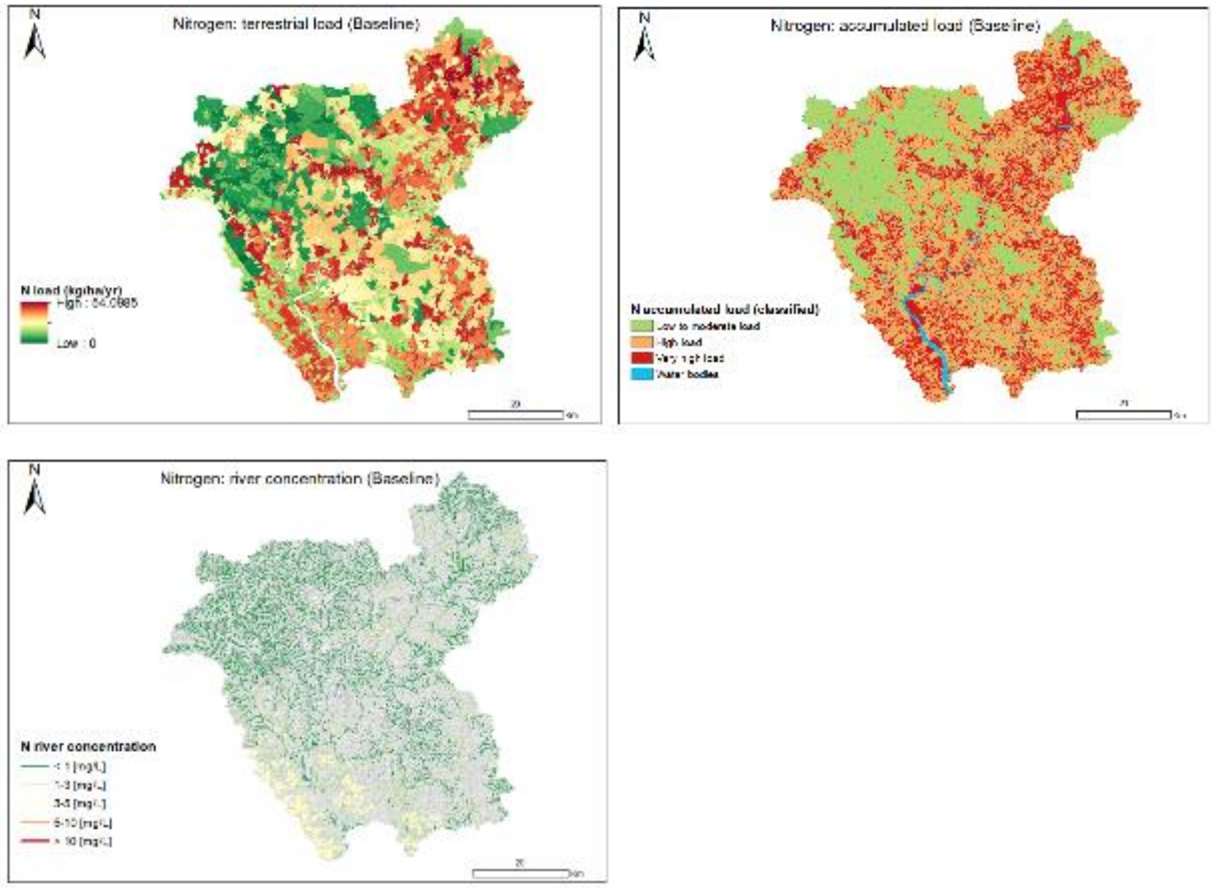


Figure 4-2: Results of nitrogen (N): Nitrogen terrestrial load, Nitrogen accumulated load classification and Nitrogen in-stream concentration.

Nature Braid estimates the terrestrial nutrient load (kg/ha/yr) through a modified export coefficient approach that uses spatially explicit information on land, soil, topography, and rainfall in addition to regional information on fertiliser, stocking, and irrigation to generate accumulated load at a point. This approach is combined with water and sediment delivery models to understand nutrient delivery to streams. The estimated maximum nitrogen load in the Wairoa catchment is 54.1 kg/ha/yr and the mean value is 10.7 kg/ha/yr (Table 4-3), which is higher than the Mataura case study (8.7 kg/ha/yr).

Table 4-3: Summary statistics of nitrogen terrestrial loads for the baseline scenario.

	Nitrogen terrestrial load (kg/ha/yr)
Min	0
Mean	10.7
Max	54.1

Of the streams in within the Wairoa catchment, 57% have in-stream total P concentrations less than 0.01 mg/L (Table 4-4) with an average concentration of ~0.016 mg/L and maximum concentration of ~17.276 mg/L. Like the nitrogen results, all streams with a concentration greater than 0.025 mg/L are mostly found at Manganui River and Waipao Stream (Figure 4-3, bottom). From measurement data published by LAWA, high total phosphorus is also found at Waipao at Draffin Road (5-year median of 0.0351 mg/L) and Manganui at Mititai Road (5-year median of 0.0345 mg/L).

Table 4-4: Summary statistics for in-stream phosphorus concentrations for the baseline.

Phosphorus in-stream concentration (mg/L)	Baseline 2025
Min	0
Mean	0.016
Max	17.3

Table 4-5: Classified in-stream P concentrations for the baseline scenario.

In-stream P concentration	Number of reaches	Percent of total (%)
<0.01 mg/L	21,483	57.0
0.01 to 0.025 mg/L	8,179	21.7
0.025 to 0.05 mg/L	4,808	12.8
0.05 to 0.075 mg/L	2,325	6.2
>0.075 mg/L	904	2.4

The maximum phosphorus load in Wairoa is 1532 g/ha/yr with a mean value of 401.5 g/ha/yr (Table 4-6).

Table 4-6: Summary statistics for phosphorus load for the baseline scenario.

	Phosphorus load (g/ha/yr)
Min	0
Mean	401.52
Max	1,531.98

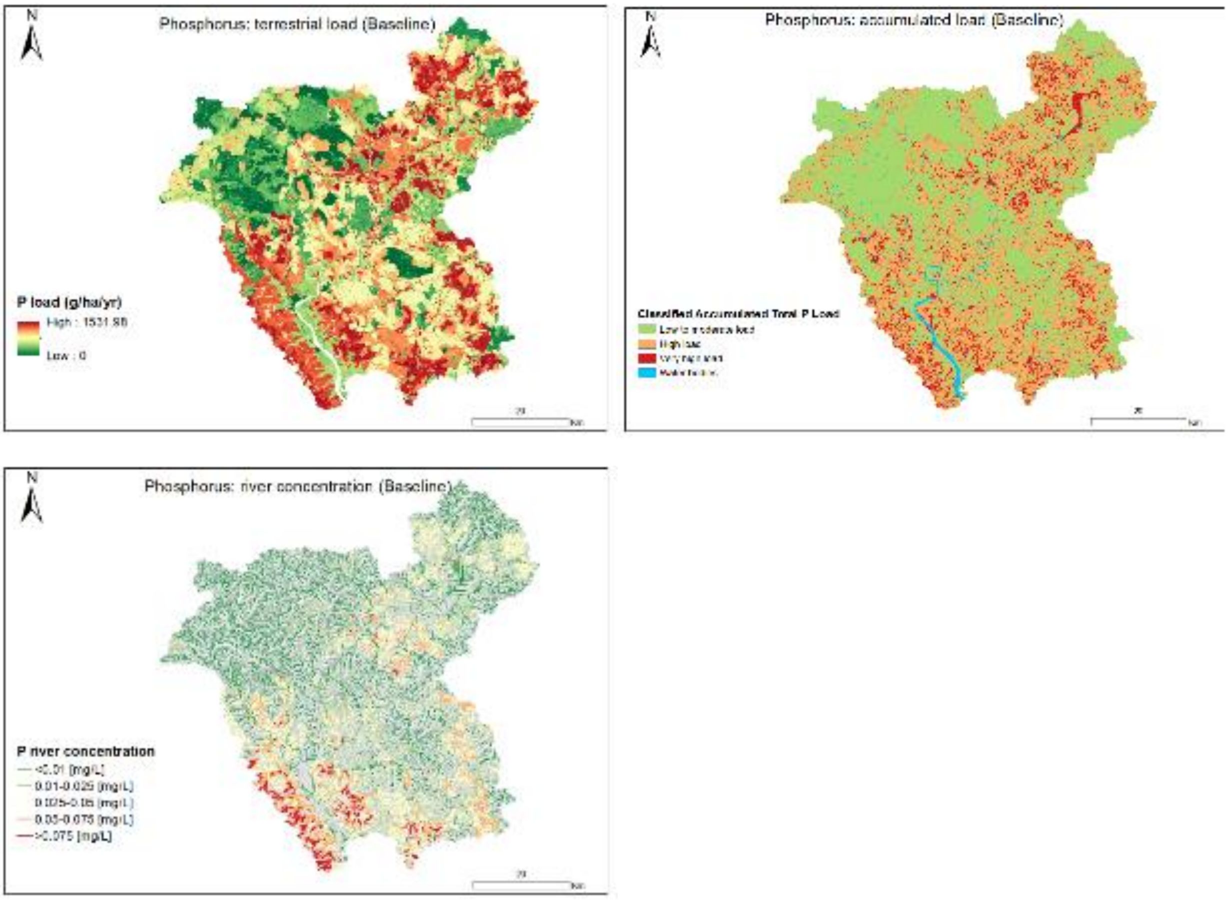


Figure 4-3: Results of phosphorus (P): Phosphorus terrestrial load, Phosphorus accumulated load classification, P in-stream concentration

The flood mitigation output uses information on water movement and landscape hydrology to delineate areas that are mitigating movement of flow (i.e., areas that slow down flows of energy and water, along with associated mass/sediments/nutrients/etc or that have high storage capacity, e.g., trees, ponds, deep permeable soils or other flow sinks); areas that are mitigated (i.e., areas that receive these mitigation benefits, as water and other mass originating there are intercepted by mitigating features before reaching a stream, lake or river); and non-mitigated features (i.e., areas with low permeability and/or storage, and flows from these areas are not being intercepted before reaching water bodies). With large areas of farming, 71.2% of the catchment is identified as non-flood mitigated features (Figure 4-4, top left). 12.6% of high flood concentrations are in places of high flow concentration and have large contributing areas with no mitigation (Figure 4-4, top right).

These unmitigated areas have the potential to carry flow and associated contaminants (e.g., nutrients and sediments) directly to streams, affecting flooding events and water quality. High flood concentration areas are located along with the riparian areas of the Manganui River (Figure 4-4, top right). High flood concentration also occurs on flat areas in small clusters of pixels across the catchment. These areas of high flood concentration and unmitigated land are potential areas of opportunity to consider management changes. The average flow map shows where higher flows can generally be expected for Wairoa (Figure 4-4, bottom).

Table 4-7: Results of the flood mitigation tool for the baseline

Flood characteristics	Area of the catchment (ha)
Mitigating features	85,300
Mitigated features	7,110
Non-mitigated features	253,150
Water bodies	10,110

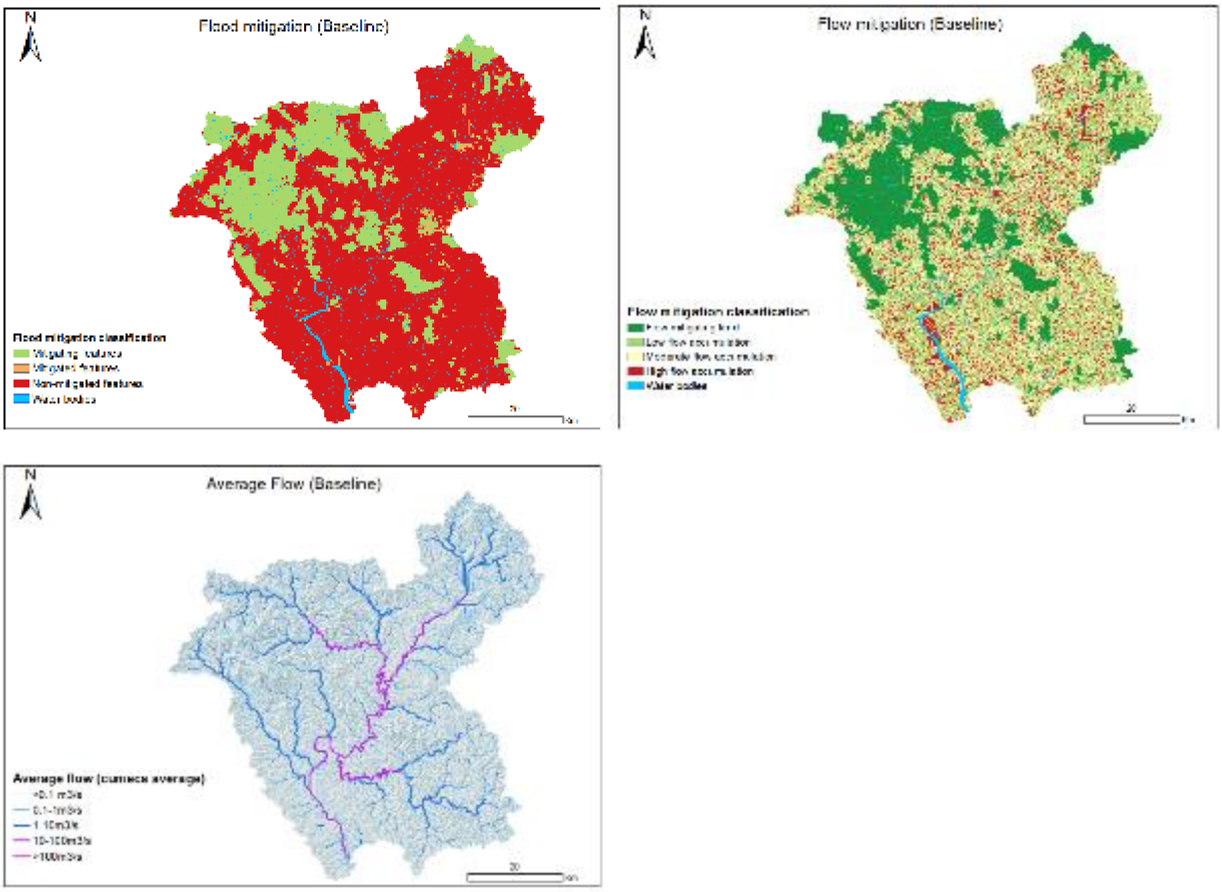


Figure 4-4: Results of flood mitigation: flood mitigation, flow mitigation and average flow

The mean soil loss for the Wairoa catchment is ~ 83.3 tonnes/ha/yr for the baseline scenario, much higher than this number of the Mataura case study (10.6 tonnes/ha/yr). The areas of high soil losses were around the north of the catchment (Figure 4-5, top left). The soil loss over small time scales is mainly driven by rainfall and topography, along with soil type and cover/management. Over longer time scales the broader climatic and geological influences have affected these shorter-term drivers of vulnerability. The north of the catchment corresponded to higher volumes of rain which have higher rainfall erosivity, and combined with the steep topography, make these areas vulnerable to soil loss. The classified soil loss risk shows that the plantation forestry and agricultural areas on hilly topography are at risk of extreme soil losses (>10 tonnes/ha/yr; Figure 4-5, top right). The sediment delivery map is useful for narrowing down the areas for potential management interventions because it considers whether the soil losses generated are being intercepted by mitigating features or not (Figure 4-5, bottom). Areas of high sediment delivery risk that are not being mitigated have the potential to contribute sediment-rich flows that affect water quality as they are not being intercepted by features that can slow down or filter sediments and flows, and instead are delivered directly to water bodies.

Table 4-8: Summary statistics for terrestrial soil loss for the baseline 2025.

Soil loss (tonnes/ha/yr)	Baseline 2025
Min	0
Mean	83.3
Max	8,663

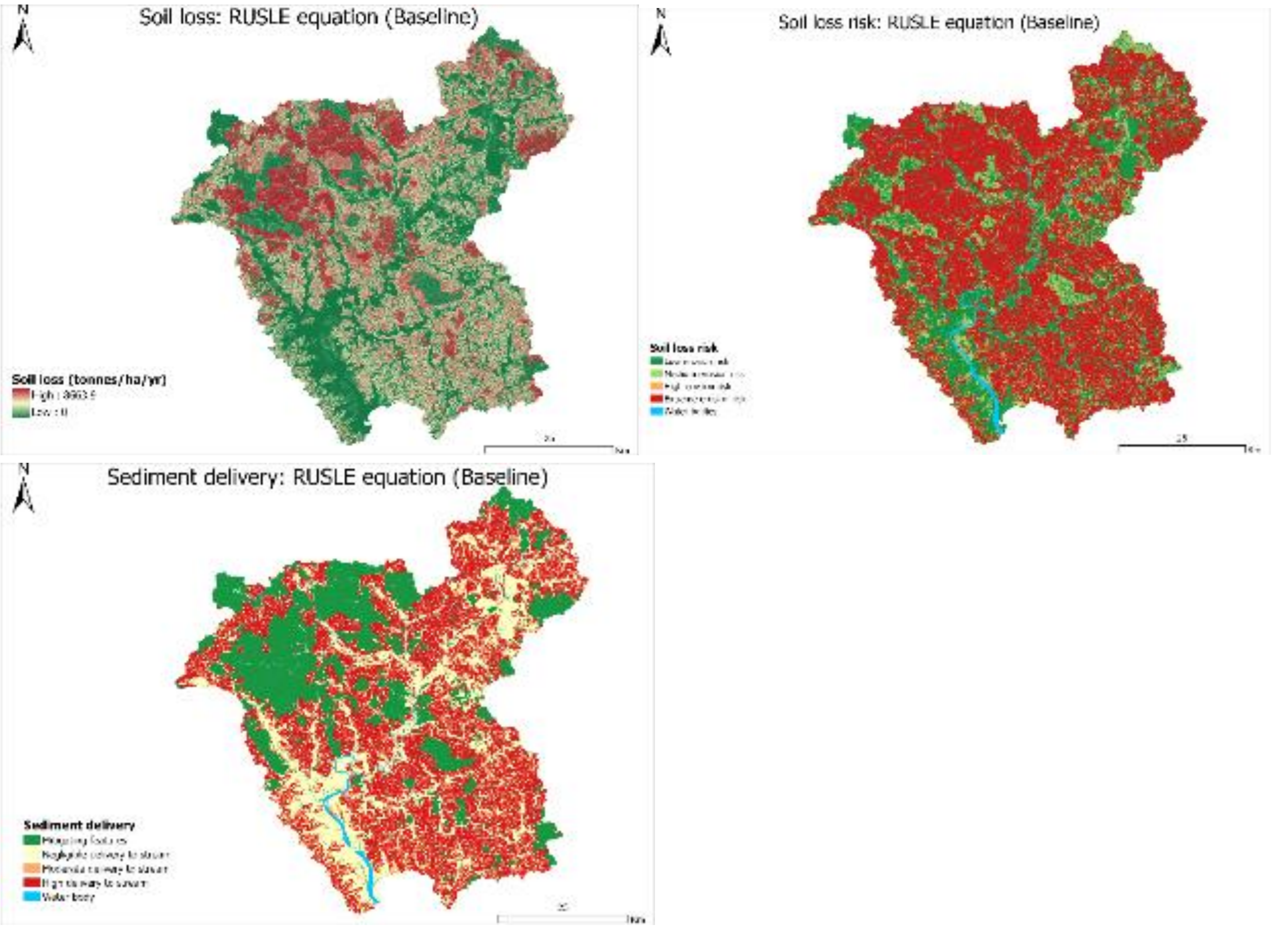


Figure 4-5: Results relating to both "point"-scale soil loss: (soil loss (tonnes/ha/yr and a categorisation of risk), and risk of this soil being delivered to water ways ("sediment delivery").

Habitat connectivity classes for kererū are presented in Figure 4-6. In the baseline, the area of habitat of interest is 28,210 ha. An area of 254,190 ha is identified as having opportunity to establish new habitat and 54,430 ha has opportunity to expand existing habitat (Table 4-9). The habitat of interest (dark green) indicates areas most suitable for kererū habitat such as native forest and vegetation. Other priority habitat (light green) indicates areas that would still benefit kererū, but less than its ideal habitat. Areas of opportunity to expand existing habitat (red) show areas that the species can currently access as they are adjacent to ideal habitat, and these areas would be ideal for interventions to extend existing habitat in order to improve connectivity. This does not mean that the entire red area needs to be converted to ideal habitat, but rather that expanding existing habitat patches here would allow for better species movement across the catchment. Areas of opportunity to establish new habitat (orange) are flagged as having less priority for management interventions because they would not be connected to existing habitat, as they may be too far for the species' dispersal ability, or the species would have to cross very hostile terrain to get to another habitat patch.

Table 4-9: Results of the habitat connectivity tool for kererū for the baseline.

Habitat classification	Area of the catchment (ha)
Habitat of interest	28,210
Other priority habitat	960
Opportunity to establish new habitat	25,4190
Opportunity to expand existing habitat	54,430

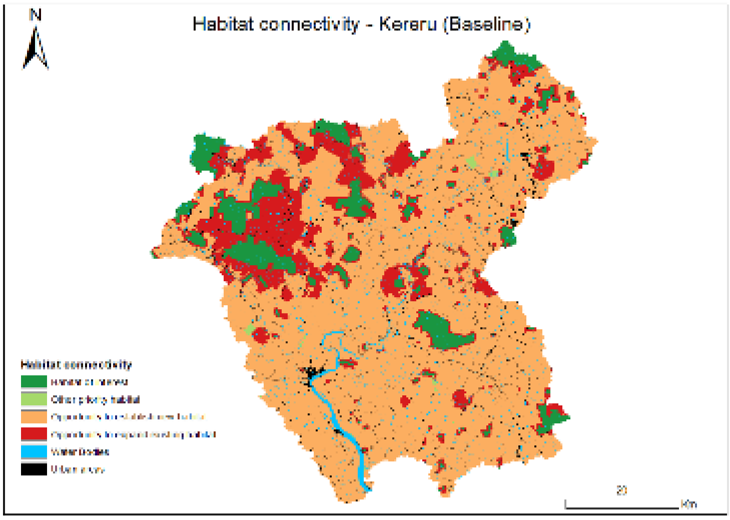


Figure 4-6: Results of habitat connectivity for kererū.

4.2 Scenario 1A

In this scenario, Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping on negligible productivity land are already unprofitable in 2025 where all this land will transition to Exotic Forestry by 2030. As the emissions levy gradually increases over time, the profitability of these four farming land uses decreases. By 2060, marginal productivity farms (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) and moderate productivity Hill Country Sheep and Beef farms become unprofitable and will switch to Exotic Forestry.

It is estimated that the catchment profitability in 2025 will be $325.41M. This will increase to $349.99M in 2030 due to the negligible productivity farming and Mixed Cropping land transitioning to a better modelled land use (Exotic Forestry). By 2060, the catchment profitability would increase to $901.92M as the marginal productivity Dairy farms and moderate productivity Hill Country Sheep and Beef and Lowland Beef Finishing farms convert to Exotic Forestry.

4.2.1 Economic analysis

Scenario 1A provides a baseline scenario under the lower emissions levy with untargeted freshwater regulations. Changes in the profitability of land use are shown in Table 4-10. Variable cost and fixed cost were separated to model profitability for the seven different land-uses. As the levy rate increases over time, all farming land uses become less profitable and by 2060, Hill Country Sheep and Beef farming will become unprofitable and Lowland Beef Finishing is barely making any profit. Exotic Forestry will receive carbon sequestration payments which increase over time, improving forestry profitability.

Table 4-10: Profitability of land types under scenario 1A for 2025, 2030 and 2060.

EFS per ha	Baseline (2025)	Scenario 1A (2030)	Scenario 1A (2060)
Dairy	$1,818	$1,729	$669
Hill Country Sheep and Beef	$356	$324	($66)
Lowland Beef Finishing	$625	$581	$67
Mixed Cropping	$8,681	$8,654	$8,329
Orchard (Avocado)	$21,015	$21,015	$21,015
Exotic Forestry	$1,519	$2,663	$7,668

The resulting changes in land use are shown in Table 4-11. In scenario 1A, all three negligible productive farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) are already unprofitable in 2025 and will be converted to Exotic Forestry by 2030. As the emission levy increases, by 2060, the three types of farming land with marginal productivity (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) and moderate productivity Hill Country Sheep and Beef farms will convert to Exotic Forestry. Land with Orchard (Avocado) is highly profitable but cannot be expanded as it is constrained by water availability.

Table 4-11: Land area distribution for each land type under the baseline 2025 and scenario 1A 2030 and 2060.

	Baseline (2025)		Scenario 1A (2030)		Scenario 1A (2060)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dairy	99,700	29.9%	90,431	27.1%	73,510	22.0%
Hill Country Sheep and Beef	124,148	37.2%	122,793	36.8%	22,237	6.7%
Lowland Beef Finishing	21,032	6.3%	15,672	4.7%	13,698	4.1%
Mixed Cropping (kumara and lamb finishing)	2,500	0.7%	2,368	0.7%	2,368	0.7%
Orchard (Avocado)	1,418	0.4%	1,418	0.4%	1,418	0.4%
Exotic Forestry	55,067	16.5%	71,183	21.3%	190,635	57.2%
Indigenous Vegetation	28,598	8.6%	28,598	8.6%	28,598	8.6%
Wetland	993	0.3%	993	0.3%	993	0.3%

A total levy revenue of $1.99B will be collected by 2060 and this has been modelled to be recycled back into the catchment as financial support for national level research.

4.2.2 Impact on overall emissions

Figure 4-7 shows the overall impact of land use changes for scenario 1A on the total emissions in t CO_2-eq. Total emissions are reduced from –350,303 t CO_2-eq in 2025, to -926,946 t CO_2-eq in 2030, and –4,854,811 t CO_2-eq in 2060.

GHG emissions for the Wairoa catchment are net negative in all years indicating sequestration from vegetation within the catchment exceeds emissions from farming land-uses. Figures for all scenarios have been derived from FARMAX outputs which uses the GWP100 metrics in the Fourth

Assessment Report (IPCC, 2007,) and manual calculation of estimated sequestration from forest or vegetation.

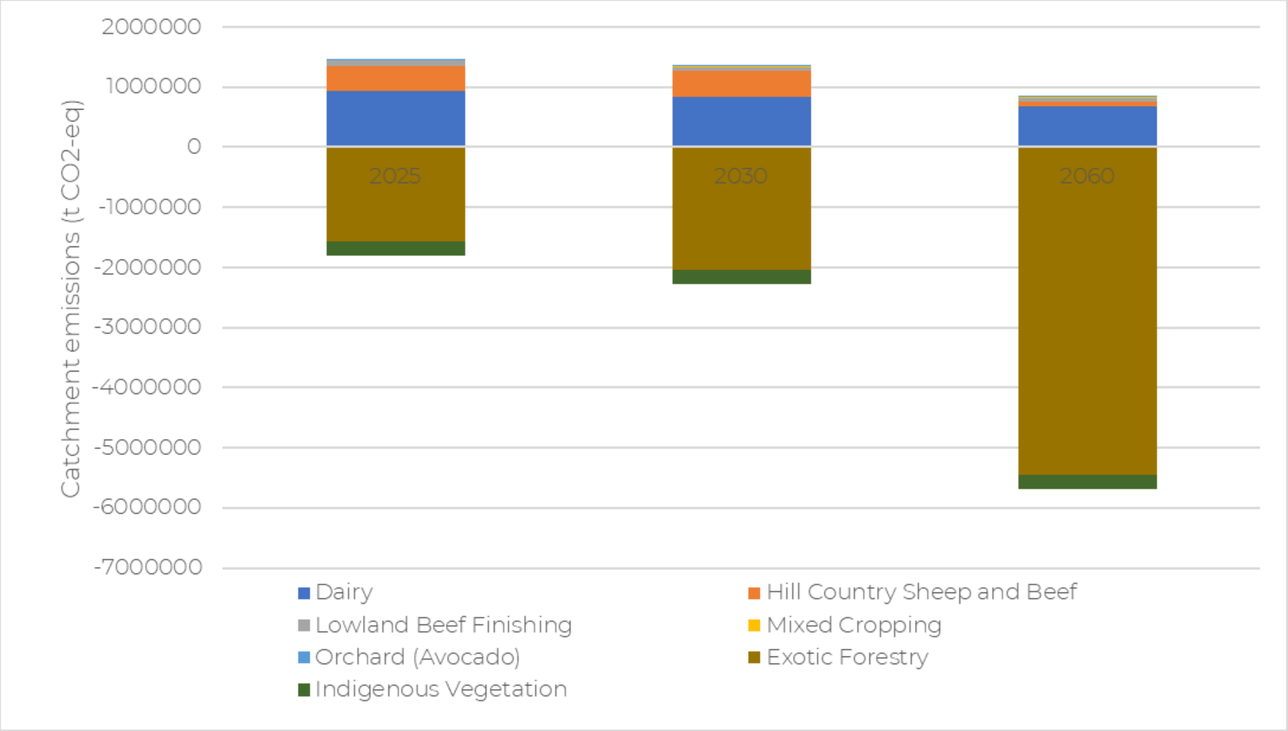


Figure 4-7: The impact of land use change on total GHG emissions for scenario 1A.

4.2.3 Environmental analysis

In scenario 1A, all negligible agricultural production capacity land (16,117 ha) in Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping was moved to Exotic Forestry in 2030. In 2060, 70,886 ha of marginal production capacity land in Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing and 48,565 ha of Hill Country Sheep and Beef farms with moderate agricultural production are also converted to Exotic Forestry.

The 2030 scenario presented a slight decrease in nitrogen terrestrial load and in-stream nitrogen concentration (Table 4-12, Figure 4-8 and Table 4-13). The significant shift from farmland (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) to Exotic Forestry in 2060 reduces the mean in-stream nitrogen concentration by half, from 0.7 mg/L to 0.3 mg/L.

Table 4-12: Summary statistics for nitrogen terrestrial load for the baseline and scenarios.

Nitrogen terrestrial load (kg/ha/yr)	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Min	0	0	0
Mean	10.7	10.0	6.6
Max	54.1	54.1	54.1

Table 4-13: Summary statistics of in-stream nitrogen concentration for the baseline and scenarios.

Nitrogen stream concentration (mg/L)	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Min	0	0	0
Mean	0.7	0.6	0.3
Max	191	188.1	23.1

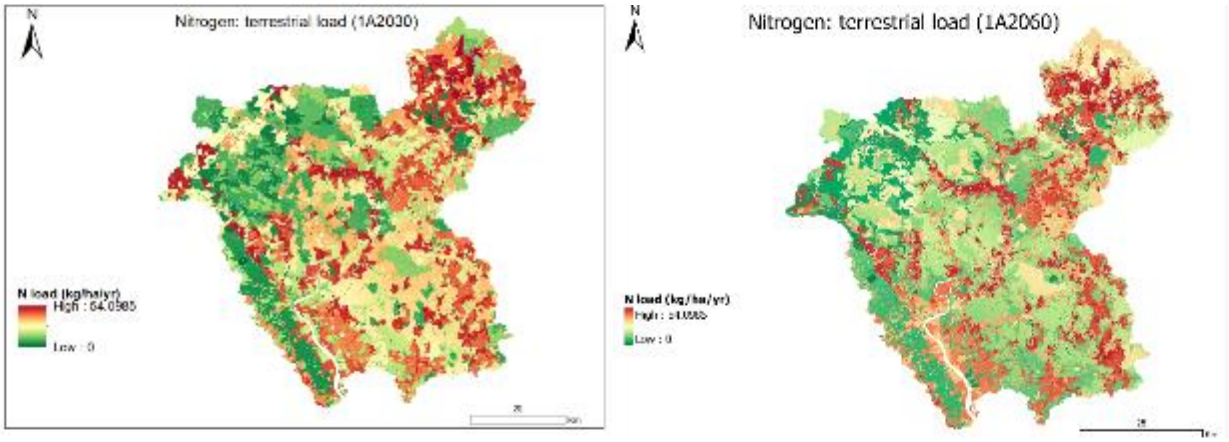


Figure 4-8: Nitrogen terrestrial load results for scenario 1A 2030 and 2060.

There are only a few slight changes in mean nitrogen terrestrial loads of farm types as the land use changes are marginal and occurred in negligible production capacity land (Table 4-14). Land use changes were in the most suitable parcels considering their size and distance to the closest areas of Exotic Forestry. As land use changes were not targeted specifically to areas of N high-risk, minor increases in the average value of Dairy and Lowland Beef Finishing are due to the land use changes happening in the areas of N low-risk.

Table 4-14: Mean N terrestrial loads for baseline 2025, scenario 1A 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean nitrogen terrestrial load (kg/ha/yr)		
	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Dairy	26.2	26.4	26.2
Hill Country Sheep and Beef	7.4	7.4	7.3
Lowland Beef Finishing	5.8	6.1	6.2
Mixed Cropping	5.2	5.2	5.2
Orchard (Avocado)	3.6	3.6	2.6

Similar to the N load maps, the 2030 and 2060 maps below (Figure 4-9) illustrate how the shift from farmland (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) to Exotic Forestry result in lower terrestrial P loading for the northern west and the centre parts of the catchment.

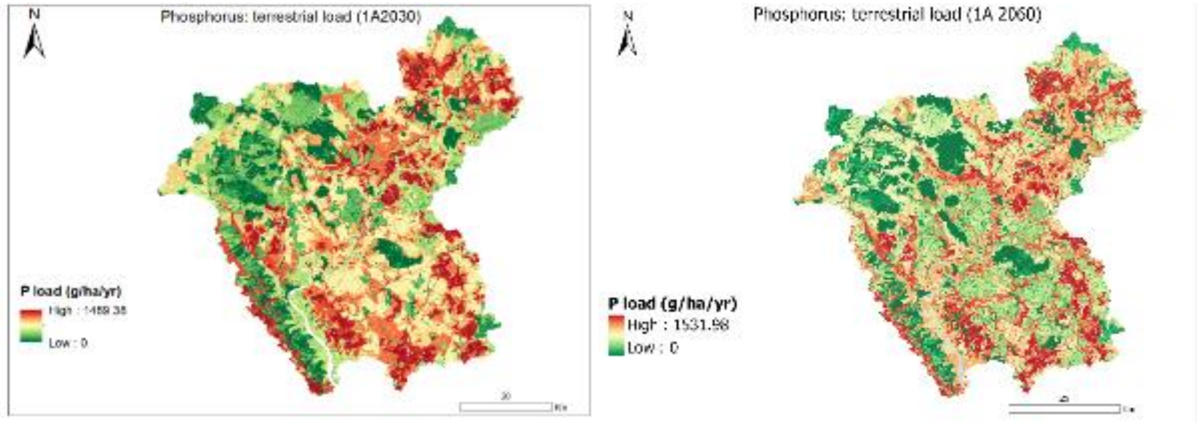


Figure 4-9: Phosphorus load results for scenario 1A 2030 and 2060

The results for P (Table 4-15 and Table 4-16) are similar to N. The changes in 2060 contribute to much lower mean P loads and in-stream concentrations.

Table 4-15: Summary statistics for phosphorus (P) terrestrial load for the baseline 2025, and scenario 1A 2030 and 2060.

P load (g/ha/yr)	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Min	0	0	0
Mean	401.5	369.0	240.4
Max	1532.0	1489.4	1482.9

Table 4-16: Summary statistics for in-stream phosphorus (P) concentrations for the baseline 2025, scenario 1A 2030 and 2060.

P stream concentration (mg/L)	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Min	0	0	0
Mean	0.016	0.013	0.006
Max	17.3	17.0	1.93

For mean phosphorus terrestrial loads per farm type, the average values for Dairy, Lowland Beef Finishing, and Mixed Cropping have decreased compared to the baseline 2025 (Table 4-17). With the big move from Hill Country Sheep and Beef in moderate production capacity and marginal production capacity land, it caused an increase in the mean value as the effect of a significant decrease in the total area of Hill Country Sheep and Beef land.

Table 4-17: Mean phosphorus (P) terrestrial loads for the baseline 2025, scenario 1A 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean P terrestrial load (g/ha/yr)		
	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Dairy	878.6	878.7	872.8
Hill Country Sheep and Beef	323.9	322.5	387.4
Lowland Beef Finishing	479.2	472.4	451.1
Mixed Cropping	101.9	88.8	88.8
Orchard (Avocado)	14.8	14.8	14.8

The flood mitigation results (Table 4-18) indicate a large increase in mitigating features in 2060 compared to the baseline and 2030. This is due to the move to Exotic Forestry which is capable of intercepting water flow and associated nutrients and sediments. Nature Braid assumes that Exotic Forestry is able to mitigate water flow and pollutants prior to harvest however it generates large amounts of sediment within Nature Braid, particularly on steep slopes as an average load including consideration of loss around harvest time.

Table 4-18: Results of the flood mitigation tool for the baseline and scenarios.

Flood characteristics	Area of the catchment (ha)		
	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Mitigating features	85,300	101,140	219,700
Mitigated features	7,110	12,240	23,880
Non-mitigated features	253,150	232,180	102,040

For soil loss by water, the mean soil loss for 2030 increases due to the presence of Exotic Forestry on the north of the catchment which interacts with the high rainfall and hilly topography (Figure 4-10, top left).

For Exotic Forestry, one of the modelling limitations is that the land use maps and scenarios do not define what stages of growth the forestry parcels are assumed to be under (planting, growth, harvesting). The model assumes general/on-average impacts of each parcel over the course of its lifetime. During growth and in mature stands, it has the potential to mitigate sediment delivery, but it would also have higher potential soil losses during harvesting. Future work with increased temporal resolution and granularity where forestry stages are defined would improve model parameterisation and estimates of potential soil loss.

Exotic Forestry clear-fell harvesting is associated with erosive practices, causing the mean to be much higher. Prior to harvest, Exotic Forestry is considered capable of mitigating flow, hence the flood mitigation results above (Table 4-18) and sediment delivery results below (Figure 4-10, bottom maps), but the clear-fell harvesting makes this land use vulnerable to erosion. Summary results of soil loss are displayed in Table 4-19.

Table 4-19: Summary statistics for terrestrial soil loss for the baseline 2025 and scenario 1A 2030 and 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Min	0	0	0
Mean	83.3	86.7	177.6
Max	8,663.9	8,663.9	8,774.2

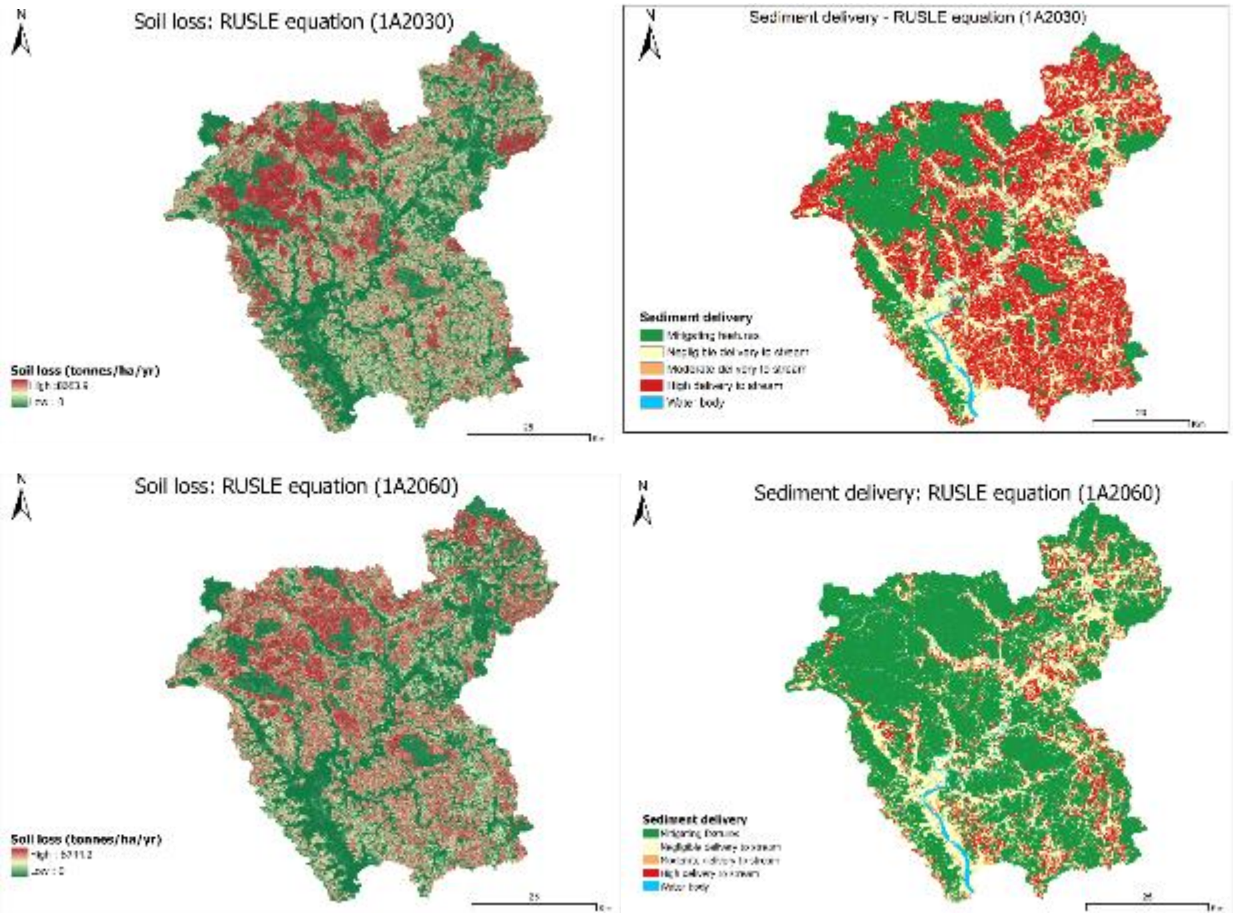


Figure 4-10: Erosion results for scenario 1A 2030 and 2060.

In 2030, the Exotic Forestry plantation adjacent to Indigenous Vegetation creates corridors for kererū to reach their ideal habitat (Indigenous Vegetation), resulting in an increase from 544.3 ha to 571.3 ha of areas with opportunity to expand existing habitat where additional patches of habitat can be placed to improve connectivity. In the 2060 scenario, the areas of opportunity to expand existing habitat increased with the move to Exotic Forestry resulted in large corridors for kererū to create more connectivity throughout the catchment (Table 4-20; Figure 4-11).

Table 4-20: Results of the habitat connectivity tool for kererū for the baseline 2025 and scenario 1A 2030 and 2060.

Habitat classification	Area of the catchment (ha)		
	Baseline 2025	Scenario 1A 2030	Scenario 1A 2060
Habitat of interest	28,210	28,210	28,210
Other priority habitat	960	960	960
Opportunity to establish new habitat	254,190	251,490	178,800
Opportunity to expand existing habitat	54,430	57,130	129,810

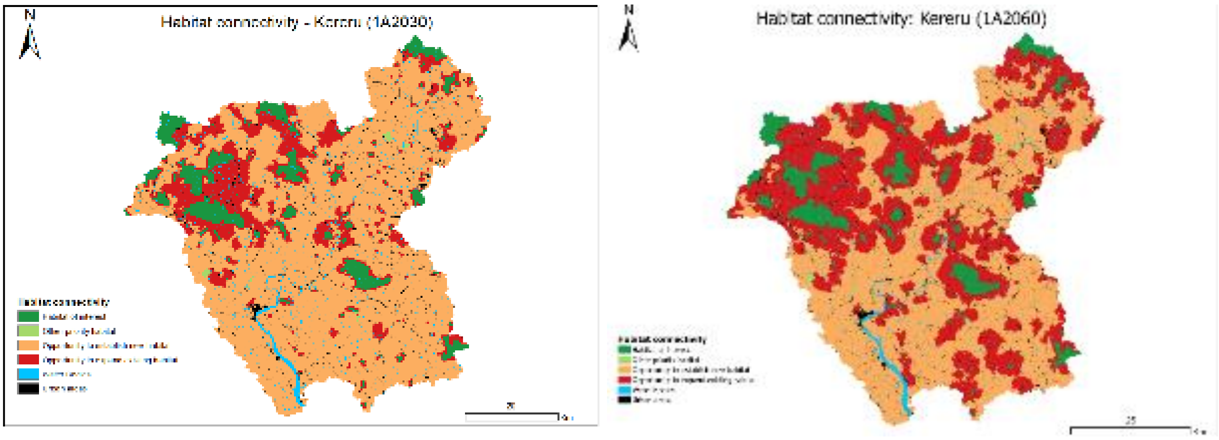


Figure 4-11: Habitat connectivity results for kererū in scenario 1A 2060.

4.3 Scenario 1B

It is estimated that for this scenario, the total catchment profitability in 2025 will be $363.35M. This is higher than the catchment profitability in 1A as the fall in all three farming types (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) and Mixed Cropping returns following the median emissions levy pathway is outweighed by the gain in returns for Exotic Forestry following the higher emission credit value. Catchment profitability increases to $417.75M in 2030 due to the three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with negligible productivity and Mixed Cropping land transitioning to a better modelled land use (Exotic Forestry). By 2060, the catchment profitability would increase to $2.42B as the marginal productivity Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing farms convert to Exotic Forestry.

This scenario presents generally positive environmental outcomes in 2030 and 2060 in terms of mean terrestrial nutrient loads, in-stream nutrient concentrations, and increased areas providing flood mitigation through the additions of Riparian Planting on streams in farmland. Improvements in habitat outcomes for kererū was also observed in 2030 and 2060 as these small areas of Riparian Planting creates better connectivity throughout the catchment.

4.3.1 Economic analysis

Scenario 1B follows the medium emissions levy pathway. Changes in the profitability of land use are shown in Table 4-21. In this scenario, the levy rate increases proportionally more over time compared to scenario 1A (refer to Appendix A.7). As the levy rate increases over time, all three types of farming land uses (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) become less profitable. By 2060, all three types of farming land uses become unsustainable except for very high production capacity and high production capacity Dairy land. These results are expected as the medium levy pathway was designed such that only the highly productive Dairy farming lands will remain in business by 2060. In contrast, Exotic Forestry becomes more profitable over time due to the increasing carbon sequestration payments.

Table 4-21: Profitability of land types under the baseline 2025, and scenario 1B for 2030 and 2060.

EFS per ha	Baseline (2025)	Scenario 1B (2030)	Scenario 1B (2060)
Dairy	$1,676	$1,487	($44)
Hill Country Sheep and Beef	$304	$235	($328)
Lowland Beef Finishing	$555	$464	($280)
Mixed Cropping	$8,637	$8,579	$8,111
Orchard (Avocado)	$21,015	$21,015	$21,015
Exotic Forestry	$1,519	$2,663	$7,668

The resulting changes in land use are shown in Table 4-22 below. For scenario 1B, all three types of farming (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) land with negligible productivity are already unprofitable in 2025 and will therefore be converted to Exotic Forestry by 2030. As the medium emission levy increases, by 2060, all three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) except for very high production capacity and high production capacity Dairy land becomes unprofitable and will be converted to Exotic Forestry. Land with Orchard (Avocado) is highly profitable but cannot be expanded due to the assumed constrained water availability.

Table 4-22: Land area distribution for each land type under the baseline 2025, and scenario 1B for 2030 and 2060.

	Baseline (2025)		Scenario 1B (2030)		Scenario 1B (2060)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dairy	99,700	29.9%	90,431	27.1%	73,510	22.0%
Hill Country Sheep and Beef	124,148	37.2%	122,793	36.8%	-	0.0%
Lowland Beef Finishing	21,032	6.3%	15,672	4.7%	-	0.0%
Mixed Cropping	2,500	0.7%	2,368	0.7%	2,368	0.7%
Orchard (Avocado)	1,418	0.4%	1,418	0.4%	1,418	0.4%
Exotic Forestry	55,067	16.5%	71,183	21.3%	226,569	67.9%
Indigenous Vegetation	28,598	8.6%	28,598	8.6%	28,598	8.6%
Wetland	993	0.3%	993	0.3%	993	0.3%

A total levy revenue of $3.21B will be collected by 2060. A total of $1.40B will be spent towards planting and maintaining riparian plants along the river streams in the catchment with the remaining $1.81B modelled to be recycled back into the catchment as financial support for national level research (Figure 4-12).

Unlike the Mataura catchment, no subsidy for stocking rate reduction is required, as under the medium levy by 2060, only Dairy farming land with moderate productivity and above are profitable enough to remain in operation. The unproductive Dairy farming lands and all Hill Country Sheep and Beef and Lowland Beef Finishing farming land are unprofitable by 2060 and will therefore convert to Exotic Forestry.

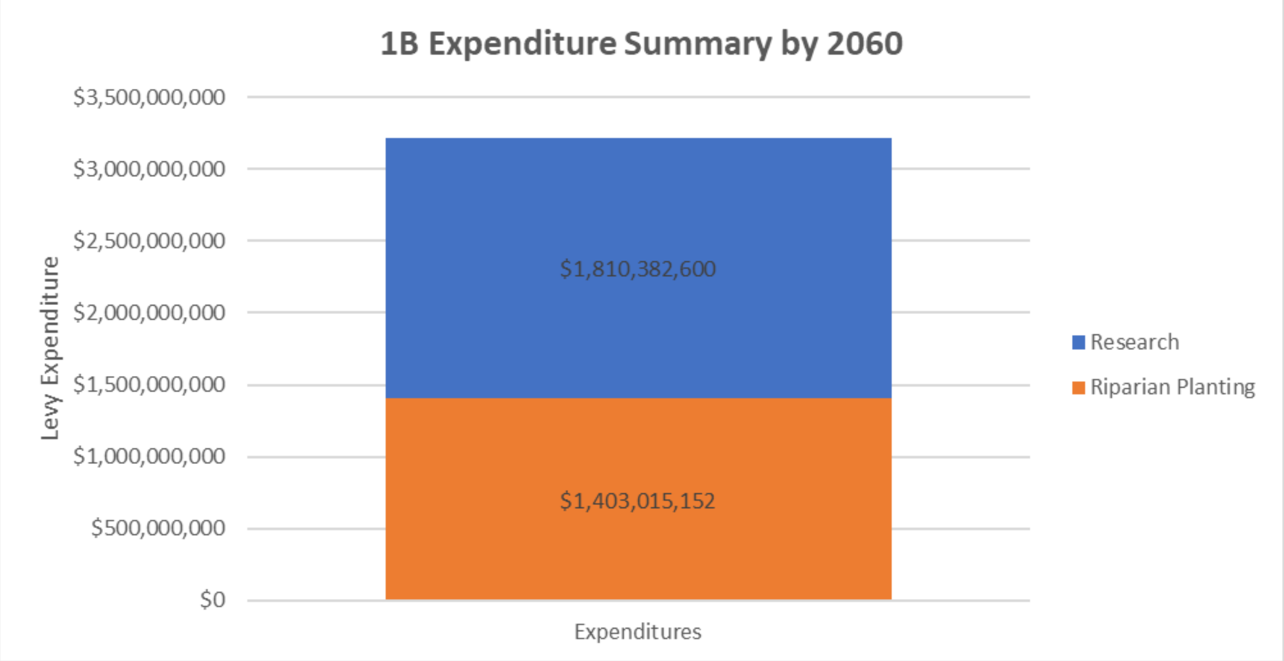


Figure 4-12: Levy revenue collected and expenditure summary for scenario 1B.

4.3.2 Impact on overall emissions

Figure 4-13 shows the overall impact of land use changes for scenario 1B on the total emissions in t CO_2-eq. Total emissions are reduced from –350,303 t CO_2-eq in 2025, to –926,946 t CO_2-eq in 2030, and –6,020,866 t CO_2-eq in 2060. GHG emissions for the Wairoa catchment are net negative in all years indicating sequestration from vegetation within the catchment exceeds emissions from farming land-uses.

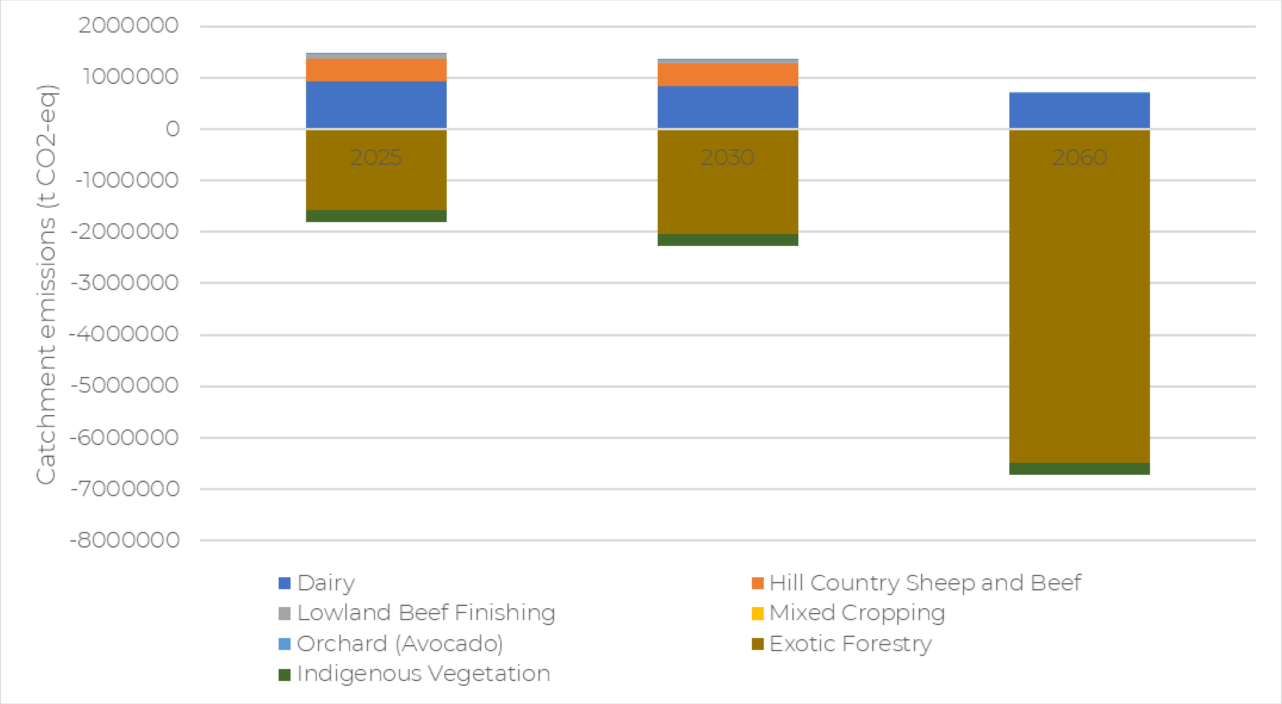


Figure 4-13: The impact of land use change on total GHG emissions for scenario 1B.

4.3.3 Environmental analysis

Scenario 1B 2030 also has 16,117 ha of negligible production land in Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping moved to Exotic Forestry, similar to 1A 2030. The difference between 1B 2030 and 1A 2030 is the addition of Riparian Planting along all streams within farmland. In 2060, 70,886 ha of marginal production capacity land and 48,565 ha with moderate productivity are converted to Exotic Forestry.

The effect of adding in Riparian Planting is illustrated in the summary statistics for in-stream N concentration (Table 4-23) where the mean is reduced by 0.2 mg/L in 2030 and 0.4 mg/L in 2060. The maximum is reduced by over 186.1 mg/L. Riparian Planting is able to intercept and mitigate the effects of nutrients on water quality.

Table 4-23: Summary statistics of nitrogen (N) in-stream concentration for the baseline 2025 and scenario 1B 2030 and 2060.

N stream concentration (mg/L)	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Min	0	0	0
Mean	0.7	0.5	0.3
Max	191	4.9	4.8

The statistics for N terrestrial load (Table 4-24 and Figure 4-14) show that the land use change also reduces the mean N load across the Wairoa catchment.

Table 4-24: Summary statistics for nitrogen (N) terrestrial load for the baseline 2025 and scenario 1B 2030 and 2060.

N terrestrial load (kg/ha/yr)	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Min	0	0	0
Mean	10.7	9.7	5.7
Max	54.1	54.1	54.1

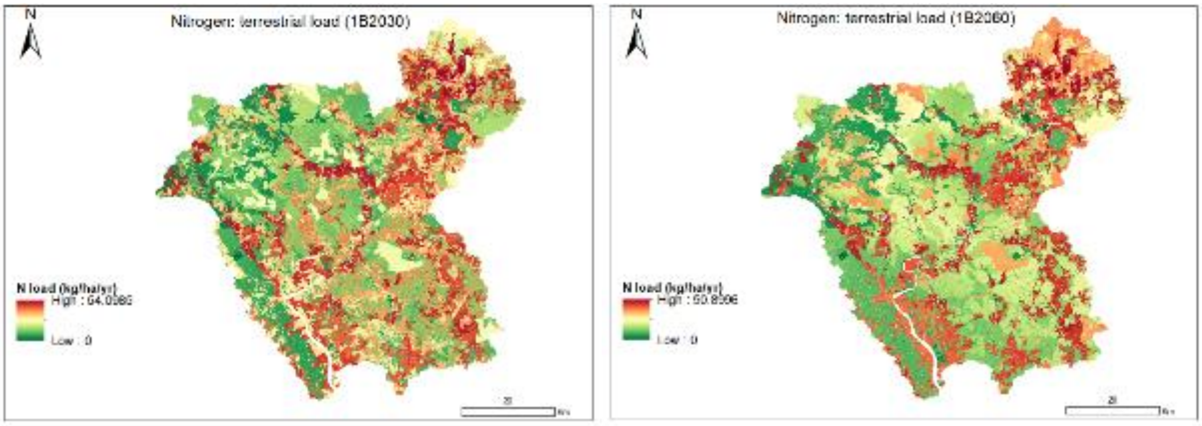


Figure 4-14: Nitrogen terrestrial load results for scenario 1B 2030 and 2060.

The effect of land use changes on mean nitrogen terrestrial load in 1B 2030 is similar to the 1A 2030 scenario. In 2060, since the main land use changes occurred in Hill Country Sheep and Beef and Lowland Beef Finishing, there were negligible changes in the mean N load of Dairy, Mixed Cropping and Orchard (Avocado) (Table 4-25).

Table 4-25: Mean N terrestrial loads for the baseline 2025, scenario 1B 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean nitrogen terrestrial load (kg/ha/yr)		
	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Dairy	26.2	26.3	26.1
Hill Country Sheep and Beef	7.4	7.4	N/a (moved to Exotic Forestry)
Lowland Beef Finishing	5.8	6.0	N/a (moved to Exotic Forestry)
Mixed Cropping	5.2	5.2	5.2
Orchard (Avocado)	3.6	3.6	3.6

Like the nitrogen results, the in-stream phosphorus concentrations show a decrease in the mean and a larger decrease in the maximum concentrations, relating to the Riparian Planting intercepting flow with nutrients (Table 4-26).

Table 4-26: Summary statistics for the phosphorus (P) concentration for the baseline 2025, scenario 1B 2030 and 2060.

P stream concentration (mg/L)	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Min	0	0	0
Mean	0.016	0.0077	0.0033
Max	17.3	0.1	0.1

The reductions in 2060 are reflected in the terrestrial phosphorus load maps (Figure 4-15). The summary statistics for phosphorus terrestrial load show decreases in the mean for both 2030 and 2060, relating to the movement of some areas under Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, and Mixed Cropping to less intensive uses (Table 4-27).

Table 4-27: Summary statistics for the phosphorus (P) terrestrial load for the baseline 2025, scenario 1B 2030 and 2060.

P terrestrial load (g/ha/yr)	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Min	0	0	0
Mean	401.5	358.94	193.19
Max	1532.0	1489.4	1482.8

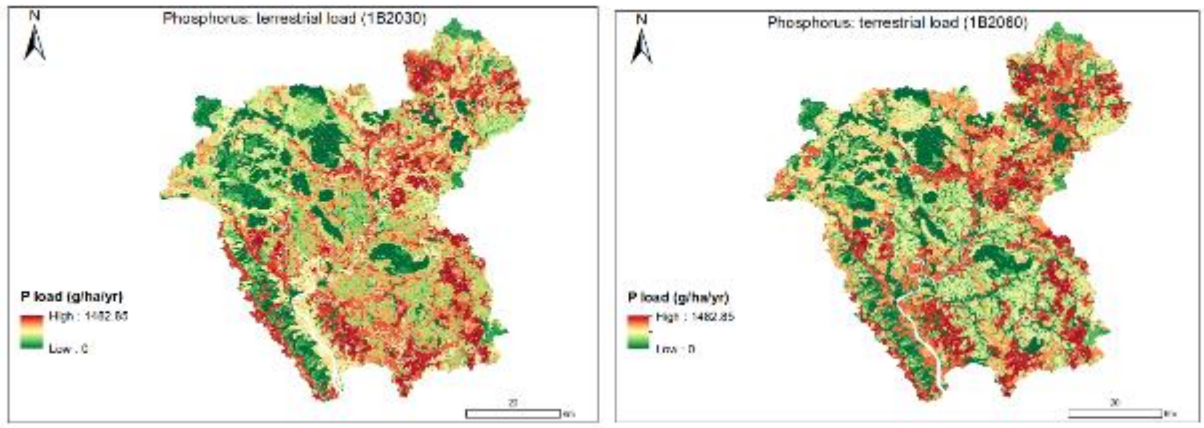


Figure 4-15: Phosphorus terrestrial load results for scenario 1B 2030 and 2060.

In 2030, decreases in estimated mean P terrestrial load were seen in Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing and Mixed Cropping (Table 4-28). The relative decrease in the estimated value of mean P terrestrial load in areas under Mixed Cropping was larger than the changes in other farm types, despite the area of Mixed Cropping land changed being smaller (132ha; Table 4-22).

Table 4-28: Mean phosphorus (P) terrestrial loads for the baseline 2025, scenario 1B 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean P terrestrial load (g/ha/yr)		
	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Dairy	878.6	877.9	871.3
Hill Country Sheep and Beef	323.9	321.5	N/a (moved to Exotic Forestry)
Lowland Beef Finishing	479.2	471.1	N/a (moved to Exotic Forestry)
Mixed Cropping	101.9	88.3	88.3
Orchard (Avocado)	14.8	14.8	14.8

The addition of Exotic Forestry and Riparian Planting leads to a large increase in the mitigating features in 2030 (+ 21,670 ha) and features considered mitigated or receiving the benefit from the additional planting (+ 91,790 ha) (Table 4-29). This shows that the area changed for Exotic Forestry and Riparian Planting benefits uphill areas approximately 4.2 times its size. The change in 2060 is not as significant, as the Exotic Forestry and Indigenous Vegetation changes are already located in uphill areas, which are also reflected in the soil loss (Figure 4-16).

Table 4-29: Results of the flood mitigation tool for the baseline 2025, scenario 1B 2030 and 2060.

Flood characteristics	Area of the catchment (ha)		
	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Mitigating features	85,300	106,970	256,930
Mitigated features	7,110	98,890	48,000
Non-mitigated features	253,150	140,610	41,750

For soil loss by water (erosion by water action), 2030 shows an increase in the estimated soil losses and areas vulnerable to soil losses due to the addition of Exotic Forestry (Figure 4-16, top left). However, the mean soil loss for 2060 further increases due to the presence of Exotic Forestry on hilly areas which interacts with high rainfall and can cause more erosion (Figure 4-16, top right).

Exotic Forestry harvesting is associated with erosive practices, causing the mean to be much higher. Prior to harvest, Exotic Forestry is considered capable of mitigating flow, hence the flood mitigation results above (Table 4-29) and sediment delivery results below (Figure 4-16, bottom maps), however harvesting practices make this land use vulnerable to erosion.

Table 4-30: Summary statistics for terrestrial soil loss for the baseline 2025 and scenario 1B 2030 and 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Min	0	0	0
Mean	83.3	86.5	178
Max	8,663.9	8,663.9	8,744.2

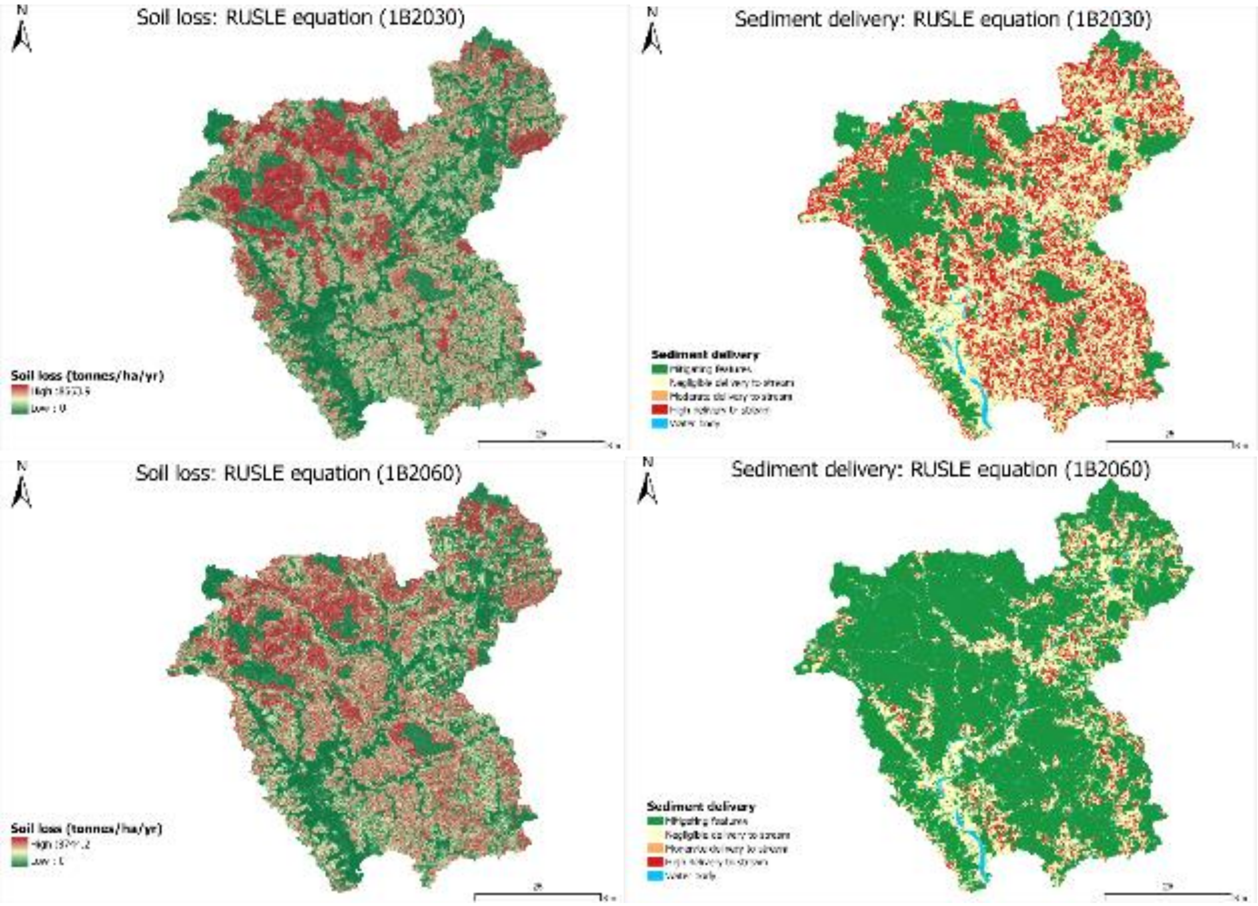


Figure 4-16: Erosion results for scenario 1B 2030 and 2060.

In 2060 for scenario 1B, the areas of opportunity to expand existing habitat increase, with the addition of Riparian Planting which is assumed to include native species ideal for kererū (Table 4-31 and Figure 4-17). The addition of small patches of native plant species through Riparian Planting is shown to improve connectivity throughout the catchment (red) in Figure 4-17.

Table 4-31: Results of the habitat connectivity tool for kererū for the baseline 2025 and scenario 1B 2030 and 2060.

Habitat classification	Area of the catchment (ha)		
	Baseline 2025	Scenario 1B 2030	Scenario 1B 2060
Habitat of interest	28,210	34,470	34,470
Other priority habitat	960	960	960
Opportunity to establish new habitat	254,190	54,950	7,650
Opportunity to expand existing habitat	54,430	247,400	294,700

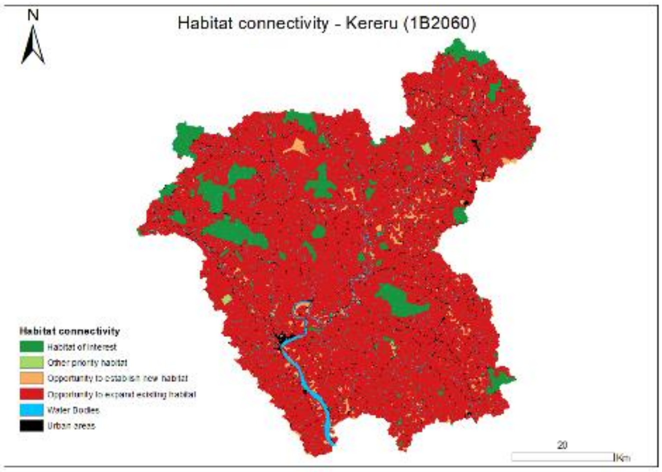


Figure 4-17: Habitat connectivity results for kererū for scenario 1B 2060.

4.4 Scenario 2A

It is estimated that for scenario 2A, the catchment profitability in 2025 will be $325.41M. This will increase to $524.82M in 2030, largely because all three types of farming land with land productivity of moderate and above and exposed to nitrogen and sediment loss risk converts to the more profitable land use of Agroforestry. Following the same process, by 2060, catchment profitability will increase to $1.02B.

These changes in land use and management had generally positive environmental outcomes with lower mean nutrient loads and in-stream concentrations, improvements in habitat connectivity throughout the catchment, and decreases in mean soil losses.

4.4.1 Economic analysis

Scenario 2A models the application of an N synthetic fertiliser cap and policy targeted to address the issue of sediment loss within the catchment area. The capped rates of 85 kg N/ha/yr for 2030, and 65 kg N/ha/yr for 2060 have been replicated from the Mataura catchment approach (see section 0 for an explanation as to why). The assumed response to address the sediment loss issue was to require tree planting in sediment high-risk areas.

Changes in the profitability of land use are shown in Table 4-32. In this scenario, the same low levy rate is applied as in scenario 1A. For 2030 and 2060, two values are shown, the “business as usual” land and the N high-risk land. N high-risk land is defined as land areas which are subject to capped synthetic N fertiliser application based on landscape susceptibility to nitrogen loss, as described in section 0. Where any of the three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) become unprofitable under the N cap and if land productivity is moderate and above, it is assumed to change to the corresponding Agroforestry system. For the three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing), under the N cap with land productivity of marginal and below, as these become unprofitable, they will convert to Exotic Forestry.

Like scenario 1A, as the levy rate increases over time, all three types of farming land uses (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) become less profitable. This is more pronounced for N high-risk land. By 2060, Hill Country Sheep and Beef and Lowland Beef Finishing become unprofitable and Dairy is making very low returns (although Hill Country Sheep and Beef is impacted only by the levy, not by the N Cap). Agroforestry is modelled as a profitable land-use alternative for N high-risk land.

Table 4-32: Profitability of land types under the baseline 2025 and scenario 2A for 2030 and 2060 including N high-risk land.

EFS per ha	Baseline (2025)	Scenario 2A (2030)	N high-risk land (2030)	Scenario 2A (2060)	N high-risk land (2060)
Dairy	$1,818	$1,729	$1,591	$669	$362
Hill Country Sheep and Beef	$356	$324	$324	($66)	($66)
Lowland Beef Finishing	$625	$581	$583	$67	($807)
Mixed Cropping	$8,681	$8,654	$8,654	$8,329	$8,329
Orchard (Avocado)	$21,015	$21,015	$21,015	$21,015	$21,015
Exotic Forestry	$1,519	$2,663	$2,663	$7,668	$7,668
Agroforestry - Dairy			$11,705		$11,175
Agroforestry - Lowland			$12,817		$12,559
Agroforestry - Hill			$12,814		$12,619

The resulting changes in land use are shown in Table 4-33. These are based on the overlap results from Nature Braid's and the LWS assessment for N high-risk areas and sediment high-risk areas (map provided in sensitivity analysis; Figure 4-36).

Sediment high-risk areas were subject to a rule requiring planting of at least 100 stems/ha. It has been assumed that this rule drives a conversion to Agroforestry systems, which occurs between 2025 and 2030. For land in the N high-risk areas, the farm system needs to be changed to comply with the N cap. All three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with negligible production capacity under reduced N fertiliser are not profitable and are therefore converted to Exotic Forestry by 2030. For land that is not classified as N high-risk or sediment high-risk, all three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with negligible production capacity and Mixed Cropping land with negligible production capacity will still switch to Exotic Forestry as they become unprofitable due to the levy payment.

By 2060, for N high-risk land with a fertiliser N cap (65kgN/ha/yr), only Dairy land with moderate production capacity and above, and Hill Country Sheep and Beef farming land with high production capacity and above will remain in their current land use as they are still able to maintain profitability under the N cap. All other land subject to the N cap will convert to the corresponding Agroforestry system. For unrestricted "normal/business as usual" land, all three types of farming (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with marginal production capacity will convert to Exotic Forestry as they become unprofitable. Orchard (Avocado) land is highly profitable in these areas but assumed not to expand due to constrained water availability.

Table 4-33: Land area distribution for each land type under scenario 2A, for 2025, 2030 & 2060.

	Baseline (2025)		Scenario 2A (2030)		Scenario 2A (2060)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dairy	99,700	29.9%	81,086	24%	68,720	20.6%
Hill Country Sheep and Beef	124,148	37.2%	96,683	29%	21,765	6.5%
Lowland Beef Finishing	21,032	6.3%	15,036	5%	11,772	3.5%
Mixed Cropping	2,500	0.7%	2,352	1%	2,352	0.7%
Orchard (Avocado)	1,418	0.4%	385	0%	385	0.1%
Exotic Forestry	55,067	16.5%	92,305	28%	173,627	52.1%
Indigenous Vegetation	28,598	8.6%	28,598	8.6%	28,598	8.6%
Wetland	993	0.3%	993	0.3%	993	0.3%
Agroforestry - Dairy			4,790	1.4%	4,790	1.4%
Agroforestry - Lowland			1,479	0.4%	2,957	0.9%
Agroforestry - Hill			9,749	2.9%	17,498	5.2%

A total levy revenue of $2.6B will be collected by 2060, which is channelled towards national level research. This is assumed to include information on and awareness raising on the benefits of agroforestry systems.

4.4.2 Impact on overall emissions

Figure 4-18 shows the overall impact of land use changes for scenario 2A on the total catchment emissions in t CO_2-eq. Total emissions are reduced from –350,304 t CO_2-eq in 2025, to –1,672,877 t CO_2-eq in 2030, and –3,360,828 t CO_2-eq in 2060. GHG emissions for the Wairoa catchment are net negative in all years indicating sequestration from vegetation within the catchment exceeds emissions from farming land-uses.

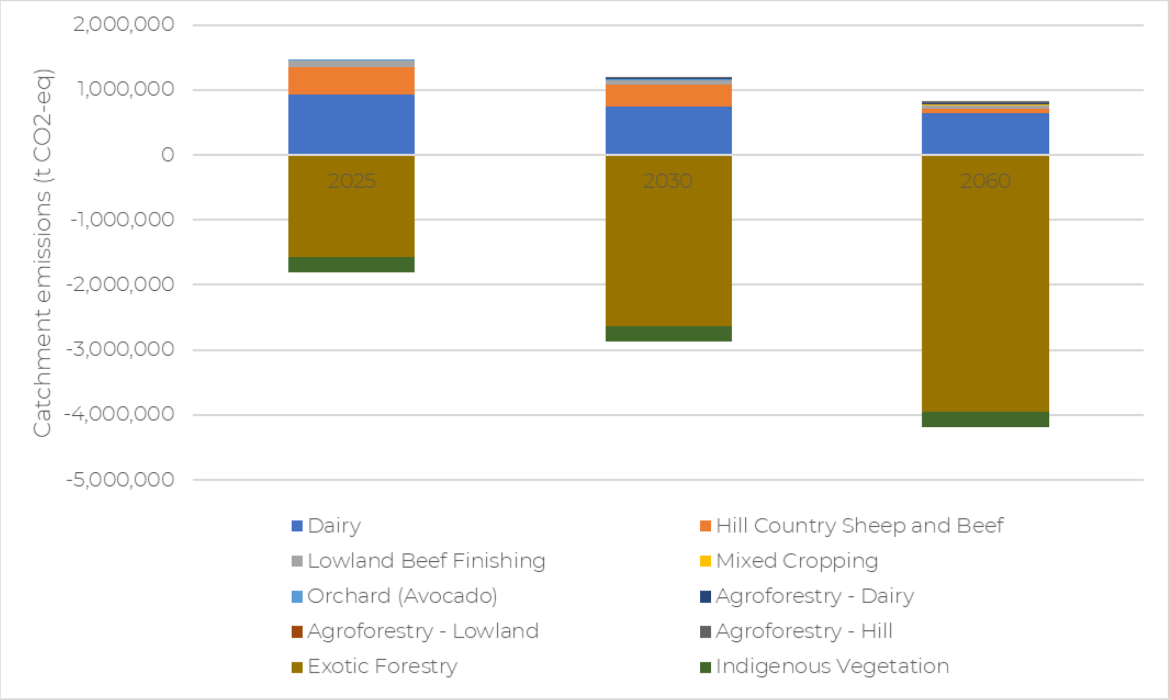


Figure 4-18: The impact of land use change on total GHG emissions for scenario 2A.

4.4.3 Environmental analysis

In scenario 2A, land use changes, reductions in stocking rate, and fertiliser use were targeted in the N high-risk (only) areas, sediment high-risk (only) areas, and the overlaps of N and sediment high-risk. Within N and sediment high-risk areas, Dairy was converted to Agroforestry - Dairy, Hill Country to Agroforestry - Hill Country and Lowland to Agroforestry - Lowland. In the N and sediments low-risk areas, land with negligible, marginal, and moderate productivity has been transitioned to Exotic Forestry. Sensitivity analysis with either the sediment high-risk area by LWS or the Nature Braid model is provided in Section 4.7.1.

The changes to land use and stocking, and limits on fertiliser inputs cause decreases in both the mean nitrogen load and in-stream concentration (Table 4-34, Table 4-35 and Figure 4-19). Compared to the baseline 2025, mean N load decreases by 1.9 kg/ha/yr in 2030 and by 4.3 kg/ha/yr in 2060. The mean N stream concentrations decrease from 0.7 mg/L in the baseline to 0.5 mg/L and 0.3 mg/L respectively in 2030 and 2060. In this scenario, the max in-stream concentrations decrease from 191 mg/L to 166.2 in 2030 and 20.5 mg/L in 2060 compared to the baseline 2025.

Table 4-34: Summary statistics for nitrogen (N) load for the baseline 2025 and scenario 2A 2030 and 2060.

N terrestrial load (kg/ha/yr)	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Min	0	0	0
Mean	10.7	8.8	6.5
Max	54.1	54.1	54.1

Table 4-35: Summary statistics of in-stream nitrogen (N) concentration for the baseline 2025 and scenario 2A 2030 and 2060.

N stream concentration (mg/L)	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Min	0	0	0
Mean	0.7	0.5	0.3
Max	191.0	166.2	20.5

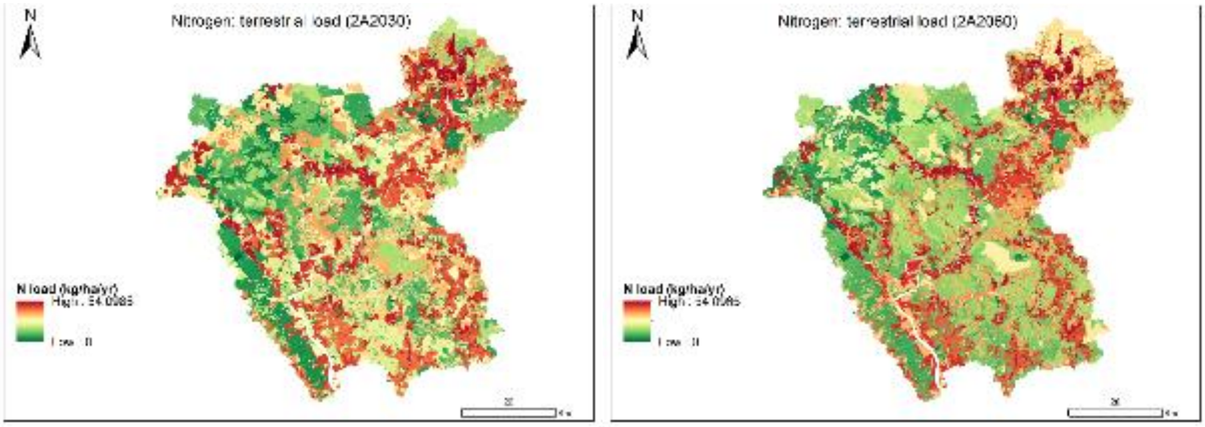


Figure 4-19: Nitrogen terrestrial load results for scenario 2A 2030 and 2060.

In this scenario, the modelling utilised information about areas vulnerable to nutrient and sediment loading in order to target areas to change land use and management practices. The effect of these changes can be seen in the decrease in mean N terrestrial load in Dairy, Agroforestry – Lowland and Agroforestry – Hill (Table 4-36). The minor increases in the value of mean terrestrial N loads for Lowland Beef Finishing and Hill Country Sheep and Beef may be caused by the difference in identifying N high-risk areas between Nature Braid and LWS.

Table 4-36: Mean nitrogen (N) terrestrial loads for the baseline 2025, scenario 2A 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean N terrestrial load (kg/ha/yr)		
	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Dairy	26.2	25.6	25.5
Hill Country Sheep and Beef	7.4	7.2	7.7
Lowland Beef Finishing	5.8	6.0	6.2
Mixed Cropping	5.2	5.2	5.2
Orchard (Avocado)	3.6	2.0	2.9
Agroforestry - Dairy	N/a	15.0	15.0
Agroforestry - Lowland	N/a	4.8	4.0
Agroforestry - Hill	N/a	4.6	4.4

When looking at the in-stream P concentrations, there is a significant decrease in the mean and maximum P stream concentration from the baseline to 2030 and 2060 (Table 4-37). The mean value decreases by approximately 2.7 times and the maximum value decreases by approximately 9.5 times in 2060.

Table 4-37: Summary statistics for the phosphorus concentration for the baseline 2025, scenario 2A 2030 and 2060.

Phosphorus stream concentration (mg/L)	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Min	0	0	0
Mean	0.016	0.01	0.006
Max	17.3	15.0	1.8

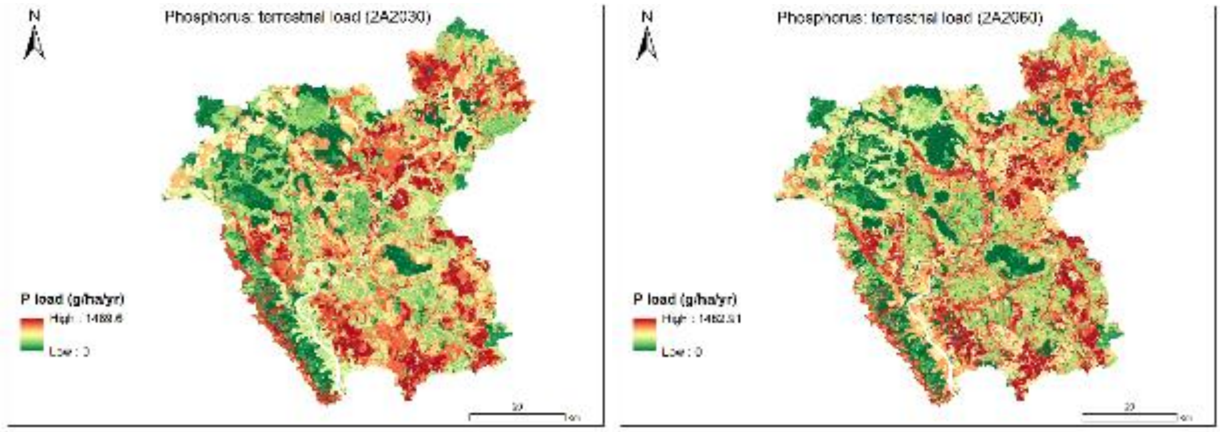


Figure 4-20: Phosphorus terrestrial load results for scenario 2A 2030 and 2060.

For scenario 2A in 2030 and 2060, the mean P terrestrial load across the catchment is lower than the baseline 2025 (Table 4-38).

Table 4-38: Summary statistics for the phosphorus terrestrial load for the baseline 2025, scenario 2A 2030 and 2060.

Phosphorus terrestrial load (g/ha/yr)	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Min	0	0	0
Mean	401.52	335.5	236.00
Max	1532.0	1490.0	1482.9

The effect of mitigations in 2A results in a decrease in the mean P terrestrial loads from Dairy, Lowland Beef Finishing, Mixed Cropping and Agroforestry - Hill (Table 4-39). The mean increase in load in 2060 for some farm types is due to changes in the area of land under those farm types.

Table 4-39: Mean phosphorus (P) terrestrial loads for the baseline 2025, scenario 2A 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean P terrestrial load (g/ha/yr)		
	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Dairy	878.6	874.7	862.6
Hill Country Sheep and Beef	323.9	340.6	388.4
Lowland Beef Finishing	479.2	468.7	444.8
Mixed Cropping	101.9	88.6	88.6
Orchard (Avocado)	14.8	14.2	14.2
Agroforestry - Dairy	N/a	406.8	406.8
Agroforestry - Lowland	N/a	140.1	171.2
Agroforestry - Hill	N/a	130.9	121.9

The flood mitigation capacity (area of mitigating and mitigated features) increases for both the 2A 2030 and 2060 years compared with the baseline 2025 (Table 4-40).

Table 4-40: Results of the flood mitigation tool for the baseline 2025, and scenario 2A for 2030 and 2060.

Flood characteristics	Area of the catchment (ha)		
	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Mitigating features	85,300	121,230	201,900
Mitigated features	7,110	22,900	30,300
Non-mitigated features	253,150	201,460	113,440

The changes for Scenario 2A in 2030 raise the mean soil loss compared to the Baseline 2025 (Table 4-41 and Figure 4-21) with further increases in 2060 with the conversion to Exotic Forestry.

Table 4-41: Summary statistics for terrestrial soil loss for the baseline 2025, and scenario 2A for 2030 and 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Min	0	0	0
Mean	83.3	107.1	168.4
Max	8,663.9	8,663.5	8,744.2

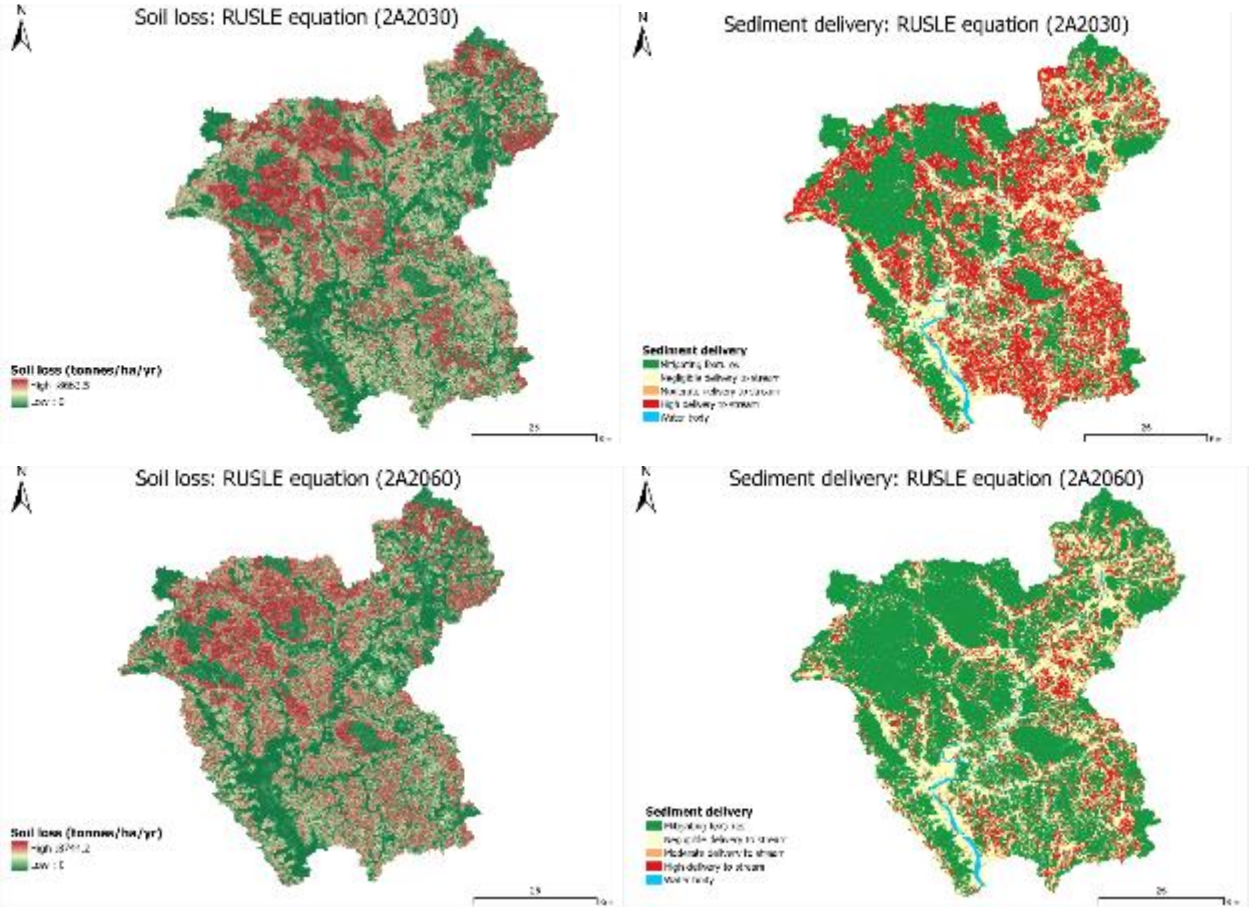


Figure 4-21: Erosion results for scenario 2A 2030 and 2060.

In 2A, the areas with "opportunity to expand existing habitat" increase in the period of 2025 and 2060. The addition of Exotic Forestry can improve habitat connectivity for kererū (Table 4-42). Although Exotic Forestry is not the most ideal habitat for kererū, the species can still move relatively easily through this type of land use and reach other areas of ideal habitat as seen in 2060 (Figure 4-22).

Table 4-42: Results of the habitat connectivity tool for kererū for the baseline 2025 and scenario 2A 2030 and 2060.

Habitat classification	Area of the catchment (ha)		
	Baseline 2025	Scenario 2A 2030	Scenario 2A 2060
Habitat of interest	28,210	28,210	28,210
Other priority habitat	961	960	960
Opportunity to establish new habitat	254,190	241,410	187,520
Opportunity to expand existing habitat	54,430	67,230	121,120

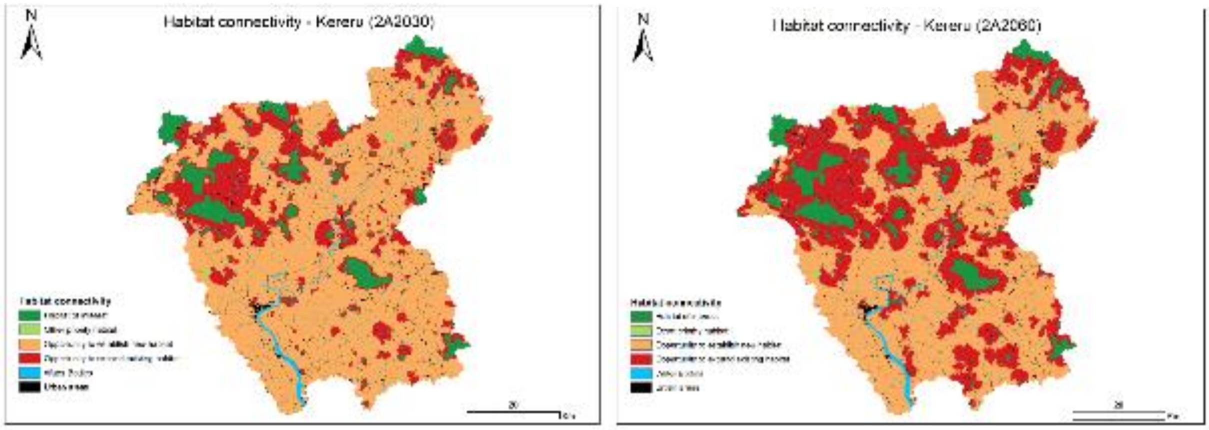


Figure 4-22: Habitat connectivity results for kererū for 2060.

4.5 Scenario 2B

In scenario 2B, the estimated catchment profitability in the baseline 2025 is $363.35M. This is higher than the catchment profitability in 1A as the fall in the three types of farming and Mixed Cropping returns following the median emissions levy pathway is outweighed by the gain in returns for Exotic Forestry following the higher carbon emission credit value. Catchment profitability will increase to $416.97M in 2030 due to Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing and Mixed Cropping land in negligible productivity areas transitioning to a more profitable modelled land use (Exotic Forestry). By 2060, the catchment profitability increases to $2.24B as all three types of farming land (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) with marginal productivity would convert to Exotic Forestry and all three types of farming land (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) identified with production capacity of moderate and above and exposed to N and sediment loss risk will convert to their corresponding Agroforestry systems.

These changes have generally positive environmental outcomes with decreases in mean terrestrial nutrient loading and in-stream nutrient concentrations, and better habitat connectivity for kererū. The conversion to Exotic Forestry in 2060 led to a slight increase in mean soil loss compared to 2030, but the mean and maximum soil losses in 2030 and 2060 are still lower compared to the baseline.

4.5.1 Economic analysis

Changes in the profitability of land use are shown in Table 4-43. In this scenario, the medium levy pathway is modelled as like scenario 1B. As the levy rate increases over time, all three types of farming land uses become less profitable. Note that the reported figures are averaged returns over the five productivity types. Even when the average is negative, highly productive land may still be profitable.

Table 4-43: Profitability of land types under scenario 2B for 2025, 2030 and 2060.

EFS per ha	Baseline (2025)	Scenario 2B (2030)	Scenario 2B (2060)
Dairy	$1,676	$1,487	($44)
Hill Country Sheep and Beef	$304	$235	($328)
Lowland Beef Finishing	$555	$464	($280)
Mixed Cropping	$8,637	$8,579	$8,111
Orchard (Avocado)	$21,015	$21,015	$21,015
Exotic Forestry	$1,519	$2,663	$7,668
Orchard (Macadamia)	$33,809	$33,809	$33,809
Agroforestry - Dairy		$11,705	$11,175
Agroforestry - Lowland		$12,817	$12,559
Agroforestry - Hill		$12,814	$12,619

The resulting changes in land use are shown in Table 4-44 below.

By 2030, all three types of farming land with negligible production capacity and negligible productivity Mixed Cropping land becomes unprofitable and will switch to Exotic Forestry.

By 2060, Dairy land feasible for Orchard (Macadamia) production will convert to Orchard (Macadamia) as it offers much higher returns. The Otonga land pocket within the Hikurangi Repo is restored to Wetland uses costing $127.63M in total. All marginal production capacity farming land (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) becomes unprofitable and will switch to Exotic Forestry. Moderate production capacity and above Hill Country Sheep and Beef and Lowland Beef Finishing will be making negative profits therefore will switch to the corresponding Agroforestry type (Agroforestry – Hill, and Agroforestry – Lowland).

In this scenario, financial support is provided for landholders to smoothen the land transition to Orchard (Macadamia). This is modelled as a progressive loan (funded by levy revenue) which begins in 2030 and will continue to issue out all levy revenue it collects annually until all feasible Dairy land has received their financial support in full and all eligible Dairy land is converted to Orchard (Macadamia). The cumulative loan issued between 2030 and 2060 will sum to $1.13B. The intention of this loan is not to generate extra revenue to the catchment, but to ensure that the Orchard (Macadamia) transition will occur. This loan has been set to require full repayment at a 5% margin, 9 years after the receival of this financial support, yielding a total loan interest revenue of $147.02M. As the loans are made interest free, yet the expected inflation over the 9-year loan period assuming an average inflation of 1% per annum compounds to around 9.4%, the modelled repayment margin of 5% is deemed to be very low, even when assessed against the required compensation for other environmentally beneficial activities or engagements.

Table 4-44: Land area distribution for each land type under the baseline 2025 and scenario 2B 2030 and 2060.

	Baseline (2025)		Scenario 2B (2030)		Scenario 2B (2060)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dairy	99,700	29.9%	90,555	27.2%	56,630	17.0%
Hill Country Sheep and Beef	124,148	37.2%	122,828	36.8%	-	0.0%
Lowland Beef Finishing	21,032	6.3%	16,312	4.9%	-	0.0%
Mixed Cropping	2,500	0.7%	2,368	0.7%	2,368	0.7%
Orchard (Avocado)	1,418	0.4%	1,418	0.4%	1,418	0.4%
Exotic Forestry	55,067	16.5%	70,384	21.1%	141,271	42.4%
Indigenous Vegetation	28,598	8.6%	28,598	8.6%	28,598	8.6%
Wetland	993	0.3%	993	0.3%	2,250	0.7%
Orchard (Macadamia)	-	0.0%	-	0.0%	16,680	5.0%
Agroforestry - Lowland	-	0.0%	-	0.0%	13,453	4.0%
Agroforestry - Hill	-	0.0%	-	0.0%	70,789	21.2%

A total levy revenue including loan margin return of $3.33B will be collected by 2060 (Figure 4-23). Loan margin revenue gained from the issue of loans to support land transition to Orchard (Macadamia) will contribute $56.52M to the total levy revenue. A total of $1.40B will be spent towards planting and maintaining riparian plants along the river streams in the catchment and a total of $127.63M will be spent towards wetland restoration of the Otonga pocket. The remaining levy funds of $ 1.80B are channelled towards national level research.

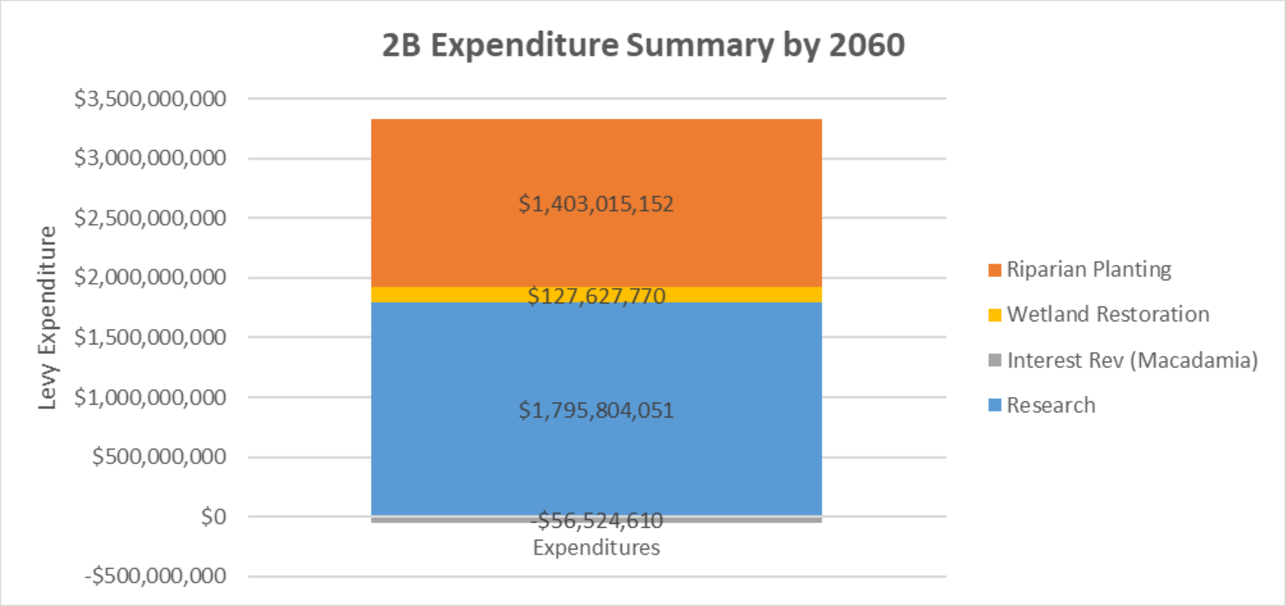


Figure 4-23: Levy revenue collected and expenditure summary for scenario 2B.

4.5.2 Impact on overall emissions

Figure 4-24 shows the overall impact of land use changes for scenario 2B on the total catchment emissions. Total emissions are reduced from –350,304 t CO_2-eq in 2025, to –899,910 t CO_2-eq in 2030, and –3,581,132 t CO_2-eq in 2060. GHG emissions for the Wairoa catchment are net negative in all years indicating sequestration from vegetation within the catchment exceeds emissions from farming land uses.

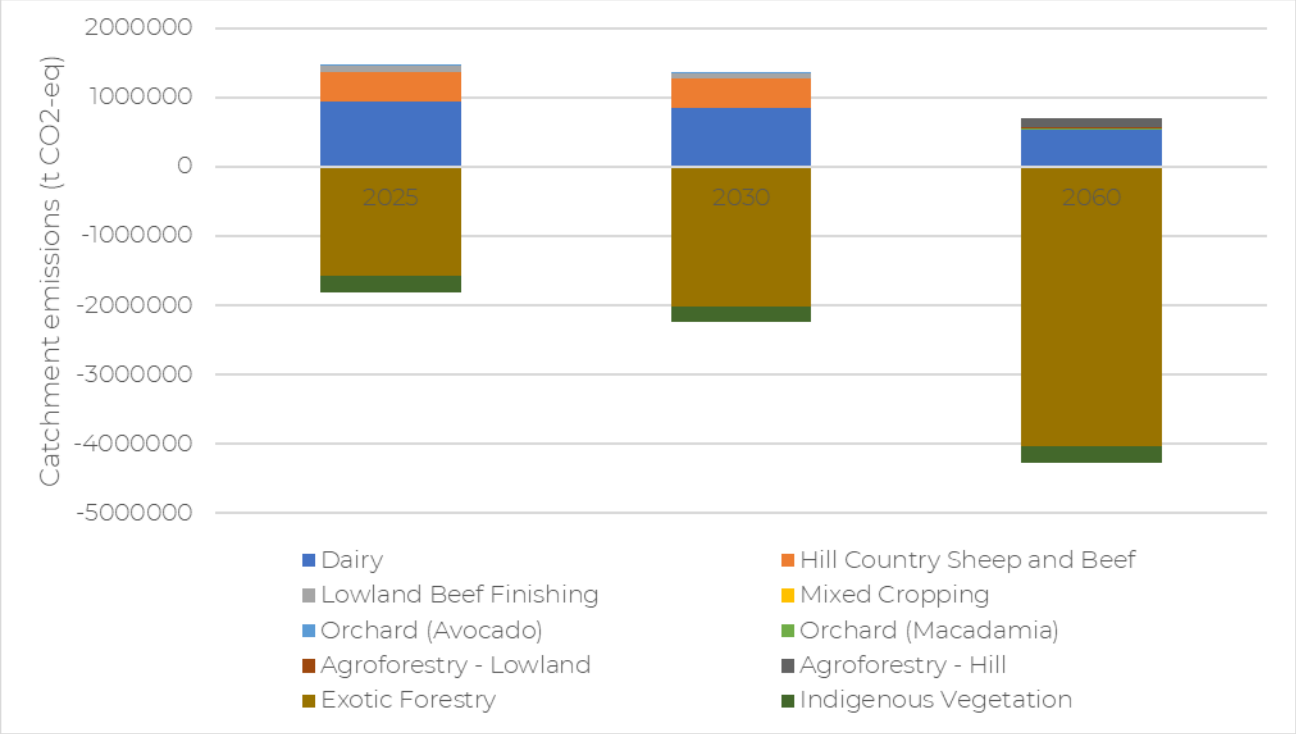


Figure 4-24: The impact of land use change on total GHG emissions for scenario 2B.

4.5.3 Environmental analysis

In 2B – 2030, the areas of agricultural land on land of negligible production capacity (Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing, Mixed Cropping) outside the Otonga pocket was changed to Exotic Forestry. Riparian planting was done by 2030. In 2B 2060, the Otonga pocket was restored, and all the Hill Country Sheep and Beef and Lowland Beef Finishing land with moderate to very high productivity was transitioned to Agroforestry. In 2060, suitable Dairy farmland was converted to Orchard (Macadamia) and farmland (Dairy, Hill Country Sheep and Beef, Lowland Beef Finishing) in marginal production capacity was changed to Exotic Forestry.

The effect of mitigation options for the whole catchment can be seen in the decrease of mean N load and in-stream nitrogen concentration. The mean terrestrial N load decreases from 10.7 to 9.7 kg/ha/yr in 2B 2030, and 5.0 kg/ha/yr in 2B 2060 (Table 4-46, Figure 4-25). The mean in-stream N concentration also decreases from 0.7 mg/L to 0.5 mg/L and 0.3 mg/L in 2B 2030 and 2B 2060 respectively, lower than these values in scenario 1B (Table 4-45). In 2B 2060, the maximum in-stream N concentration reduces to 4.2 mg/L, also lower than this value of scenario 1B.

Table 4-45: Summary statistics for in-stream nitrogen (N) concentration for the baseline 2025 and scenario 2B 2030 and 2060.

N stream concentration (mg/L)	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Min	0	0	0
Mean	0.7	0.5	0.3
Max	191.0	4.9	4.2

Table 4-46: Summary statistics for nitrogen(N) load for the baseline 2025 and scenario 2B 2030 and 2060.

N load (kg/ha/yr)	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Min	0	0	0
Mean	10.7	9.7	5.0
Max	54.1	54.1	53.9

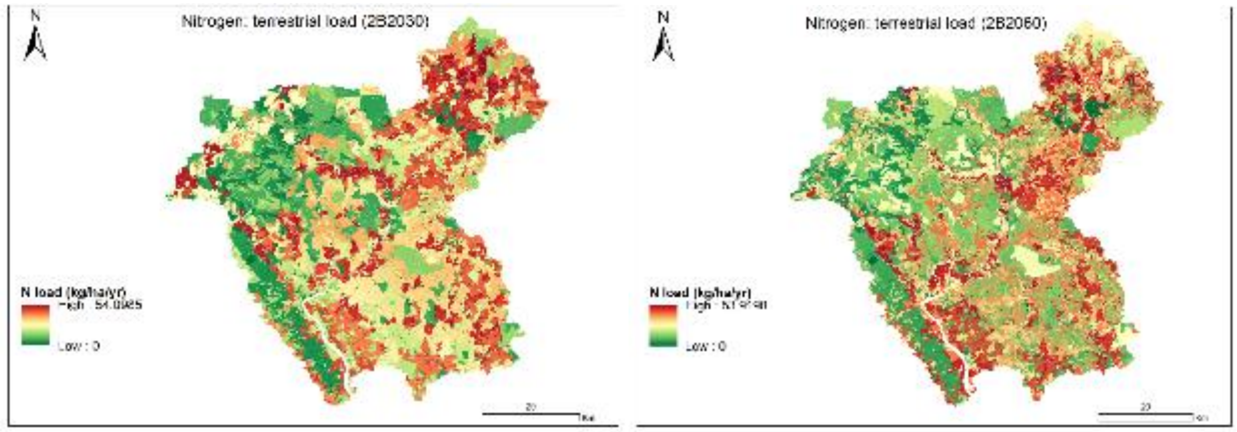


Figure 4-25: Nitrogen (N) load results for scenario 2B 2030 and 2060.

Mean N terrestrial loads per farm type of scenario 2B were presented in Table 4-47. Interventions in this scenario led to the decrease in mean N terrestrial load of Dairy and Hill Country Sheep and Beef. As land use changes were not targeted specifically to N high-risk areas (scenario 2A), the minor increase in the average value mean N terrestrial load in areas under Lowland Beef Finishing may likely be due to the land use changes happening in the N low-risk areas rather than N high-risk areas.

Table 4-47: Mean N terrestrial loads for baseline 2025 and scenario 2B 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean nitrogen terrestrial load (kg/ha/yr)		
	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Dairy	26.3	26.3	23.0
Hill Country Sheep and Beef	7.4	7.4	N/a (moved to other land uses)
Lowland Beef Finishing	5.8	6.0	N/a (moved to other land uses)
Mixed Cropping	5.2	5.2	5.2
Orchard (Avocado)	3.6	3.6	3.6
Orchard (Macadamia)	N/a	N/a	2.2
Agroforestry - Lowland	N/a	N/a	3.4
Agroforestry - Hill	N/a	N/a	4.1

Similar to the nitrogen results, reductions are evident for this scenario in the mean in-stream P concentration, and terrestrial P load. Mean and max in-stream P concentrations for 2030 show a significant decrease compared to the baseline (Table 4-48). The mean in-stream P value in 2060 reduces approximately 4.4 times compared with the baseline. Mean phosphorus terrestrial load in the whole catchment is decreased for both 2030 and 2060 (Table 4-49, Table 4-27).

Table 4-48: Summary statistics for the phosphorus concentration for the baseline 2025 and scenario 2B 2030 and 2060.

Phosphorus stream concentration (mg/L)	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Min	0	0	0
Mean	0.016	0.0077	0.0036
Max	17.3	0.1	0.1

Table 4-49: Summary statistics for the phosphorus terrestrial load for the baseline 2025 and scenario 2B 2030 and 2060.

Phosphorus load (g/ha/yr)	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Min	0	0	0
Mean	401.52	359.8	197.4
Max	1,532.0	1,490.0	1,483.0

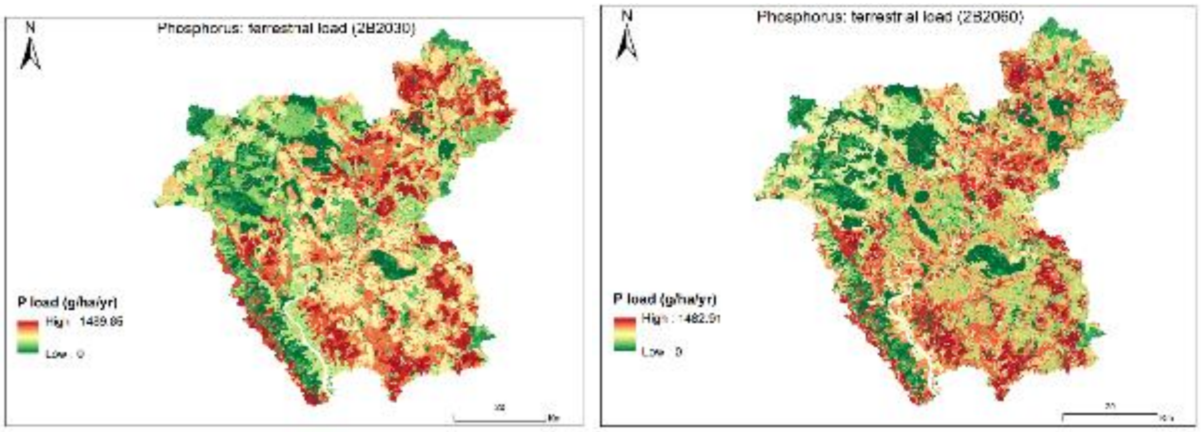


Figure 4-26: Phosphorus terrestrial load results for scenario 2B 2030 and 2060.

Mean P terrestrial loads tended to decrease in Hill Country Sheep and Beef, Lowland Beef Finishing and Mixed Cropping (Table 4-50). An increase in the average P load for Dairy is due to the changes only happening on marginal production capacity and negligible production capacity land which were not defined as P high-risk in Nature Braid.

Table 4-50: Mean P terrestrial loads for the baseline 2025 and scenario 2B 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean phosphorus terrestrial load (g/ha/yr)		
	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Dairy	878.6	877.5	921.5
Hill Country Sheep and Beef	323.9	321.7	N/a (moved to other land uses)
Lowland Beef Finishing	479.2	462.3	N/a (moved to other land uses)
Mixed Cropping	101.9	88.6	88.6
Orchard (Avocado)	14.8	14.9	14.9
Orchard (Macadamia)	N/a	N/a	11.6
Agroforestry - Lowland	N/a	N/a	202.2
Agroforestry - Hill	N/a	N/a	161.4

The restoration of the Otonga pocket, Riparian Planting, and Exotic Forestry in 2060 creates a large increase in the area of mitigating features (+ 108,360 ha) and features considered mitigated or receiving the benefit from the additional planting (+76,970 ha) from the baseline year to 2060 (Table 4-51). This shows that interventions in 2060 benefit uphill areas approximately 1.4 times their size.

Table 4-51: Results of the flood mitigation tool for the baseline 2025 and scenario 2B 2030 and 2060.

Flood characteristics	Area of the catchment (ha)		
	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Mitigating features	85,300	106,240	193,660
Mitigated features	7,110	99,650	84,080
Non-mitigated features	253,150	140,610	68,820

The changes in 2030 had a slight increase in mean soil loss within the catchment, but with further increases in 2060 with the conversion to Exotic Forestry (Table 4-52 and Figure 4-27).

Table 4-52: Summary statistics for terrestrial soil loss for the baseline 2025 and scenario 2B 2030 and 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Min	0	0	0
Mean	83.3	86.7	152.5
Max	8,663.9	8,663.5	8,744.2

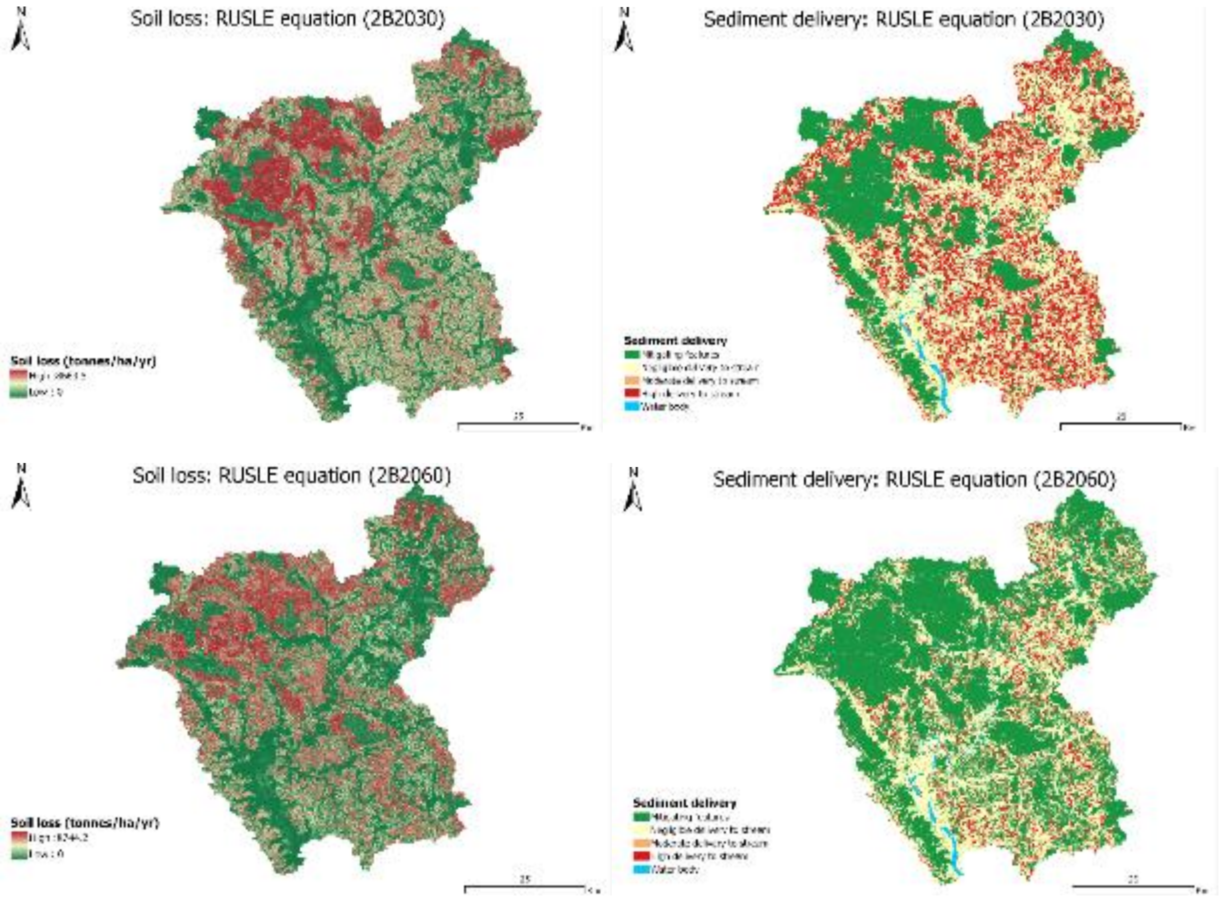


Figure 4-27: Erosion results – soil loss and sediment delivery for scenario 2B 2030 and 2060.

In 2030, the habitat of interest or ideal habitat for the kererū increases to 34,480 ha (Table 4-53 and Figure 4-28). The area of opportunity to expand existing habitat increases significantly to 246,900 ha. These areas are adjacent to ideal habitat, and management interventions can be placed here to increase connectivity over the catchment area. In 2060, the area of habitat of interest remains the same but the area of other priority habitat, or habitat that may still benefit the kererū, increases. These areas will still contribute to improved connectivity as they are landscapes where the species can travel through without much difficulty.

Table 4-53: Results of the habitat connectivity tool for kererū, for the baseline 2025 and scenario 2B 2030 and 2060.

Habitat classification	Area of the catchment (ha)		
	Baseline 2025	Scenario 2B 2030	Scenario 2B 2060
Habitat of interest	28,210	34,480	34,480
Other priority habitat	961	960	2,110
Opportunity to establish new habitat	254,190	55,470	14,010
Opportunity to expand existing habitat	54,430	246,900	287,210

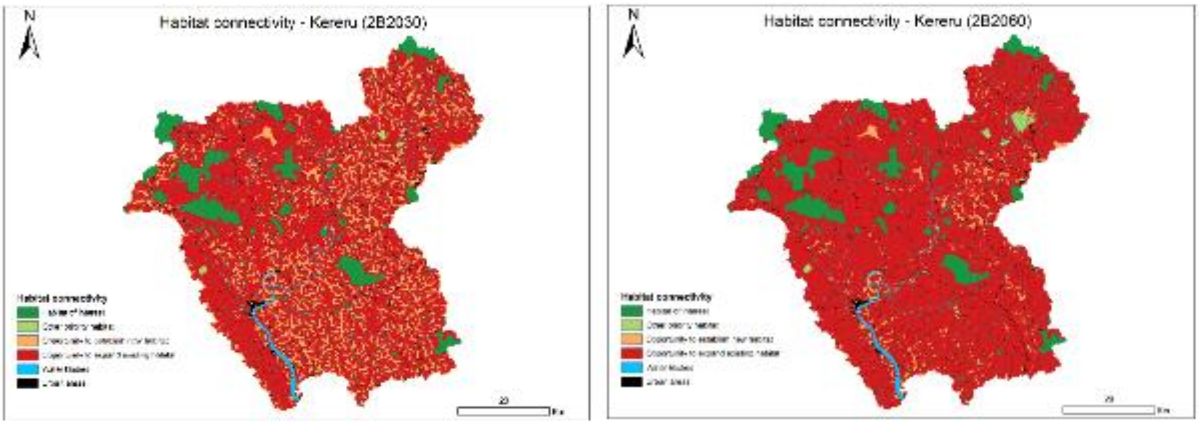


Figure 4-28: Habitat connectivity results for kererū for scenario 2B 2030 and 2060.

4.6 Scenario 2C

It's estimated that the catchment profitability in 2025 will be $363.35M. This is higher than the catchment profitability in 2A as the fall in the three types of farming (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) and Mixed Cropping returns following the median emissions levy pathway is outweighed by the gain in returns for Exotic Forestry following the higher carbon emission credit value. Catchment profitability will fall to $284.96M in 2030 due to the three types of farming (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with negligible productivity and negligible production capacity Mixed Cropping land not identified as part of the wetland restoration process will transition to a more economical land use (Exotic Forestry). As the ETS is phased out in 2030, the return on exotic forestry. By 2060, the catchment profitability would increase to $2.24B due to the three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with marginal productivity converting to Totara Forestry, and Hill Country Sheep and Beef and Lowland Beef Finishing farming with moderate productivity and above and exposed to nitrogen and sediment loss will convert to Agroforestry – Hill and Agroforestry – Lowland.

These land use changes have positive environmental outcomes through decreases in mean terrestrial nutrient loads and in-stream nutrient concentrations, mean soil losses, and improvements to habitat connectivity. The areas capable of mitigating flow and intercepting water, nutrients, sediments, and other contaminants, were able to benefit uphill areas approximately 4.9 times their size.

4.6.1 Economic analysis

Scenario 2C is similar to 2B as it follows the same medium levy pricing pathway with the levy revenue recycled back into the catchment and prioritised to be spent following the simple targeted approach. It repeats the same targeted mitigations such as Riparian Plantings and financial support to smoothen the Dairy transition to Orchard (Macadamia). Land transitions follow the same pathway as in 2B, but with all eight pockets of the Hikurangi Repo land being restored as Wetland rather than just the Otonga pocket between 2030 and 2060. By 2060, all three types of farming land with marginal production capacity will be subsidised to convert to Totara Forestry. Any remaining levy revenue after the simple targeted expenditures will be channelled to fund national level research.

Changes in the profitability of land use are shown in Table 4-54. In this scenario, the medium levy pathway is modelled. As the levy rate increases over time, all three types of farming land uses (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) become less profitable. Note that the reported figures are averaged returns over the five productivity types. Even when the average is negative, highly productive land may still be profitable.

Table 4-54: Profitability of land types under the baseline 2025 and scenario 2C for 2030 and 2060.

EFS per ha	Baseline (2025)	Scenario 2C (2030)	Scenario 2C (2060)
Dairy	$1,676	$1,487	($44)
Hill Country Sheep and Beef	$304	$235	($328)
Lowland Beef Finishing	$555	$464	($280)
Mixed Cropping	$8,637	$8,579	$8,111
Orchard (Avocado)	$21,015	$21,015	$21,015
Exotic Forestry	$1,519	$518	$518
Totara Forestry	($1,007)	($1,294)	($1,294)
Orchard (Macadamia)	$33,809	$33,809	$33,809
Agroforestry - Dairy		$11,705	$11,175
Agroforestry - Lowland		$12,817	$12,559
Agroforestry - Hill		$12,814	$12,619

The resulting changes in land use are shown in Table 4-55. By 2030, all three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with negligible production capacity and negligible productivity Mixed Cropping land becomes unprofitable and will switch to Exotic Forestry.

By 2060, productive Dairy land identified by Nature Braid as feasible for Orchard (Macadamia) production will switch to this land use as it offers significantly higher returns. All eight pockets of the Hikurangi Repo will be restored, costing $907.84M in total. As the three types of farming land (Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing) with marginal production capacity become unprofitable, they will switch to Totara Forestry. As Exotic Forestry offers a greater return than Totara Forestry, it would require a total subsidy of $2.57B to encourage conversion to Totara Forestry. Hill Country Sheep and Beef and Lowland Beef Finishing with moderate production capacity and above will be unprofitable and therefore will switch to the corresponding Agroforestry system (Agroforestry – Hill or Agroforestry – Lowland).

Table 4-55: Land area distribution for each land type under the baseline 2025 and scenario 2C for 2030 and 2060.

	Baseline (2025)		Scenario 2C (2030)		Scenario 2C (2060)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dairy	99,700	29.9%	92,562	27.8%	53,434	16.0%
Hill Country Sheep and Beef	124,148	37.2%	122,848	36.8%	-	0.0%
Lowland Beef Finishing	21,032	6.3%	16,484	4.9%	-	0.0%
Mixed Cropping	2,500	0.7%	2,368	0.7%	2,368	0.7%
Orchard (Avocado)	1,418	0.4%	1,418	0.4%	1,408	0.4%
Exotic Forestry	55,067	16.5%	68,185	20.4%	68,185	20.4%
Totara Forestry	-	0.0%	-	0.0%	70,883	21.3%
Indigenous Vegetation	28,598	8.6%	28,598	8.6%	28,594	8.6%
Wetland	993	0.3%	993	0.3%	8,145	2.4%
Orchard (Macadamia)	-	0.0%	-	0.0%	16,680	5.0%
Agroforestry - Lowland	-	0.0%	-	0.0%	13,158	3.9%
Agroforestry - Hill	-	0.0%	-	0.0%	70,601	21.2%

In this scenario, a total levy revenue including loan margin return of $3.76B will be collected by 2060 (Figure 4-29). Loan margin gained from the issue of loans to support land transition to Orchard (Macadamia) will contribute $56.5M to the total levy revenue. A total of $1.40B will be spent towards planting and maintaining riparian plants along the river streams in the catchment and a total of $908M will be spent towards Wetland restoration of the eight pockets of the Hikurangi Repo. There will be $1.45B leftover which has been assumed to be channelled to fund national level research.

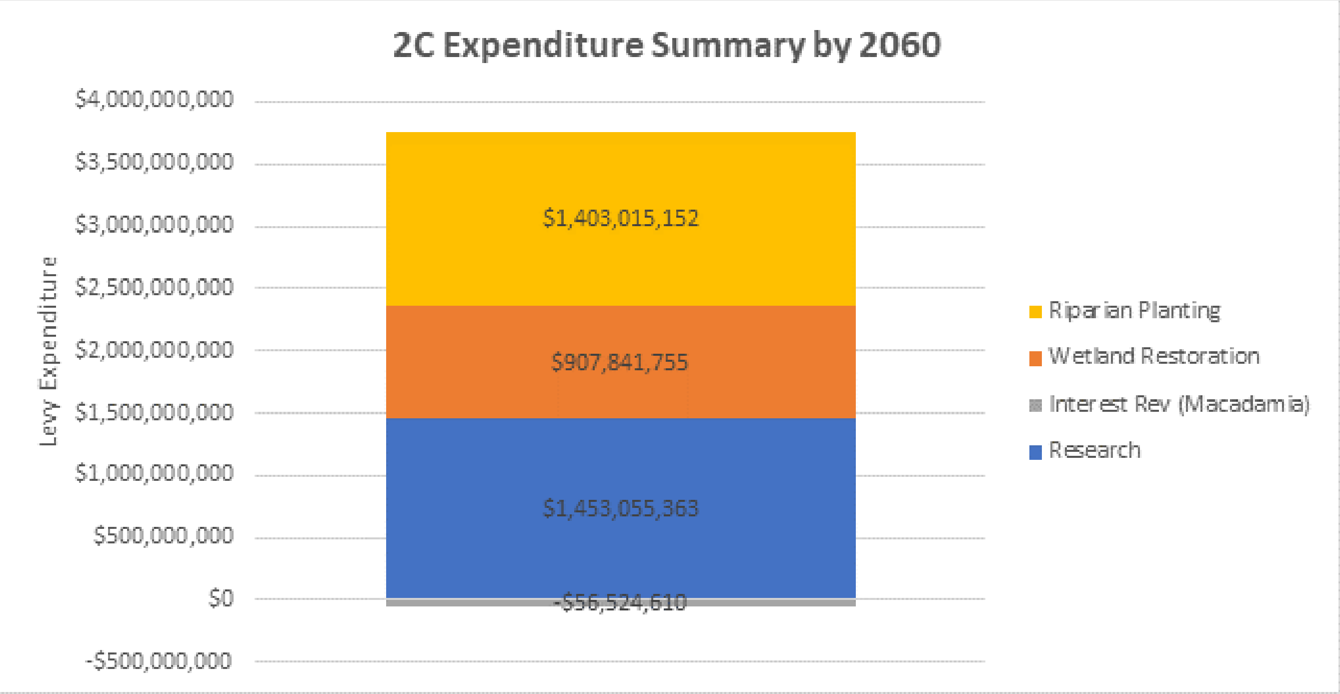


Figure 4-29: Levy revenue collected and expenditure summary for scenario 2C.

4.6.2 Impact on overall emissions

Figure 4-30 shows the overall impact of land use changes for scenario 2C on the total catchment emissions. Total emissions are reduced from –350,304 t CO_2-eq in 2025, to –817,465 t CO_2-eq in 2030, and –2,101,853t CO_2-eq in 2060. GHG emissions for the Wairoa catchment are net negative in all years indicating sequestration from vegetation within the catchment exceeds emissions from farming land uses in 2060.

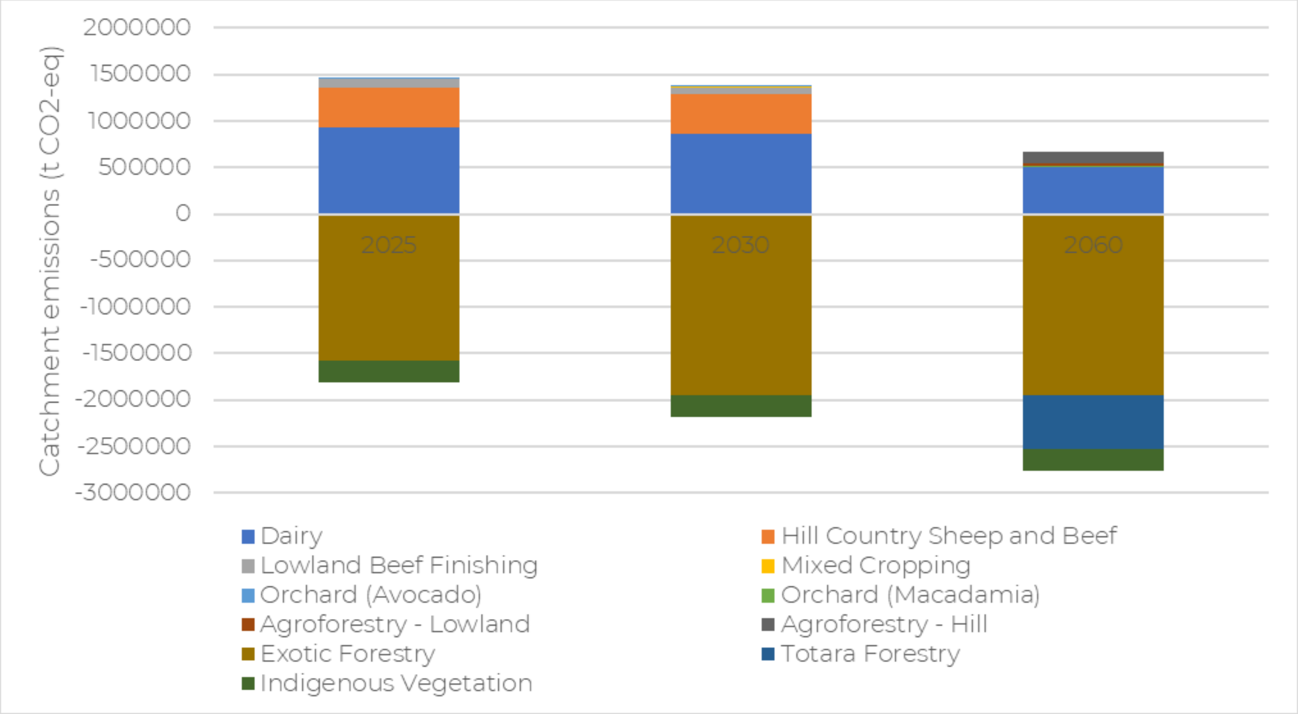


Figure 4-30: The impact of land use change on total GHG emissions under scenario 2C.

4.6.3 Environmental analysis

In 2030, the negligible productivity agricultural land which is not within the Hikurangi Repo pockets is changed to Exotic Forestry. Riparian Planting is completed by 2030. In 2060, all the Hikurangi Repo pockets are restored, and all the Hill Country Sheep and Beef and Lowland Finishing Beef with moderate to very high productivity is transitioned to Agroforestry. In 2060, suitable Dairy farmland is converted to Orchard (Macadamia) and all three types of farmland (Dairy, Hill Country Sheep and Beef, and Lowland Finishing Beef) in marginal production capacity is transitioned to Totara Forestry.

The effect of mitigation options for the whole catchment can be seen in the decrease of mean N load and in-stream N concentration in 2030 and 2060. The mean in-stream N concentration decreases from 0.7 mg/L in the baseline to 0.5 mg/L in 2030 and to 0.3 mg/L in 2060 (Table 4-56). The maximum in-stream N concentration reduces significantly by about 186mg/L in 2030 and 2060. The mean terrestrial N load decreases from 10.7 to 9.9 kg/ha/yr in 2C 2030, and 4.9 kg/ha/yr in 2C 2060 (Table 4-57 and Figure 4-31). The reduction in terrestrial N load and in-stream N concentration in 2C 2060 is similar to 2B 2060.

Table 4-56: Summary statistics for in-stream nitrogen concentration for the baseline 2025 and scenario 2C 2030 and 2060.

Nitrogen stream concentration (mg/L)	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Min	0	0	0
Mean	0.7	0.5	0.3
Max	191	4.9	4.2

Table 4-57: Summary statistics for terrestrial nitrogen load for the baseline 2025 and scenario 2C 2030 and 2060.

Nitrogen load (kg/ha/yr)	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Min	0	0	0
Mean	10.7	9.9	4.9
Max	54.1	54.1	53.9

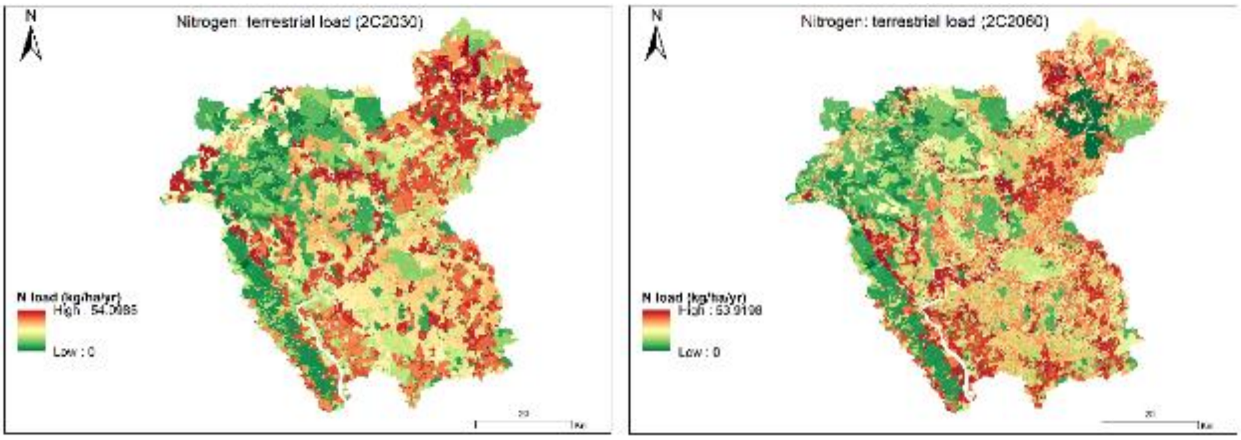


Figure 4-31: Nitrogen terrestrial load results for scenario 2C 2030 and 2060.

In this scenario, land use changes result in a slight decrease in the mean N terrestrial load of land being used for Dairy. There is a slight increase in the mean N terrestrial load of Lowland Beef Finishing. This may be as a result of the changes in 2030 where areas of low/medium N risk under Lowland Beef Finishing on negligible productivity moved to other land uses and left the areas of Lowland Beef Finishing that had higher N risk.

Table 4-58: Mean N terrestrial loads for the baseline 2025 and scenario 2C 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean nitrogen terrestrial load (kg/ha/yr)		
	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Dairy	26.2	25.3	23.0
Hill Country Sheep and Beef	7.4	7.4	N/a (moved to other land uses)
Lowland Beef Finishing	5.8	6.0	N/a (moved to other land uses)
Mixed Cropping	5.2	5.2	5.2
Orchard (Avocado)	3.6	3.6	3.6
Orchard (Macadamia)	N/a	N/a	2.2
Agroforestry - Lowland	N/a	N/a	3.4
Agroforestry - Hill	N/a	N/a	4.8

The mean in-stream P concentration (Table 4-59) and terrestrial P load (Table 4-60 and Figure 4-32) also reduce significantly in both 2030 and 2060 compared to the baseline 2025. The mean in-stream P concentration reduces more than 2 times from 0.016 to 0.0078 mg/L and the maximum reduces by about 160 times in 2060. This shows the significant impacts of Totara Forestry and Wetland restoration on reducing phosphorus loading within the catchment.

Table 4-59: Summary statistics for the phosphorus in-stream concentration for the baseline 2025 and scenario 2C 2030 and 2060.

Phosphorus stream concentration (mg/L)	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Min	0	0	0
Mean	0.016	0.0078	0.0035
Max	17.276	0.118	0.108

Table 4-60: Summary statistics for the phosphorus terrestrial load for the baseline and scenario 2C 2030 and 2060.

Phosphorus load (g/ha/yr)	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Min	0	0	0
Mean	401.52	363.11	190.48
Max	1531.98	1489.64	1482.9

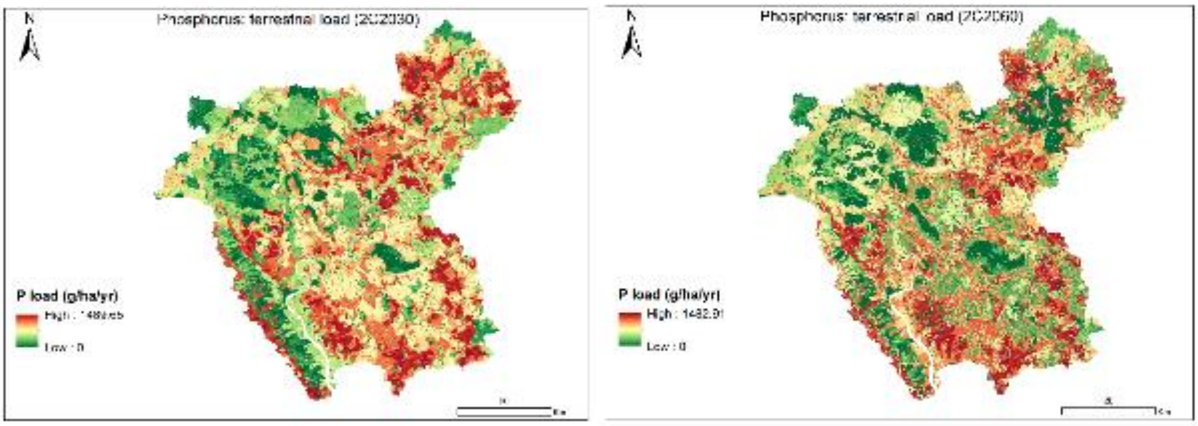


Figure 4-32: Phosphorus terrestrial load results for scenario 2C 2030 and 2060.

Similar to scenario 2B, mean P terrestrial loads decreased in Hill Country Sheep and Beef, Lowland Beef Finishing and Mixed Cropping (Table 4-61). An increase in the average P load for Dairy is a result of the changes only happening on marginal production capacity and negligible production capacity land which were not defined as P high-risk areas in Nature Braid.

Table 4-61: Mean P terrestrial loads for the baseline 2025, scenario 2C 2030 and 2060 for farm types in the Wairoa.

Farm types	Mean phosphorus terrestrial load (g/ha/yr)		
	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Dairy	878.6	871.1	962.4
Hill Country Sheep and Beef	323.9	321.7	N/a (moved to other land uses)
Lowland Beef Finishing	479.2	460.6	N/a (moved to other land uses)
Mixed Cropping	101.9	88.6	88.6
Orchard (Avocado)	14.8	14.9	14.7
Orchard (Macadamia)	N/a	N/a	11.3
Agroforestry - Lowland	N/a	N/a	203.7
Agroforestry - Hill	N/a	N/a	161.5

The land use changes to Totara Forestry, Wetland, and Riparian Planting create a large increase in the area of mitigating features in 2030 with an 18,890 ha increase in areas that have the capability to intercept flow from uphill areas (Table 4-62). This also led to an increase in areas considered mitigated, or receiving these interception benefits, of + 93,090 ha. This shows that the areas changed benefit uphill areas approximately 4.9 times their size.

Table 4-62: Results of the flood mitigation tool for the baseline 2025 and scenario 2C 2030 and 2060.

Flood characteristics	Area of the catchment (ha)		
	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Mitigating features	85,300	104,190	196,290
Mitigated features	7,110	100,200	82.700
Non-mitigated features	253,200	142,100	67,550

The changes in 2060 lead to a large decrease in mean soil loss from 83.3 tonnes/ha/yr in the baseline 2025 and 86.6 tonnes/ha/yr in 2030 to 70.7 tonnes/ha/yr in 2060 (Table 4-63). With the introduction of a large area of Totara Forestry in 2060, a greater area within the Wairoa catchment experiences reduced soil loss risk compared to the other scenarios which also involve Riparian Planting (1B and 2B,

Figure 4-33).

Table 4-63: Summary statistics for terrestrial soil loss for the baseline 2025 and scenario 2C 2030 and 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Min	0	0	0
Mean	83.3	86.6	70.7
Max	8,663.9	8,663.5	8,663.5

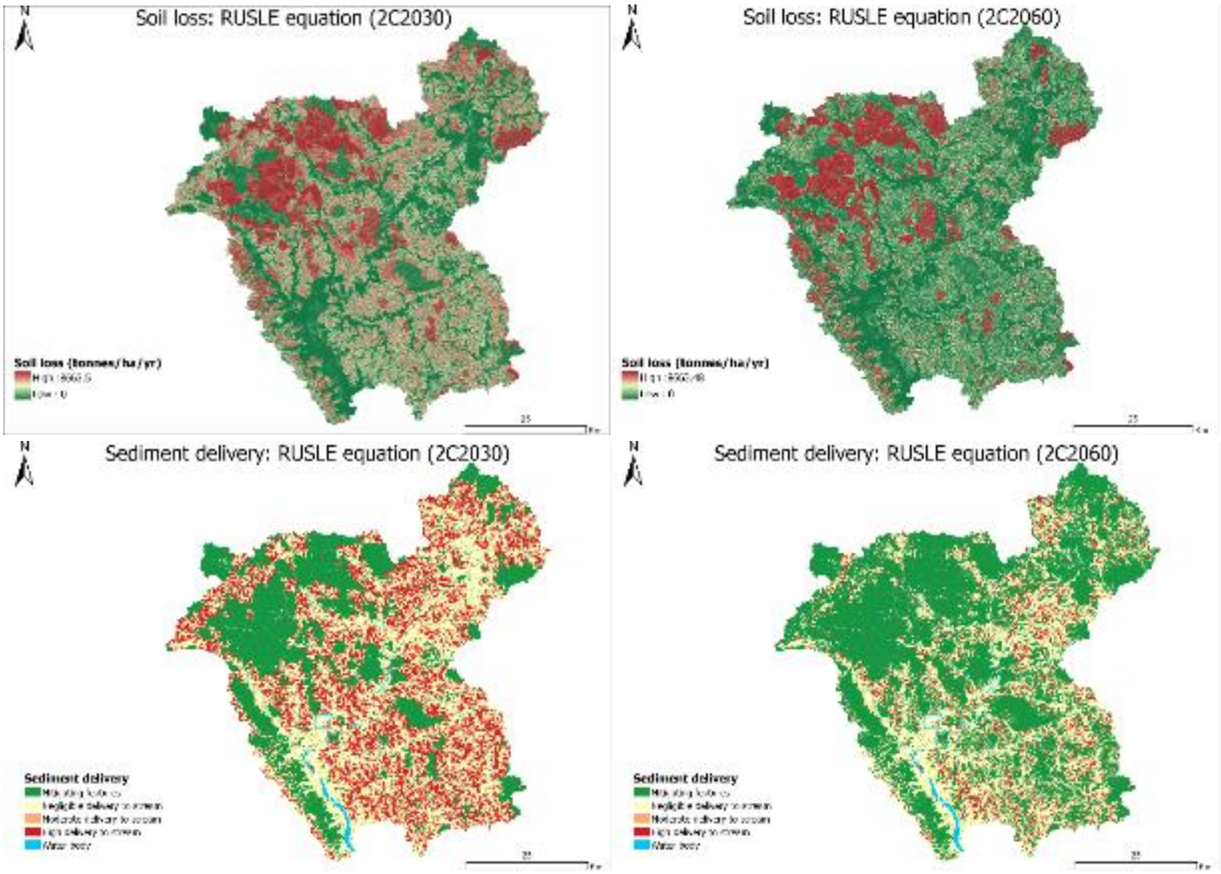


Figure 4-33: Erosion results – soil loss and sediment delivery for scenario 2C 2030 and 2060.

The introduction of large areas of Totara Forestry and the addition of Riparian Planting increases the amount of habitat available for kererū (Table 4-64 and Figure 4-34). The Riparian Planting and Totara Forestry areas have native trees favourable for kererū hence the habitat of interest in 2060 increases by almost four times compared to the baseline 2025.

Table 4-64: Results of the habitat connectivity tool for kererū, for the baseline 2025 and scenario 2C 2030 and 2060.

Habitat classification	Area of the catchment (ha)		
	Baseline 2025	Scenario 2C 2030	Scenario 2C 2060
Habitat of interest	28,210	34,480	104,550
Other priority habitat	960	960	7,920
Opportunity to establish new habitat	254,190	55,900	7,600
Opportunity to expand existing habitat	54,430	246,480	217,740

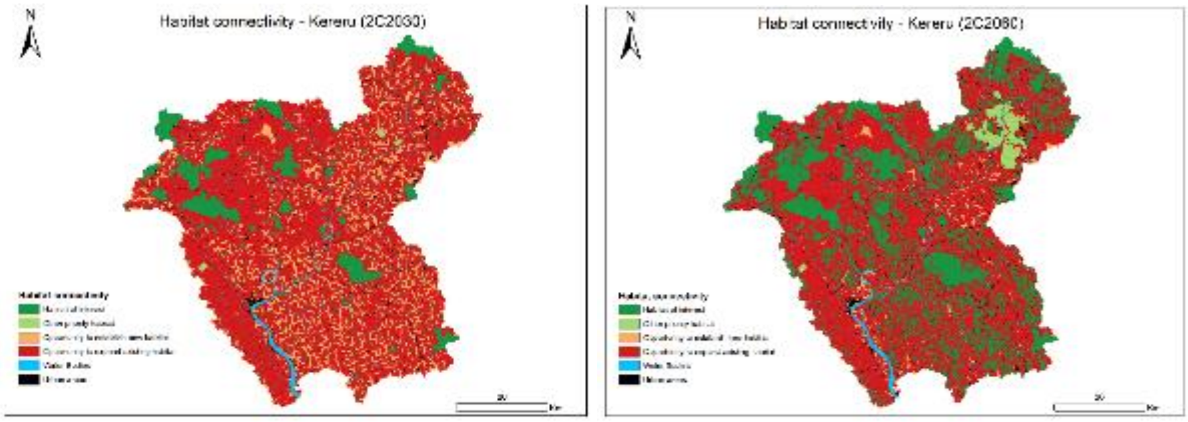


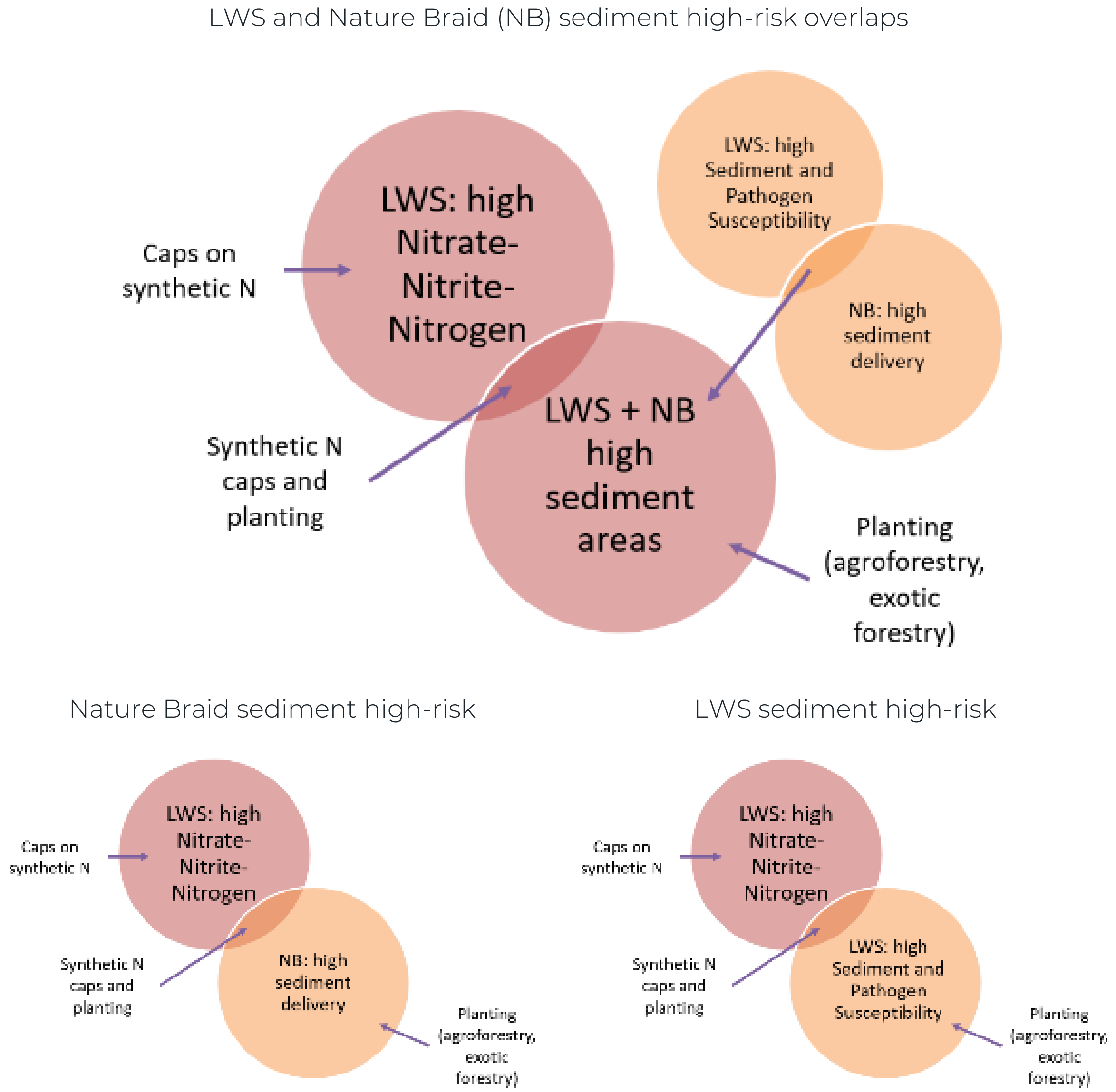
Figure 4-34: Habitat connectivity results for kererū for scenario 2C 2030 and 2060.

4.7 Sensitivity analysis

As for the Mataura catchment, to assess the robustness of the model results, a sensitivity analysis has been carried out for a selected set of parameters to examine the extent to which results are affected by changes in assumptions.

For the economic analysis, key assumptions that may affect outcomes include the selected discount rate, and commodity prices. To represent variability in commodity prices, milk price has been selected as this fluctuates considerably from year to year and affects the most profitable business operation in the Hikurangi Repo.

This section gives an overview of the sensitivity analysis based on changing land use depending on the areas of sediment high-risk identified by (1) overlapping outputs from LWS and Nature Braid, (2) Nature Braid only, and (3) LWS only. This sensitivity analysis shows the difference in environmental outcomes when different areas are targeted to apply interventions of synthetic N caps, planting, or a combination thereof. Between the outputs from LWS and Nature Braid that identify areas of high sediment risk, there is an approximate 45% overlap (Figure 4-35). The differences in model outputs are as a result of differences in what processes are represented by the models, the input data and resolution, and underlying limitations, uncertainties, and assumptions as previously explained in the description for scenario 2A in Section 3.3.


LWS and Nature Braid (NB) sediment high-risk overlaps

Nature Braid sediment high-risk

LWS sediment high-risk

Figure 4-35: Venn diagrams showing what information was used to produce (1) LWS and Nature Braid sediment high-risk overlaps, (2) Nature Braid sediment high-risk, and (3) LWS sediment high-risk.

4.7.1 Inputs to sediment classification sensitivity analysis

Figure 4-36 shows the areas identified as sediment high-risk based on (1) overlapping the Nature Braid and LWS outputs in purple, (2) the Nature Braid sediment output only in orange, and (3) LWS sediment output only in blue. These influence the orange circle in the Venn diagrams in Figure 4-35.

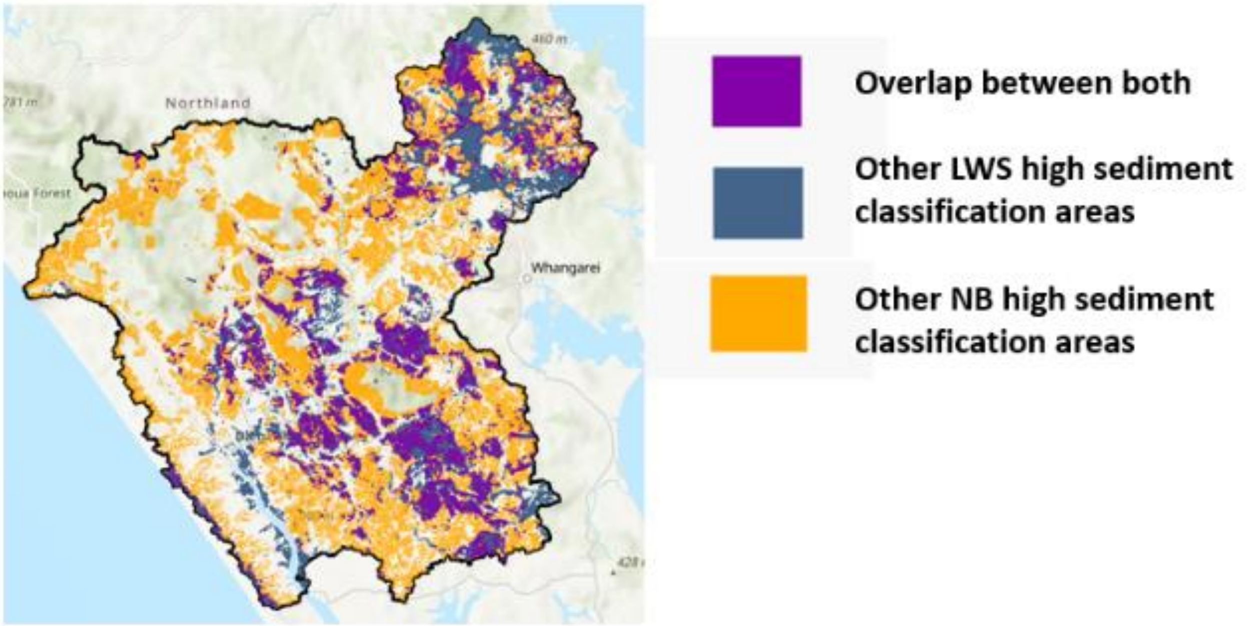


Figure 4-36: Sediment risk comparison: LWS and Nature Braid, 45% overlap.

4.7.2 Detailed scenario sensitivity testing to sediment classification using LWS sediment high-risk areas and Nature Braid sediment high-risk areas

Nitrogen

Table 4-65 compares the summary statistics of N terrestrial load output for scenario 2A 2030 using three methods to identify sediment high-risk areas. Mean N terrestrial load has the lowest value when using the Nature Braid sediment layer to target areas for land use changes. Using the LWS layer resulted in a similar mean N terrestrial load value as when using the overlaps of Nature Braid and LWS sediment high-risk areas.

Table 4-65: Summary statistics for nitrogen load for the baseline 2025 and scenario 2A 2030.

Nitrogen terrestrial load (kg/ha/yr)	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Min	0	0	0	0
Mean	10.7	8.8	6.6	8.2
Max	54.1	54.1	54.1	54.1

The estimated mean N terrestrial load for scenario 2A 2060 was higher when using the overlapping areas in both Nature Braid and LWS compared with using each layer separately to guide land use changes (Table 4-66).

Table 4-66: Summary statistics for nitrogen load for the baseline 2025 and scenario 2A 2060.

Nitrogen terrestrial load (kg/ha/yr)	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Min	0	0	0	0
Mean	10.7	6.5	6.0	6.0
Max	54.1	54.1	54.1	54.1

Similar to the results for N terrestrial load in 2030, the mean and maximum N in-stream concentration from land use changes in areas identified using overlapping Nature Braid and LWS areas and using the LWS layer only were higher than the results based on land use changes in areas identified using the Nature Braid sediment risk layer. This was observed for both 2030 and 2060 (Table 4-67 and Table 4-68).

Table 4-67: Summary statistics of in-stream nitrogen concentration for the baseline 2025 and scenario 2A 2030.

Nitrogen stream concentration (mg/L)	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Min	0	0	0	0
Mean	0.7	0.5	0.3	0.5
Max	191	166.2	37.7	163.4

Table 4-68: Summary statistics of in-stream nitrogen concentration for the baseline 2025 and scenario 2A 2060.

Nitrogen stream concentration (mg/L)	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Min	0	0	0	0
Mean	0.7	0.3	0.3	0.3
Max	191	20.5	20.4	22.8

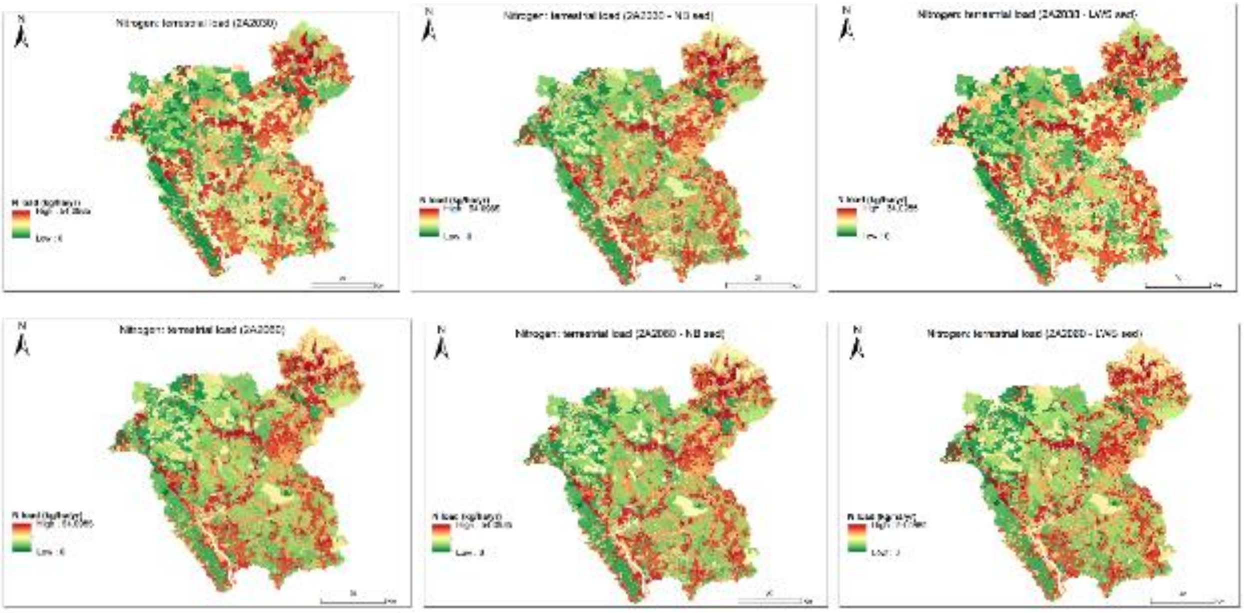


Figure 4-37: Nitrogen terrestrial load results for scenario 2A 2030 and 2060.

Phosphorus

Table 4-69 and Table 4-70 compare the summary statistics of P in-stream concentrations for Scenario 2A 2030 and 2060 when making land use changes based on the area identified by the three sediment high-risk areas (LWS overlapping with Nature Braid, Nature Braid only, or LWS only). Similar to N in-stream concentration, making land use changes in the area identified using the LWS layer only and the overlaps of Nature Braid and LWS sediment high-risk areas gave higher estimations of P compared to changing land use in areas identified using the Nature Braid layer. A similar result can is observed for terrestrial load (Table 4-71, Table 4-72 and Figure 4-38). Changes in all three sediment high-risk areas gave lower estimations for P (both in-stream concentration, and terrestrial load) compared to the baseline 2025.

Table 4-69: Summary statistics for phosphorus in-stream concentration for the baseline 2025 and scenario 2A 2030.

Phosphorus stream concentration (mg/L)	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Min	0	0	0	0
Mean	0.016	0.0114	0.0058	0.011
Max	17.3	15.0	3.8	14.8

Table 4-70: Summary statistics for the phosphorus concentration for the baseline 2025 and scenario 2A 2060

Phosphorus stream concentration (mg/L)	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Min	0	0	0	0
Mean	0.016	0.006	0.005	0.0055
Max	17.3	1.8	1.7	2.2

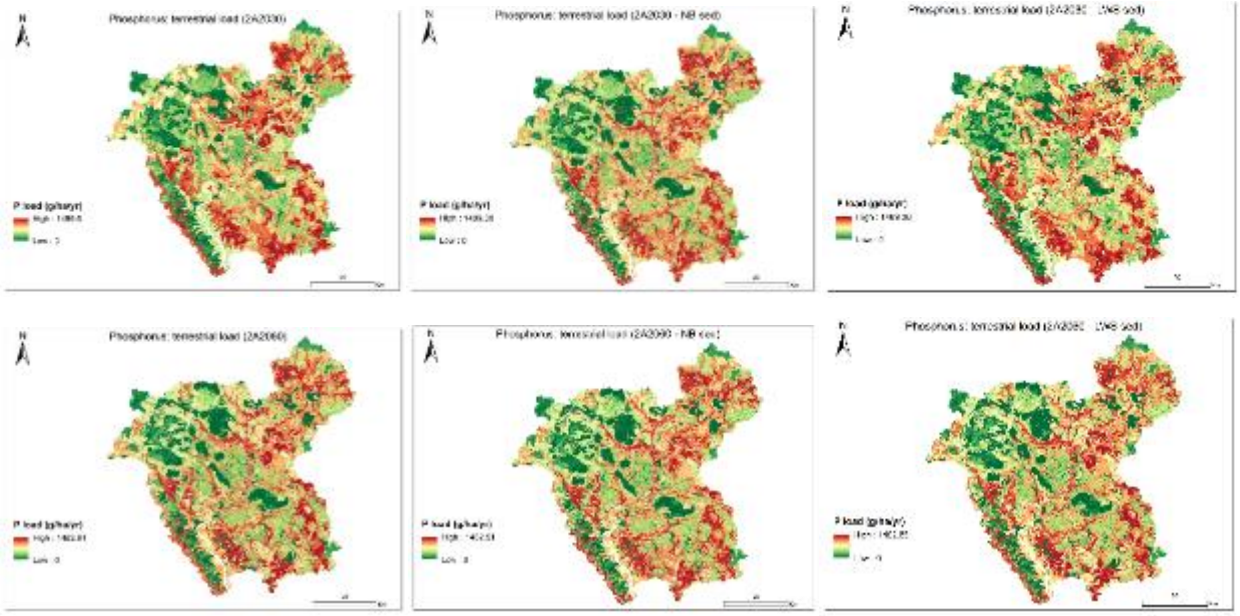


Figure 4-38: Phosphorus terrestrial load results for scenario 2A 2030 and 2060.

Table 4-71: Summary statistics for the phosphorus terrestrial load for the baseline 2025 and scenario 2A 2030.

Phosphorus terrestrial load (g/ha/yr)	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Min	0	0	0	0
Mean	401.5	335.5	229.5	315.2
Max	1,532	1,489.6	1,489.4	1,489.4

Table 4-72: Summary statistics for the phosphorus terrestrial load for the baseline 2025 and scenario 2A 2060

Phosphorus terrestrial load (g/ha/yr)	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Min	0	0	0	0
Mean	401.5	236.0	211.2	219.4
Max	1,532	1,482.9	1,482.9	1,482.9

Flood mitigation

A comparison of the results from the flood mitigation tool are presented in Table 4-73 (baseline 2025 and 2030) and Table 4-74 (baseline 2025 and 2060) and Figure 4-39. Mitigations applied in areas based on the locations of sediment high-risk areas using the Nature Braid layer resulted in the largest increase in areas of mitigating and mitigated features.

Table 4-73: Results of the flood mitigation tool for the baseline 2025 and scenario 2A 2030.

Flood characteristics	Area of the catchment (ha)			
	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Mitigating features	85,300	121,230	164,630	123,210
Mitigated features	7,110	22,900	36,980	20,970
Non-mitigated features	253,150	201,460	143,990	201,390

Table 4-74: Results of the flood mitigation tool for the baseline and scenario 2A 2036.

Flood characteristics	Area of the catchment (ha)			
	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Mitigating features	85,300	201,900	181,660	199,730
Mitigated features	7,110	30,300	31,270	30,250
Non-mitigated features	253,150	113,440	132,690	115,630

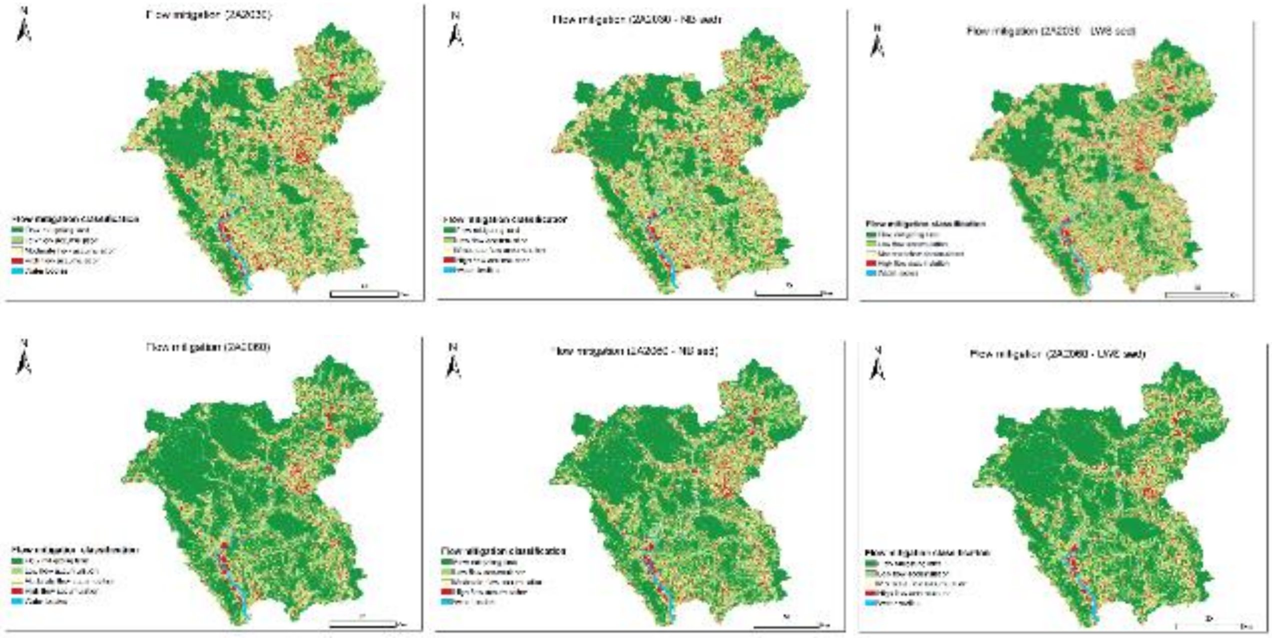


Figure 4-39: Flood mitigation results for scenario 2A 2030 and 2060.

Soil loss

Unlike the results for N, P, and flood mitigation, for soil loss results the land use changes that were made based on the overlap of LWS and Nature Braid, and based on the LWS layer only, led to lower estimates of soil losses compared with the Nature Braid layer result (Table 4-75). Terrestrial soil loss and sediment delivery maps are presented in Figure 4-40 and Figure 4-41.

Table 4-75: Summary statistics for terrestrial soil loss for the baseline and scenario 2A 2030.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Min	0	0	0	0
Mean	83.3	107.1	150.9	107.21
Max	8,663.9	8,663.5	8,744.2	8,663.9

Table 4-76: Summary statistics for terrestrial soil loss for the baseline and scenario 2A 2060.

Soil loss (tonnes/ha/yr)	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Min	0	0	0	0
Mean	83.3	168.4	153.7	167.8
Max	8,663.9	8,744.2	8,744.2	8,774.2

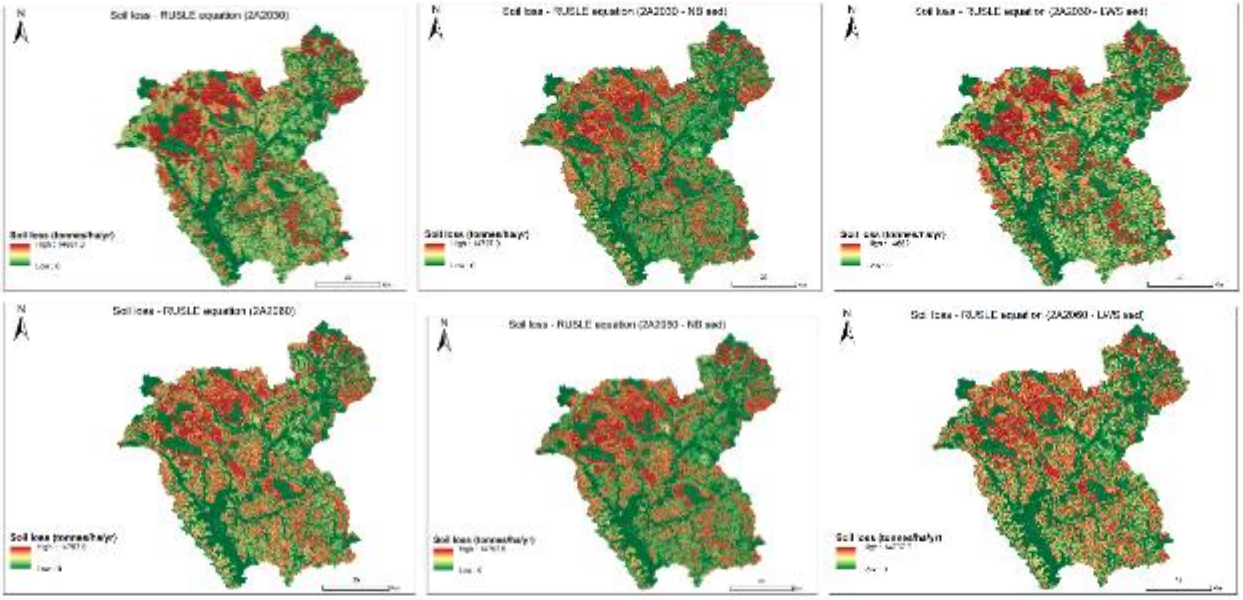


Figure 4-40: Soil loss results for scenario 2A 2030 and 2060.

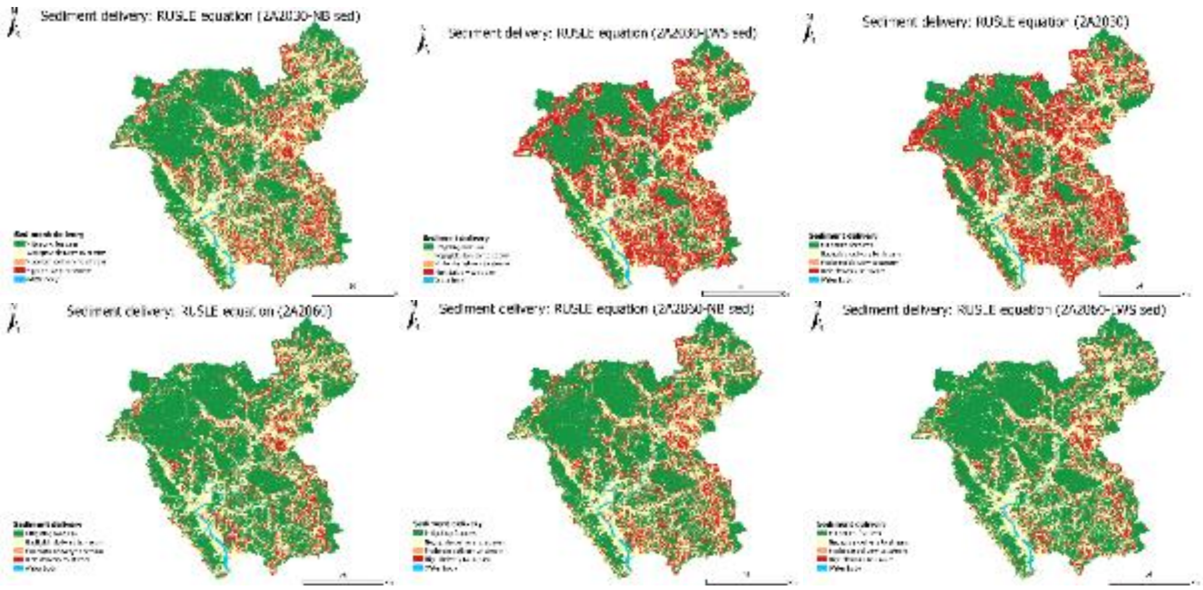


Figure 4-41: Sediment delivery results for scenario 2A 2030 and 2060.

Habitat connectivity

For 2030, the area of opportunity to expand existing habitat is highest and opportunity to establish new habitat is lowest when the Nature Braid sediment risk layer is used to guide land use changes, compared to using the LWS or LWS – Nature Braid overlapped sediment high-risk area (Table 4-77). However, for 2060 the result is opposite: the area of opportunity to expand existing habitat is highest opportunity to establish new habitat is lowest when using the LWS – Nature Braid overlap (Table 4-78).

Table 4-77: Results of the habitat connectivity tool for kererū for the baseline 2025 and scenario 2A 2030,

Habitat classification	Area of the catchment (ha)			
	Baseline 2025	Scenario 2A 2030 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2030 (Nature Braid sediment high-risk)	Scenario 2A 2030 (LWS sediment high-risk)
Habitat of interest	28,210	28,210	28,210	28,210
Other priority habitat	960	960	960	960
Opportunity to establish new habitat	254,190	241,410	210,900	239,970
Opportunity to expand existing habitat	54,430	67,230	97,730	68,650

Table 4-78: Results of the habitat connectivity tool for kererū for the baseline 2025 and scenario 2A 2060.

Habitat classification	Area of the catchment (ha)			
	Baseline 2025	Scenario 2A 2060 (LWS and Nature Braid sediment high-risk overlaps)	Scenario 2A 2060 (Nature Braid sediment high-risk)	Scenario 2A 2060 (LWS sediment high-risk)
Habitat of interest	28,210	28,210	28,210	28,210
Other priority habitat	960	960	960	960
Opportunity to establish new habitat	254,190	187,520	196,260	190,210
Opportunity to expand existing habitat	54,430	121,120	112,380	118,410

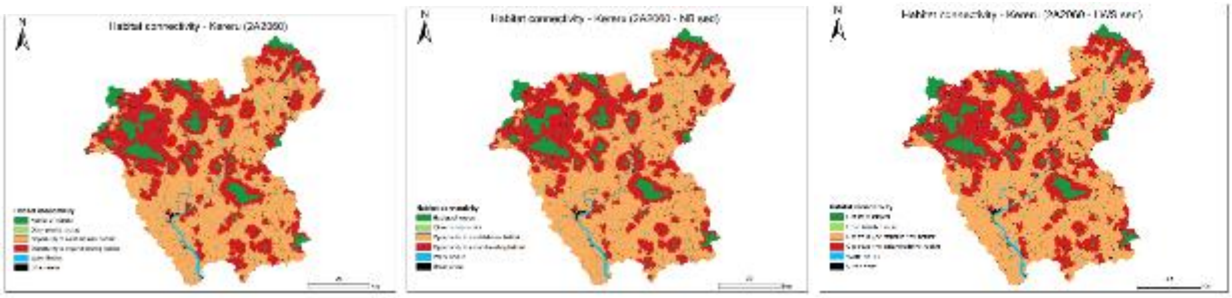


Figure 4-42: Habitat connectivity results for kererū for scenario 2A 2060.

4.7.3 Discount rate sensitivity analysis

Both Exotic Forestry (pine) and Totara Forestry have a long time to maturity, but this is particularly important for totara, with at least 60 years to harvest. Thus, returns depend heavily on the assumed discount rate. Given the importance of the cost of subsidy required to compensate for Totara Forestry, it is crucial that the effects of varying the discount rate assumption is examined. The impact of a varying real discount rate on scenario 2C has been assessed. This is summarised in Table 4-79 below.

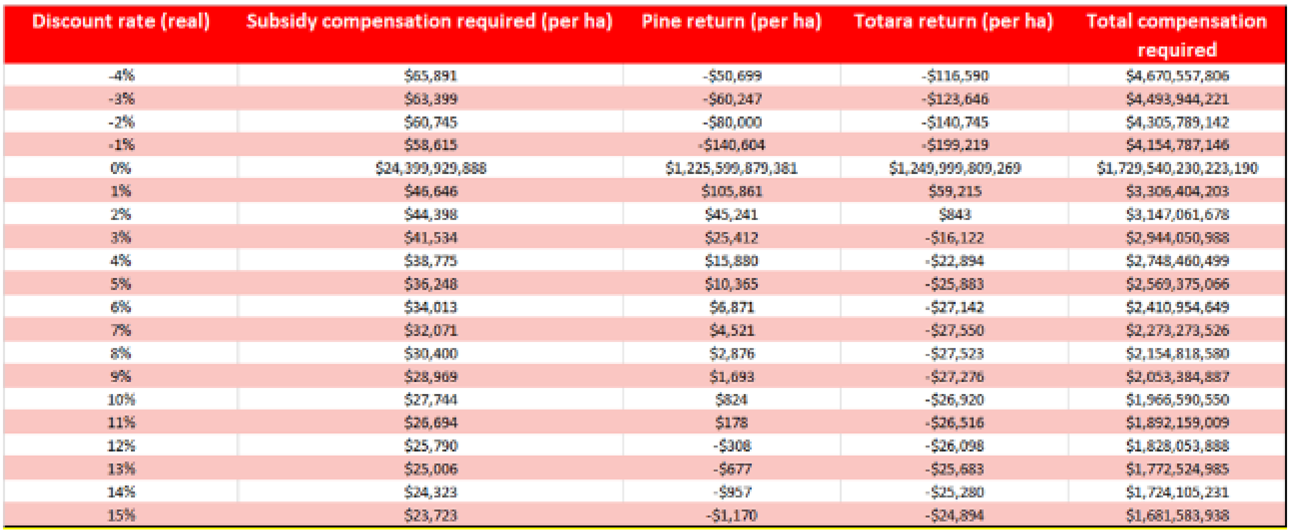
The current assumption for the real discount rate is set at 5% based on the estimation of farmers weighted average cost of capital which conveniently happens to align with the discount rate proposed by The Treasury (Te Tai Ohanga - The Treasury, 2020).

In this sensitivity analysis, the impact of varying the real discount rate between -4% to 15% has been modelled. Although negative discount rates or extreme discount rates like 15% are unlikely and could only be short-lived, these have been included for the purpose of assessing the reliability of the findings. The results from the sensitivity analysis suggest that for all discount rates assessed, the finding in the base model does not change as a subsidy compensation will be required to foster the desired land transition of marginal production capacity farming land to Totara Forestry instead of Exotic Forestry.

This model would not be appropriate when the discount rate is close to 0% as there will be mathematical inconsistency resulting in formula errors in the model. Inferred from the sensitivity analysis, the greater the discount rate, the less subsidy compensation is required for landowners to plant Totara Forestry instead of planting Exotic Forestry. Given the current market uncertainty around long term inflation, interest rate and political relations, this adopted model discount rate of 5% is quite conservative. The actual expected discount rate will likely be higher than 5%, hence the required compensation will likely be lower than modelled.

Supported by the sensitivity analysis, this gives confidence in the finding that Totara Forestry will occur between 2030 and 2060 in scenario 2C as the modelled best land use for the three types of farming land (Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing) with marginal production capacity. We are confident that the long-term real discount rates should be positive and at least 5%. The total compensation required would be financially feasible as this has been modelled this to be financed separately outside of the catchment funds.

Table 4-79: Summary of the discount rate sensitivity analysis for scenario 2C.



Discount rate (real)	Subsidy compensation required (per ha)	Pine return (per ha)	Totara return (per ha)	Total compensation required
-4%	$65,891	-$50,699	-$116,590	$4,670,557,806
-3%	$63,399	-$60,247	-$123,646	$4,493,944,221
-2%	$60,745	-$80,000	-$140,745	$4,305,789,142
-1%	$58,615	-$140,604	-$199,219	$4,154,787,146
0%	$24,399,929,888	$1,225,599,879,381	$1,249,999,809,269	$1,729,540,230,223,190
1%	$46,646	$105,861	$59,215	$3,306,404,203
2%	$44,398	$45,241	$843	$3,147,061,678
3%	$41,534	$25,412	-$16,122	$2,944,050,988
4%	$38,775	$15,880	-$22,894	$2,748,460,499
5%	$36,248	$10,365	-$25,883	$2,569,375,066
6%	$34,013	$6,871	-$27,142	$2,410,954,649
7%	$32,071	$4,521	-$27,550	$2,273,273,526
8%	$30,400	$2,876	-$27,523	$2,154,818,580
9%	$28,969	$1,693	-$27,276	$2,053,384,887
10%	$27,744	$824	-$26,920	$1,966,590,550
11%	$26,694	$178	-$26,516	$1,892,159,009
12%	$25,790	-$308	-$26,098	$1,828,053,888
13%	$25,006	-$677	-$25,683	$1,772,524,985
14%	$24,323	-$957	-$25,280	$1,724,105,231
15%	$23,723	-$1,170	-$24,894	$1,681,583,938

4.7.4 Milk price sensitivity analysis

Our Dairy model assumes a milk price of $7.29 per kgMS which is what dairy farmers in the catchment receive from the milk company (e.g., Fonterra) for their milk supply. This assumption is based on the FARMAX model which is an annual average price. It is acknowledged that the actual milk price which a farmer is expected to receive changes frequently and differs hugely in different seasons.

It is important to note that dairy farmers are price takers and not price setters when it comes to milk price. The key difference here is that individual dairy farmers have no control over what milk price they receive as that is dependent on what milk companies such as Fonterra see as an objective market price to offer. This adds a lot of uncertainty to dairy farmers' operation and financial performance hence the implication of varying milk prices have been assessed in scenario 2C.

The critical milk prices which makes Dairy unprofitable (return of $0) for the five different production capacities in 2025, 2030 and 2060 have been analysed. This is summarised in Table 4-80 below.

In 2025, under the current milk price assumption of $7.29 per kgMS, only the negligible productivity Dairy land is assessed to be offering a negative return where it should consider transitioning to a better land use. This conclusion will hold until the modelled milk price goes above $39.44 which would be an increase of 441%. It is examined that it would require a 6% decrease in milk price to $6.89 per kgMS for marginal productivity Dairy land to become unprofitable and a 40% decrease in milk price to $4.35 per kgMS for all Dairy farms in the catchment to become unprofitable.

Overall, we are confident with the findings in 2025 as the current Fonterra forecasted farm gate milk prices are all higher than our conservative milk price assumption. The market anticipates a lot of upwards pressure in the next few years following global inflation and prolonged market distortions. The market consensus for the lower bound milk price estimation is set at $8.5 per kgMS.

Similarly in 2030, only the negligible productivity Dairy land is assessed to be offering a negative return. This conclusion will hold until the modelled milk price goes above $39.67 which would be an increase of 444%. It is examined that it would require a 2% decrease in milk price to $7.12 per kgMS for marginal productivity Dairy land to become unprofitable and a 37% decrease in milk price to $4.58 per kgMS for all Dairy farms in the catchment to become unprofitable.

In 2060, both the negligible productivity and marginal productivity Dairy land have been assessed to be offering a negative return. This conclusion will hold until the modelled milk price goes above $41.52 which would be an increase of 469%. It is examined that it would require a 1% decrease in milk price to $7.22 per kgMS for moderate productivity Dairy land to become unprofitable and a 12% decrease in milk price to $6.43 per kgMS for all Dairy farms in the catchment to become unprofitable.

We are confident with our findings in 2030 and 2060 as after examining historical milk price movements in New Zealand and global milk price projections, milk prices do not tend to fall over time as that suggests deflation. Milk prices are unlikely to increase phenomenally above 400% to make negligible productivity Dairy lands profitable. The only exception is that milk price will likely go above $8.96 per kgMS by 2060 whereby making marginal productivity Dairy economical. In such a case, this modelled land (16,921 hectares) would stay in Dairy rather than being converted to Totara Forestry.

Table 4-80: Critical milk prices in scenario 2C.

Dairy Production Capacity	2025	% change	2030	% change	2060	% change
Very high	$4.35	-40%	$4.58	-37%	$6.43	-12%
High	$4.45	-39%	$4.68	-36%	$6.52	-11%
Moderate	$5.15	-29%	$5.38	-26%	$7.22	-1%
Marginal	$6.89	-6%	$7.12	-2%	$8.96	23%
Negligible	$39.44	441%	$39.67	444%	$41.52	469%

5 Discussion

In the first Wairoa workshop, the participants shared their concerns for the catchment in the present, and a vision for what they would wish it to look like in the future. Through these scenarios, a set of different ideas have been explored which were interpreted for the modelling exercise but aligned as closely as possible with those shared.

The scenarios were a useful thought exercise to spark conversation, and to explore the feasibility and potential barriers to implementing interventions.

In responding to the research question: *Could an integrated landscape approach enable rural communities and tangata whenua to achieve better climate, water, soil, and biodiversity outcomes than an untargeted approach?* It is important to consider the wide range of scenarios and the way this question has been interpreted within each.

It is also important to note that the scenarios are not directly comparable; each scenario effectively represents an independent case study. Arguably, also the distinction between targeted and untargeted approaches can be open to some interpretation, depending primarily on the scale of the intervention. For example, support for Riparian Planting is modelled as an untargeted approach but incorporates landscape features as it is implemented.

However, the results of this study spoke strongly to the importance of place, highlighting the fact that spatially explicit and targeted interventions may offer better outcomes, but also the importance of involving communities in enabling specific, place-based conversations and initiatives around land use change.

Land use change and economic impacts

A number of key drivers were clear across the outcomes of the different scenarios: The first was the heavy impact of the levy on pastoral farming in the catchment. While it was not possible to represent the diversity of farming systems across the catchment, a proxy for this was provided by the economic differentiation of the levels potential productivity ("utilisation") provided by the Nature Braid model. This is based only on landscape characteristics rather than farm system set up or skill of the farmer but does indicate that the impact of the levy may fall unevenly, driving farms with a lower margin out of business more quickly. However, all pastoral farming systems were significantly affected and became less profitable. This is particularly marked under the higher levy rate – for scenarios 1B, 2B and 2C it was necessary to adjust the original "high levy" rate used in the Mataura catchment down to a medium levy rate, in order to provide outcomes that would stimulate more nuanced discussions around land use change, rather than simply highlighting the impact of the levy by driving most pastoral farms out of business and leaving almost no levy to collect for recycling back into the catchment.

While the transition point for a given land use has been modelled primarily as occurring when profitability reaches $0/ha, the impact on farmers and their community will be felt long before this point. No consideration has been given in this study to factors such as farm debt, which may be of key importance. There is also some potential that economic pressure may create a perverse incentive for the remaining farmers to increase stocking rates and invest less in environmental improvements. In addition, there has been no consideration of the wider social/economic implications of large-scale land conversion to Exotic Forestry.

The assumptions and modifications to the farm systems in response to policy or targeted mitigations only captures a simplified economic response. In reality, farmers and farm systems are highly unique, and a range of adaptations would be seen by landowners in order to meet regulations. Extensive work is underway across multiple sectors to research and provide solutions to greenhouse gas emissions at farm level. If new technologies become available that significantly reduce methane emissions from livestock, for example, this would likely present a different picture with less land use change in all scenarios. However, these developing options were considered beyond the scope of this study.

In all scenarios, there was a shift towards forestry options, either by default (as uneconomic pastoral farms transitioned to Exotic Forestry) or by design, with the introduction of a rule for a minimum number of stems/ha considered to be accompanied by information on and promotion of agroforestry systems; and in 2C the introduction of a subsidy for Totara Forestry. The new land use selected for modelling, Orchards (Macadamia), was selected on the basis of its profitability as well as lower environmental impact and water use. This land use does already exist currently in the area, although concerns were raised during the second in-person workshop on its viability in the catchment. These issues would require further exploration – as discussed in the Mataura catchment report, buy in from landowners in the catchment and the creation of critical mass for any new or growing industry would be an essential element in its success. This is also an important consideration for the Agroforestry system as defined here, which relies on a market for poplar wood.

A range of policy approaches have been explored at high level in these scenarios: direct subsidies, for example for Totara Forestry; direct payments, for riparian planting and wetland restoration; and in the case of Orchards (Macadamia), loans which must be repaid once the land use becomes profitable. There is a high transition cost to Orchards (Macadamia) but, once established, these are highly profitable. The loan scheme was intended to enable farmers to easily transition. There is a 5% interest rate on these loans, providing an extra return to the overall fund.

The impact of these changes is generally positive for all scenarios in terms of the overall economics of the catchment, and for agricultural emissions. However, these outcomes are significantly better under Exotic Forestry, although the Agroforestry system is also highly profitable and provides significant sequestration. It should be noted that for the purposes of this study, we have referred to the standard lookup tables (Ministry for Primary Industries, 2017) for sequestration rates. However, these are recognised to currently provide inadequate representation of native species, implying that the sequestration for Indigenous Vegetation and Totara Forestry in these scenarios is likely to be significantly underrepresented.

Regarding the appropriateness of land use as indicated by the Nature Braid model, in the baseline 54.9% of the catchment is flagged as somewhat or significantly over-utilised. These areas include some Dairy, Hill Country Sheep and Beef and Lowland Beef Finishing farms. Some parts of the catchment (approx. 12%) are also indicated as under-utilised. The areas potentially being over-utilised are generally located in areas of high waterlogging or poor drainage, steep slopes, and low fertility. Conversely, the areas being flagged as under-utilised were areas of low waterlogging or good drainage, gentle slopes, and high fertility that were not being used for agricultural activity. However, these areas may potentially be used for other important land uses that provide non-agricultural benefits (e.g., forested areas for habitat or flood mitigation).

Environmental outcomes

In the scenarios where land is retired from agricultural activities due to marginal/negligible production capacity, the changes presented positive outcomes in terms of balancing the productive capability of the land with its actual use. Agricultural activity on high slopes, waterlogged soils, and low fertility (marginal/negligible production) being retired to less intensive usage contributed to this outcome, especially in 2060. For terrestrial N loads, 1B, 2B, and 2C outcomes had the largest decrease in mean loads, especially in 2060. For terrestrial P loads, 1A, 2A, and 2C outcomes had the largest decrease in mean loads in 2060. However, for in-stream P concentrations, the largest decrease in mean concentrations were in 1B, 2B, and 2C. The Riparian Planting scenarios (1B, 2B, and 2C) had the best benefits for flow mitigation, as these areas were benefitting areas larger than their extent. The mean terrestrial soil losses increased for almost all scenarios in 2030, except for 2B. In 2060, with large-scale conversions to Exotic Forestry, the mean soil loss further increased, except for 2C.

The scenarios that involved Riparian Planting generally had better environmental outcomes. The retiring of negligible/marginal agriculturally productive land to less intensive land uses (e.g., exotic forestry, indigenous vegetation, Agroforestry) led to lower terrestrial loads and in-stream concentrations for nitrogen and phosphorus. Flow mitigation services benefited hugely, with the area changed to Riparian Planting, wetland restoration, and forest (exotic and native) able to benefit upslope/uphill areas ~4.5 times their size. There was more ideal habitat for kererū in Scenario 2C 2060 with the addition of Totara Forestry, but the Exotic Forestry areas were also more permeable for the species.

The shifts to Agroforestry farm systems (2A, 2B, and 2C) also presented positive outcomes to agricultural utilisation, nutrients, soil losses, and flow mitigation. However, their parameterisation within the Nature Braid model was very conservative and may be improved by further research and more specific parameterisation to better reflect the potential environmental outcomes possible from Agroforestry systems. For example, while the Agroforestry system was not considered favourable for kererū in the model setup, at the Wairoa workshop it was noted that since kererū have had to adapt to exotic tree species due to habitat loss, they may also receive benefits from trees such as poplar.

Scenario 2C had the most ideal environmental outcomes in 2060 for habitat due to the addition of totara, and high benefits to flow mitigation due to Riparian Planting, Totara Forestry, and restoration of the Hikurangi Repo. While all other scenarios had higher potential soil losses in 2060 due to conversions to Exotic Forestry (pine), 2C 2060 had the inverse.

In order to better understand the outcomes on specific species of N and P, relating to thresholds for ecological protection, health, and national bottom lines, the nutrient tools (see Appendix A.2) were used to compare the outcomes of 2C 2060 to the baseline: When compared to the national bottom lines for NO_3-N (Ministry for the Environment, 2020), the changes in 2C 2060 increased the percentage of stream reaches within the Wairoa catchment to a mean below 2.4 mg NO_3-N/L. The percentage of reaches within Band A ($\leq$1.0 mg NO3-N/L) increased to 96% in Scenario 2C 2060 compared to 15% in the baseline. For ammonia (NH4-N), percentage of reaches within Band A ($\leq$ 0.03 mg NH_4-N/L annual median) and Band B (>0.03 and $\leq$ 0.24 mg NH_4-N/L) increased to 84% in Scenario 2C 2060 compared to 83% in the baseline. It should be noted that the bands are set using medians from monthly sampling while the Nature Braid model uses daily hydrology and mean annual estimates of N and P load. However, the changes are still indicative of movement between the bands.

Although Scenario 2C had generally good environmental outcomes, there were questions raised during the results workshop regarding the interventions in this scenario. In particular, the complete restoration of the Hikurangi Repo would mean the loss of productive land that has been farmed over multiple generations. The addition of Agroforestry provides benefits for nutrients, soil losses, and flow mitigation, but the source of funding for these systems was unclear to participants.

The conversions to Exotic Forestry (pine) also raised concern, particularly due to the sedimentation issues in the Wairoa catchment, and the potential interactions with extreme events.

Limitations of the methodology

As with any future modelling scenarios, there are significant limitations on the accuracy with which both the current and future landscape can be modelled. There are a wide range of variables and uncertainties beyond the scope of this work. Significant limitations arise from both data uncertainty and modelling assumptions. Multiple assumptions, simplifications and subjective choices were required in order to bring together the different disciplines, scales, and models used for this work. In all such choices, the aim has been not to propose, recommend or predict the impacts of a specific future policy, but rather to highlight the trade-offs between different policy approaches as a thought exercise. The intent is to stimulate useful, science-based, and policy-focussed conversations about some of the future pathways under consideration.

A number of specific limitations have been identified and mentioned throughout the report, as the approach has been described. In particular, modelling the economics and environmental outcomes of land use was limited in the kinds of farm and management systems that could be represented, due to limited spatial delineation of the different farming systems and broad-brush estimates of typical management characteristics. Similarly, the lack of data regarding point sources of nutrients in the Wairoa such as wastewater treatment plants and septic tanks means that the modelled estimates for nutrients may be an under-estimation of actual conditions. If this information was available, it could be incorporated into the Nature Braid, but only diffuse sources are represented in the current report.

The soil loss modelling within the Nature Braid mainly accounts for terrestrial soil losses by water, but not explicitly for soil losses from landslides or mass wasting. This means it underestimates sediment delivery and hence particulate P losses from steep unconsolidated soils and is likely the main reason why estimated P concentrations under high country Exotic Forestry are lower than expected. For harvesting, clear-felling was assumed for Exotic Forestry, but future work and more data could enable modelling more sustainable harvesting regimes.

Finally, for modelling simplicity, Riparian Planting was not modelled economically as a change in land use. While this was kept consistently simple across the scenarios that included Riparian Planting (1B, 2B and 2C), enabling comparison; in practice the removal of this land from production is also likely to have an economic impact. In addition, this was modelled for all scenarios as occurring to a consistent distance from each waterway. In order to target model targeted Riparian Planting more effectively, further work would be required to analyse the optimal areas for increasing or decreasing riparian buffer areas.

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Appendices

A.1 Overview of policy scenarios for Wairoa

Scenario	1. Untargeted approach		2. Targeted landscape approach		
Variation	1A. Low levy, untargeted freshwater regulations	1B. High levy, untargeted revenue recycling	2A. Low levy, targeted freshwater regulations	2B. High levy, targeted revenue recycling	2C. Forestry removed from NZ ETS + additional public funding
Purpose	This scenario is based on a farm-level levy on biological emissions. The initial levy rate is relatively low and increases gradually over time. The levy revenue collected is small and is recycled into research on reducing emissions from agriculture.	This scenario has higher levy rates that rise more rapidly than 1A (medium levy). All of the revenue from the levy is recycled back into central government funding programmes and spent using a simple untargeted approach, as well as national level research. This enables comparison to 2B where the revenue is distributed to the catchment in a targeted, landscape-specific manner.	This scenario shows the effect of targeted, landscape-specific freshwater regulations. A cap on nitrogen, and mitigation measures to control soil loss, is based on landscape susceptibility. In all other features it is the same as 1A.	This scenario shows the effect of targeted revenue recycling. It is the same as 1B except that the revenue from the emissions levy is recycled back into a community fund, which is used to support targeted actions (land management practices, farm system changes and/or land use change) that produce multiple environmental outcomes. The community (including tangata whenua), local government and iwi/hapu decide together how the community fund is spent.	This scenario shows the effect of removing forestry from the NZ ETS and increasing public funding for integrated landscape management in the catchment, in addition to targeted revenue recycling. It is the same as 2B except that no new forests are registered in the NZ ETS after 2030. The additional public funding that would be needed to support the planting of totara forests and restore the Hikurangi Repo is estimated.
Biological emissions pricing	- Levy introduced in 2025 at the farm level - Split-gas approach with separate prices for methane and long-lived gases (N_2O and CO_2) - Levy rate set at a relatively low in 2025, increasing gradually over time	- Same as 1A, except with medium levy rates that rise more rapidly over time	Same as 1A	Same as 1B	Same as 1B
	None (for modelling purposes) (The assumption is that revenue collected from the levy will be small, and likely to be channelled mainly to	Levy revenue is recycled back into central government funding programmes and spent on Riparian Planting. For modelling purposes and to make the scenario	Same as 1A	Levy revenue is recycled back into a community fund. The community, tangata whenua and local government decide how the revenue is spent. As per feedback from the first	Same as 2B except the levy revenue is supplemented by additional public funding for activities that improve freshwater, biodiversity, and climate outcomes in the

Use of levy revenue	research at the national level. Accounting for this is beyond the scope of this study.)	comparable to 2B, the amount of levy revenue spent in the catchment is set equal to the amount raised in the catchment. Some of the levy fund is still channelled back to national level research.		wananga, the revenue will be spent on: • Wetlands restoration (restoring one pocket of the Hikurangi Repo) • Riparian Planting • Support (loan) for targeted conversion of intensive dairy farms to an alternative land use (Macadamia nuts) The payments are allocated in a targeted manner by using tools such as landscape susceptibility mapping and Nature Braid to identify the best locations to undertake actions. Some of the levy fund is still channelled back to national level research.	catchment. The levy revenue is spent on the same targeted mitigations as in 2B. In addition to the revenue from the levy, the amount of additional public funding that would be needed to achieve the following mitigation actions is estimated: • All new forests are “sustainable totara” plantation forests instead of pine plantation forests. The LWS susceptibility layers and Nature Braid are used to target forest planting. • All pockets of the Hikurangi Repo are retired from productive land uses and restored.
NZ ETS	• No limits on forestry in the NZ ETS	Same as 1A	Same as 1A	Same as 1A	No new forests are registered in the NZ ETS after 2030
Freshwater regulations	• Current nitrogen fertiliser application rate limited (for pastoral land use only) • No controls on phosphorous inputs • Stock exclusion regulations • Intensive winter grazing regulations	Same as 1A	• Nitrogen fertiliser application rate limits based on landscape susceptibility to loss of nitrogen • Targeted controls on land use, based on landscape susceptibility to erosion/soil loss • Stock exclusion regulations: same as 1A	Same as 1A	Same as 1A

			• Intensive winter grazing regulations: same as 1A		

A.2The Nature Braid Model

Biophysical modelling was carried out using the Nature Braid model. The Nature Braid framework is a land management and decision support tool that uses landscape information to create quantitative and qualitative spatial outputs (Jackson, et al., 2013). These outputs show areas providing ecosystem services (agricultural productivity, flood mitigation), hotspots for management interventions (nutrient loads and delivery, soil erosion and sedimentation), and areas of trade-offs/synergies between services. Nature Braid runs at fine spatial scales (~5m to 10m; field to catchment to national scales) and is spatially explicit as its algorithms maintain biophysical principles and spatial configuration.

In this project, Nature Braid was used to provide maps of agricultural productivity, nitrogen, phosphorus, flood mitigation, erosion, and habitat connectivity of kererū (*Hemiphaga novaseelandiae*). With the majority of the catchment used for agricultural land (Table A-1), assessing the agricultural productivity and nutrient delivery under current conditions was important for building scenarios. Flood mitigation and erosion are services that have synergies with nutrient delivery, meaning that management interventions that address nutrient delivery are likely to provide benefits for flooding and erosion too. Kererū are species of interest due to their ability to disperse seeds of large-fruited tree species over long distances, providing benefits to populations of fleshy-fruited trees in fragmented landscapes (Powlesland, Moran, & Wotton, 2011).

The inputs used for the Nature Braid model are listed in Table A2. The specific parameterisation for the six FARMAX farm types was done based on FARMAX outputs on stocking rate and fertiliser uses under baseline 2025 and different scenarios.

Table A - 1: Summary of input datasets used for this application of Nature Braid.

Model input	Information	Source
Digital elevation model	8-metre resolution raster	(Land Information New Zealand, 2012)
Land use map	Northland land use layer	Northland Regional Council
Soil	Fundamental Soils Layer (FSL)- polygon	(Landcare Research NZ, 2010)
Rivers and streams	River Environment Classification (REC2)	(NIWA, 2019)
Rainfall and evapotranspiration	500 metre resolution raster	(NIWA, 2012)

As described in Jackson et al. (2013) the agricultural valuation tools within the Nature Braid model provide screening methods to categorise land by its productivity value (production capacity) for farmers. This serves an important purpose when it comes to considering trade-offs and synergies between ecosystem services (including production), which is particularly critical to this project.

Nature Braid's agricultural productivity tool evaluates production potential, utilisation, and status. Areas that are flat, well-draining, and fertile are considered to have high agricultural production potential while areas that are susceptible to waterlogging or very hilly are considered to have low agricultural production potential. The relative agricultural "utilisation" identifies areas that are over-utilised which may be indicative of farming that requires more management activities to make it productive/sustainable. Areas that are under-utilised indicate where opportunities to increase agricultural productivity may be present. Agricultural utilisation status combines the current and predicted optimal output in a different way to the relative utilisation described previously. Land with appropriate utilisation is considered worthy of protection, and areas where land is over or under-utilised are flagged for consideration of management change.

Additionally, the current land use regime is considered in order to examine the degree to which this value is currently utilised. In the calculation of perceived agricultural value (i.e., the value of the land independent of its current land management utilisation), each element in the landscape is categorised as one of: very high value, high value, marginal, low value, or no value according to (a) slope and aspect, (b) soil drainage characteristics and (c) fertility information with soil organic matter/organic carbon as the proxy (where available). It should be noted that this valuation layer ignores existing land use (except implicitly, insofar as land use may have modified soil characteristics, etc.); it is an indication of potential rather than current value. Further valuation layers consider the current utilisation of the land and how this compares to its predicted utility for agricultural production

Table A - 2: Overview of output from the agricultural productivity tool.

Output layer from agricultural productivity tool	Influenced by	Indicates
Predicted optimal agricultural utilisation	Soil type, using assigned values of fertility, waterlogging (permanent, seasonal, or negligible) and topographic data (aspect, slope, and elevation)	Low to very high agricultural potential
Current agricultural utilisation	Land cover/management data	Ranks areas from highest agricultural productivity to lowest
Relative agricultural utilisation	Combines predicted optimal agricultural utilisation and current agricultural utilisation outputs above	Delineates where land appears to have very high utilisation, potentially being over-utilised, or have very low utilisation, potentially being under-utilised - very high utilisation and potentially being over-utilised when current utilisation category is higher than predicted optimal agricultural utilisation - predicted average utilisation when current utilisation and predicted optimal agricultural utilisation are in the same category - very low utilisation and potentially being under-utilised when current utilisation category is lower than predicted optimal agricultural utilisation
Agricultural utilisation status		Considers whether the current agricultural utilisation may be worthy of preservation or change: - typical/usual utilisation: current utilisation and predicted optimal productivity are in the same category or current utilisation is appropriate for predicted optimal productivity - unusually utilised: current utilisation and predicted optimal productivity are in different categories or current utilisation is appropriate for predicted optimal productivity

Agricultural utilisation

Predicted optimal agricultural utilisation

This output ignores the input land cover and instead predicts a near-optimal utilisation based on:

1. Soil water holding characteristics: permanent, seasonal, or negligible.
2. Fertility: organic carbon is used as a proxy, OC is divided in 5 ranges: 0-2%, 2-6%, 6-15%, 15-30% and >30%
3. Topography: elevation (based on elevation thresholds in meters above sea level (masl) set by user including elevation threshold of productive agricultural land and elevation threshold of all agricultural land), slope (based on slope thresholds in degrees set by user including slope threshold for very productive land and slope threshold for somewhat productive land) and aspect (varying according to hemisphere and with zero effect near the equator)

Flat, well-draining, and fertile areas are predicted to have a high potential for agricultural production for example, more waterlogged areas or steeper areas have less potential. This model output is dependent on the accuracy of user set thresholds and weightings, as well as the soil data layer supplied as input to the scenario pre-processing tool.

Uncertainty may also be introduced through model processing since values for soil fertility and waterlogging are based on estimates or national averages for the soil type and may not reflect site conditions accurately.

Categories	Meaning
Very high production capacity	Well-drained soil, very high fertility and slope is less than or equal to slope threshold for very productive land and elevation are less than the elevation threshold for productive land
High production capacity	Well-drained soil. high fertility, and slope is less than or equal to slope threshold for very productive land and elevation are less than the elevation threshold for productive land
Moderate production capacity	Well-drained soil, moderate fertility, slope is less than or equal to slope threshold for somewhat productive land and elevation are less than the elevation threshold of all agricultural land
Marginal production capacity	Seasonal waterlogged soil, low fertility, slope, slope is less than or equal to slope threshold for somewhat productive land and elevation are less than the elevation threshold of all agricultural land
Negligible production capacity	Permanent water-logged soil, low fertility and slope is more than the slope threshold for somewhat productive land and elevation are more than the elevation threshold of all agricultural land

Current agricultural utilisation

This output shows utilisation according to current land cover/use, ignoring predicted production capacity. Uncertainty is reliant on the accuracy of land cover/land use data. Arable and improved grassland are considered to be highly productive, for example, while bare ground, or built infrastructure such as railways and roads, are considered to provide no agricultural utilisation.

Categories	Meaning
Very high production	Well-drained soil, very high fertility and slope is less than or equal to slope threshold for very productive land and elevation are less than the elevation threshold for productive land
High production	The current land use is medium producing grassland
Moderate production	The current land use is low producing grassland
Marginal production	The current land use is marginally productive, such as woodland and/or heath, vegetation that is not used for agricultural production
No production	The current land use is bog or wetlands, sand and/or rock

Relative agricultural utilisation

This output is calculated from a comparison of predicted optimal agricultural utilisation and current agricultural utilisation outputs. It flags where land appears to be over or under-utilised. If both current and predicted utilisation are within one category of each other, land is considered to be appropriately utilised. If they differ by more than one category, Nature Braid flags where current production appears to be over utilising the land (so may be inefficient farming, or not sustainable), and also where opportunities to increase agricultural production may be present. Any errors in the model output for current and predicted agricultural utilisation will propagate through to this data layer.

Categories	Meaning
Very high utilisation Somewhat high utilisation	Current utilisation category is higher than predicted optimal agricultural utilisation (i.e., land is potentially over-utilised).
Predicted/average utilisation	Current utilisation and predicted optimal agricultural utilisation are in the same category.
Somewhat low utilisation Very low utilisation	Current utilisation category is lower than predicted optimal agricultural utilisation (i.e., land is potentially being under-utilised).

Agricultural utilisation status

This output combines the current and predicted optimal output but in a different way to the relative agricultural utilisation output category. Rather than being concerned with direction of change (under or over utilisation), it considers whether the current agricultural utilisation may be worthy of preservation or change. Land in appropriate utilisation (predicted/average utilisation class in the relative agricultural utilisation map) is considered worthy of protection, areas where land is over or under-utilised are flagged for consideration of change to management. Errors in model output for current and predicted agricultural utilisation will propagate through to this data layer.

Categories	Meaning
Typical/usual agricultural production status	Current utilisation and predicted optimal productivity are in the same category or current utilisation is appropriate for predicted optimal productivity.
Near-typical agricultural production status	Current utilisation and predicted optimal productivity differ by one category
Land on somewhat unusually utilised Land very unusually utilised	Current utilisation and predicted optimal productivity are in different categories or current utilisation is not appropriate for predicted optimal productivity. Land somewhat unusually utilised has current utilisation and predicted optimal productivity are different in two categories. Land very unusually utilised has current utilisation and predicted optimal productivity are different in three categories or more.

Flood Mitigation

The flood mitigation tool considers spatially explicit hydrological and topographical routing with connectivity and configuration details. It uses information on the storage and permeability capacity of elements within the landscape from soil and land use data. Flow accumulation determined using GIS is then modified according to permeability and storage of the landscape. This tool maps areas where overland and near-surface flow may accumulate as well as "mitigating features" with the capacity to help mitigate floods and high stream flow which may follow high-intensity precipitation events. Areas with high water storage capacity and/or high infiltration capacity can help to mitigate downstream flood risk by acting as a sink for fast-moving overland flow and near-surface subsurface flow; either storing this or routing the water more slowly through subsurface routes.

Table A - 3: Overview of output from the flood mitigation tool.

Output layer from flood mitigation tool	Influenced by	Indicates
Flood/flow mitigation	Soil, land use, topography	Mitigation classification of current soil/land use
Flood interception	Soil, land use, topography, climate	Identifies high-priority areas where land is not mitigated by any vegetation and where flow is either being generated or accumulated
Average flow in cumecs (m^3/s)		Flow delivery to all points in the river and lake networks, to estimate water supply services

Flood interception classification

This output shows the flood mitigation layer, which is influenced by soil, land use, topography, and climate. It identifies high-priority areas where land is not mitigated by any vegetation and where flow is either being generated or accumulated. Potential sources of error include inaccuracies in land use input data or Nature Braid classification of land cover as mitigating or not-mitigating. Failure to account for storage capacity of deep soils in non-wetland areas, or faster runoff in urban areas with paved surface may reduce accuracy of mapping of areas of high and low flood concentration.

Category	Meaning
Flood mitigating land	Areas that are providing mitigation of flow (e.g., trees, ponds, deep permeable soils, or other flow sinks) and can intercept flows (and their associated mass, nutrients, sediments, contaminants etc) before reaching streams.
Low flood concentration	Areas with low flow concentration based on a threshold set by the user.
Moderate flood concentration	Areas with moderate flood concentration based on a threshold set by the user.
High flood concentration	Areas of high flood concentration (large contributing area with no mitigation) and where the landscape could benefit from mitigation based on a threshold set by the user.

Flood mitigation classification

This output maps the mitigation classification of the current soil/land use and areas. Potential sources of error include inaccuracies in land use input data or Nature Braid classification of land cover as mitigating or not-mitigating, as well as failure to account for soil permeability.

Category	Meaning
Mitigating features	Areas that are providing mitigation of flow by slowing down flow or having high storage capacity (e.g., trees, ponds, deep permeable soils, or other flow sinks).
Mitigated features	Areas that receive mitigation benefits as water and other mass originating in these areas are intercepted by mitigating features before reaching a stream, lake, or river.
Non-mitigated features	Areas with low permeability and/or storage that do not flow through mitigating features. Any flows from these areas are going directly into water bodies without any features to buffer them.

Habitat

The habitat connectivity tool can be applied for identification of suitable areas for habitat expansion and protection. The tool follows a cost-distance approach to evaluating habitat connectivity, following the approach outlined by Forest Research's BEETLE project (Biological and Environmental Evaluation Tools for Landscape Ecology). Given the importance of kererū in Mataura and to fragmented landscapes more generally due to the species' ability to disperse the seeds of fleshy-fruited trees over long distances, the preliminary habitat connectivity map was produced for kererū in the catchment. Habitat connectivity parameterisation for kererū by Nguyen et. al (2021) was used to provide the preliminary habitat connectivity map of kererū.

Habitat connectivity

This output highlights areas of ideal habitat based on land use/cover and user-defined thresholds of minimum habitat size. It uses information about species ability to travel through hostile terrain to highlight how far it can travel from patches of ideal habitat.

Category	Meaning
Habitat of interest	Native vegetation patches meet the habitat threshold of 0.05 ha which is the minimum foraging habitat size for bush and water birds. The habitat threshold for kererū is 0.05 ha.
Other priority habitat	Not the habitat of interest but being conserved for other purposes, for example, herbaceous freshwater and saline vegetation.
Opportunity to establish new habitat	Within these areas, habitat establishment is possible but exceeds the maximum cost-distance travelled, meaning that any new habitat established here would not be connected to existing habitat of interest.
Opportunity to expand existing habitat	New habitat in this area would act to extend the existing habitat. This does not suggest that the entire area in this category needs to be established with the habitat of interest; rather this shows the maximal extent within which new habitat would be connected to existing habitat. Establishing habitat at this edge of this extent will improve connectivity because the distance travelled across 'hostile' terrain to get to this patch is within the maximum cost-distance through 'hostile' terrain threshold. Outside of this extent, too much 'hostile' terrain would need to be traversed and therefore would not improve connectivity.

Nutrients

Nature Braid estimates the terrestrial nutrient load through a modified export coefficients which consider biophysical and climate characteristics, nutrient inputs, irrigation, stock, Olsen P, and topography (Troldal, 2018). The accumulated load (classified) map combines the predictions of accumulated nutrient load with user-specified thresholds, to categorise the nutrient loading into very low to very high categories. It is influenced by the load contributed from "uphill" sources, topographic routing, and effective precipitation to consider delivery to streams. In-stream nutrient concentrations and loads are also estimated, with the concentrations used to classify stream reaches into having low to very high concentrations based on user-defined thresholds.

Table A - 4: Overview of output from the nutrient tools.

Output layer from flood mitigation tool	Influenced by	Indicates
Terrestrial nutrient loads	Modified export coefficients, rainfall, irrigation, fertiliser, effluent, stock units, topography Water movement; sediment movement Additionally, phosphorus loading is also influenced by Olsen P levels where data is available and assumes best practice where not	Total nutrient load generated at any point within the landscape Nitrogen: kg/ha/yr (Nitrate, Ammonium are treated separately as nitrate is more soluble while ammonium somewhat sorbed) Phosphorus: g/ha/yr (particulate and dissolved species considered separately)
Accumulated load (kg/yr and classified)	Estimates of accumulated nutrient loads based on terrestrial nutrient loads combined with topographic routing and effective precipitation to route water through the landscape	Estimates delivery of nutrients to water bodies Thresholds (user-defined): Nitrogen: • High: 0.1 kg/yr • Very high: 1 kg/yr Phosphorus: • High: 10 g/yr • Very high: 100 g/yr
Nutrient in-stream concentration (mg/L and classified)	Based on accumulated load (above), sediment and nutrients (above) and stream/groundwater attenuation (lags and variable residence times in groundwater can be input where quality information exists)	Concentration of nutrients in-stream for each pixel (mg/L) and reach (classified) Thresholds (user-defined): Total Nitrogen*: • High: 5 mg/L • Very high: 10 mg/L Total Phosphorus: • High: 0.025 mg/L • Very high: 0.075 mg/L

* These thresholds are based on the World Health Organisation's recommendation of a maximum concentration of 11.3mg/L nitrate-N for drinking water and the New Zealand College of Midwives recommendation for pregnant women to avoid water with ≥ 5mg/L nitrate-N (WHO, 2022).

Nitrogen

Classified Nitrogen accumulated load

This output combines the predictions of accumulated total N load with user specified thresholds, to categorise the nutrient loading into very low to very high categories.

Thresholds:

- N critical load threshold 1 (kg/yr): below which accumulated N load is considered of no concern, the default value is 0.1 kg/yr
- N critical load threshold 2 (kg/yr): above which accumulated N load is considered of significant concern, the default value is 1 kg/yr

Category	Meaning
Low to moderate load	Total N accumulated is less than N critical load threshold 1 defined by user
High load	Total N accumulated load is between N critical load threshold 1 and 2
Very high load	Total N accumulated load is higher than N critical load threshold 2

Classified Nitrogen in-stream concentration

This output combines the predictions of N stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.

Thresholds:

- Threshold of high N concentration (mg/L): below which accumulated N concentration is to be considered of no concern, the default value is 5 mg/L based on World Health Organisation recommendation of maximum concentration of 11.3mg/L for drinking water
- Threshold for very high concentration (mg/L): above which accumulated N concentration is to be considered of significant concern, the default value is 10 mg/L based on World Health Organisation recommendation of maximum concentration of 11.3mg/L N for drinking water

Nitrogen accumulated load

This output shows the accumulated total N load (in kg/yr), considering the load not just at a point (depending on modified export coefficients which are influenced by rainfall, irrigation, fertiliser, effluent, and stock), but also that contributed from “uphill” sources. N accumulated load is estimated based on terrestrial nutrient loads combined with topographic routing and effective precipitation to route water through the landscape. High values are prime targets for mitigation or interception opportunities. Accuracy reflects that of the input data on land use and the relevant Nature Braid export coefficient, as well as the DEM and topographic routing approach used to model accumulation. The output can be used to extract total N accumulated load (kg/yr) at any point.

Total Nitrogen in-stream concentration

This output shows total N concentration (in mg/L) at all points in-stream. High values suggest that the catchment of this point should be targeted for mitigation/interception opportunities. N in-stream concentration is influenced by N accumulated load and stream attenuation. This is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial nutrient concentration.

Phosphorus

Classified Phosphorus accumulated load

This output combines the predictions of accumulated total P load with user specified thresholds, to categorise the nutrient loading into very low to very high categories.

Thresholds:

- P critical load threshold 1 (kg/yr): below which accumulated P load is considered of no concern, the default value is 0.01 kg/yr
- P critical load threshold 2 (kg/yr): above which accumulated P load is considered of significant concern, the default value is 0.1 kg/yr

Category	Meaning
Low to moderate load	Total P accumulated is less than P critical load threshold 1 defined by user.
High load	Total P accumulated load is between P critical load threshold 1 and 2.
Very high load	Total P accumulated load is higher than P critical load threshold 2.

Classified Phosphorus in-stream concentration

This output combines the predictions of P stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.

Thresholds:

- Threshold of high P concentration (mg/L): below which accumulated P concentration is to be considered of no concern (oligotrophic). The default value is 0.025 mg/L, based on guidance from Dodds et al. (1998).

- Threshold for very high concentration (mg/L): above which accumulated P concentration is to be considered of significant concern, the default value is 0.075 mg/L based on guidance from Dodds et al. (1998)

Phosphorus accumulated load

This output shows the accumulated total P load (in g/yr), considering the load not just at a point (depending on modified export coefficients which are influenced by rainfall, irrigation, fertiliser, effluent and stock), but also that contributed from "uphill" sources. P accumulated load is estimated based on terrestrial nutrient loads combined with topographic routing and effective precipitation to route water through the landscape. High values are prime targets for mitigation or interception opportunities. Accuracy reflects that of the input data on land use and the relevant Nature Braid export coefficient, as well as the DEM and topographic routing approach used to model accumulation.

Total Phosphorus in-stream concentration

This output shows total P concentration (in mg/L) at all points in-stream. High values suggest catchment of this point should be targeted for mitigation/interception opportunities. P in-stream concentration is influenced by P accumulated load (below) and stream attenuation. This is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial nutrient concentration.

RUSLE

The RUSLE (Revised Universal Soil Loss Equation) uses methods initially applied to agricultural land in the United States of America which have been further developed and applied in various contexts around the world (Wischmeier and Smith, 1978; Renard et al. 1997; Benavidez et al. 2018). It uses information about rainfall erosivity, soil erodibility, topography, land use/cover, and management to estimate soil erosion by water (i.e., rainfall and runoff). The effect of rainfall on erosion is calculated based on coefficients produced by Klik et. al. (2015). The RUSLE mainly accounts for terrestrial soil losses by water, but not explicitly for soil losses from landslides or mass wasting.

Nature Braid extends this by examining which areas have high susceptibility to soil loss and do not have any land use downhill that can intercept sediments, making the receiving streams vulnerable to sediment delivery. The methods and data we use are more highly resolved and updated versus the "USLE" component of NZ Sednet, although we are not routing sediment through the river network in detail as this requires more information on bank form and characteristics than was available.

Table A - 5: Overview of output from the RUSLE.

Output layer from flood mitigation tool	Influenced by	Indicates
Terrestrial soil erosion by water	Rainfall, soil, land use/cover, management, topography	Estimates of soil erosion (tonnes/ha/yr)
Soil loss risk	Terrestrial soil erosion (above) and user-defined thresholds	Risk of soil loss based on thresholds (by default, any soil loss beyond 5 tonnes/ha/yr is considered high)
Risk of sediment delivery	Soil loss risk (above) and mitigating vs non-mitigating features	Whether land use is mitigating (intercepts flow and sediment) or risk of sediment delivery (negligible to high)

Risk of sediment delivery

This output shows sediment delivery vulnerability depending on whether the soil loss (using 'Soil loss risk') is occurring on non-mitigated land.

Category	Meaning
Mitigating features	Areas that are providing mitigation of sediment delivery (e.g., trees, ponds, deep permeable soils or other flow sinks.
Negligible delivery to stream	Areas where soil loss is occurring, but this is being intercepted by mitigating features before reaching water bodies.
Moderate delivery to stream	Areas of high soil erosion risk which are not being mitigated before reaching water bodies.
High delivery to stream	Areas of extreme soil erosion risk which are not being mitigated before reaching water bodies.

Soil loss risk

This output shows the risk of soil loss based on Terrestrial soil erosion and user-defined thresholds.

Thresholds:

- Lower threshold for medium erosion risk (2.5 tonnes/ha/yr)
- Lower threshold for high erosion risk (5 tonnes/ha/yr)

- Lower threshold for extreme erosion risk (10 tonnes/ha/yr)

Terrestrial soil erosion by water

This output shows the annual soil loss by water using the RUSLE which considers rainfall, soil, land use/cover, management, and topography. The rainfall factor uses the New Zealand constants formulated by Klik et al. (2015) and the user is referred to that article to find the constants for their study area.

A.3The FARMAX model

FARMAX is a decision support tool designed to help pastoral farmers to monitor, review and analyse their farming businesses, in order to optimise their profits and farming systems. Developed by AgResearch and commercially launched in 1993, the FARMAX engine utilises AgResearch published science and expertise to ensure all information feeding into the model is relevant and up to date. The engine is designed to model both the biological systems and economic outcomes of various farming systems, with individual Dairy and Redmeat software packages.

The software allows for actual physical farm parameters to be inputted including farm size, regional location, livestock stock numbers by class, breed, mating and reproductive performance and production information as well as timing of product sale along with product statistics. The model calculates the required feed demand for a modelled livestock system within the constraints of user-defined pasture growth rates and animal performance data. It uses feed demand data for different livestock classes and feed supply information from an extensive database of pasture growth and crop yields. This is integrated with economic information so that complex farm systems can be modelled. However, it does not consider spatial aspects and only models nitrogen fertiliser inputs in relation to pasture growth. It can be used to predict physical and financial outcomes of a farm so is a useful tool for optimising a farm system given different scenarios.

For economic analysis, up to date meat and milk schedules are built into the FARMAX model but these can be adjusted to reflect farm actuals. Nitrogen fertiliser inputs, cropping and conservation areas and pasture production can all be manually input in the model. Where information is unavailable, FARMAX libraries provide industry average information. Farm expenses are also built into the model and are either from a library of information or can be manually corrected for increased accuracy for an individual user.

Assumptions and limitations of FARMAX for this project

All scenarios were run in ‘long-term’ mode. This provides checks and balances to ensure that the model is balanced for factors such as pasture covers, stock reconciliations, animal liveweight gains, for example prompting checks on opening and closing stock numbers to ensure that the system is stable over multiple years.

Modelling hypothetical farms was a limitation of the farm system modelling as financial results and farm management decisions are not real for any specific farm types. Taking an average approach was preferred over identifying a real farm in the catchment, to prevent the selection of a farm business which would not be considered average in the catchment. The non-spatial nature of the FARMAX model was also a limitation when feeding physical farm information into the Nature Braid model which has a spatial element.

It is important to note that during this project, FARMAX software underwent an update. WSP has not investigated whether this update has affected any calculations or processes within the model. This does not affect results within catchment, however when comparing results between the Mataura and Wairoa catchments, care will need to be taken as these are modelled in two different versions of FARMAX.

A.4 Information used for the creation of the FARMAX base farm setups

Dairy

400 Kiwi cross cows are milked on 165 hectares. Off farm grazing of youngstock is assumed.

5% of the milking platform is used for growing a summer bulb turnip, and 15% of the platform is conserved for pasture silage in spring.

Replacement rate is 20%

Key Performance Indicators	2025	
Milking area (ha)	165	
Support block area (ha)	0	
Peak cows milked	393	
Stocking rate (cows/ha)	2.4	
Liveweight (kg/cow)	500	
liveweight/ha (kg/ha)	1105	
Nitrogen fertiliser use (kgN/ha/yr)	117 kgN/ha to pasture + 109 kgN/ha to turnips	
Crop area (ha)	8ha summer turnips	
Production Summary		
Milk (kgMS /ha)	829	
Meat (kg/ha)		
Emissions	kg/ha	Total (tonne)
Methane	279	46.0
Nitrous Oxide	7.3	1.2
CO_2e	9324	1538
Financial		
Milk price ($/kgMS)	$7.29	
EFS ($/ha)	$1857	

Hill Country Sheep and Beef

Predominantly moderate hill farm, with 60 ha of easy country and 100 ha of steep contour. Pasture grows at an average of 7,351 kgDM/ha and is medium quality ryegrass and clover pasture, with high quality pasture on the easy contour.

400 Romney ewes are wintered, at a 25% replacement rate. Half the ewe mob is mated to a terminal ram (polled Dorset as a proxy for Wiltshire). Replacement hogget's are mated, with excess ewe lambs retained unmated and sold as prime hogget's. 90% of all lambs are finished on farm.

50 MA beef-type cows are wintered at a 20% replacement rate. An additional 250 dairy weaner bulls or mixed sex beef-type weaners are purchased to fatten, with tails sold store.

Key Performance Indicators	2025	
Effective area (ha)	360	
Species ratio (sheep: beef)	22:78	
Stocking rate (SU/ha)	9.3	
Nitrogen fertiliser summary (kgN/ha/yr)	22 kgN/ha on pasture	
Crop area (ha)	0	
Production Summary		
Product per effective ha (kg)	198.6	
Opening MA ewes	400	
Opening MA cows	50	
Lambs sold	331, 89% prime	
Cattle sold	291, 79% prime	
Emissions	kg/ha	Total (tonne)
Methane	109.2	39.3
Nitrous Oxide	2.2	0.8
CO_2e	3429	1234
Financial		
Gross margin per kg product	$4.05	
Gross margin (per effective ha)	$803.9	
EFS ($/ha)	$286	

Mixed Cropping (kumara and lamb finishing)

The farms predominant venture is Kumara production, with lambs finished on pasture and addition baleage made for sale off farm.

It’s assumed that kumara is grown on the same area every second year to minimise disease prevalence and for soil recovery. Therefore only 50% of the available area is cropped per year.

9 ha of red kumara and 9 ha of orange Kumara is sown in October, receiving 44 kgN/ha and 15.6 kgN/ha from Yara Mila Complex fertiliser 5 days after sowing. The assumed yield for red and orange kumara was 13.5 bins/acre and 21 bins/acre respectively. The cost to produce a bin was $400 excl. debt servicing, with returns of $780 per 500 kg bin.

Lambs are purchased and finished on pasture, dependant on feed supply.

Key Performance Indicators	2025
Effective area (ha)	35 (18 ha crop)
Species ratio (sheep: beef)	100:0
Stocking rate (SU/ha)	8.5 (whole farm)
Nitrogen fertiliser summary (kgN/ha/yr)	55 kg N/ha to pasture + new grass and 30 kgN/ha to crop block
Crop area (ha)	18
Production Summary	
Product per effective ha (kg)	234.9
Opening MA ewes	0
Opening MA cows	0
Lambs sold	1423, 100% prime
Beef sold	0 (100%)

Emissions	kg/ha	Total (tonne)
Methane	88.2	3.1
Nitrous Oxide	2.0	0.07
CO_2e	2855	4.7

Financial	
Gross margin per kg product	$37.74
Gross margin (per effective ha)	$12,662
EFS ($/ha)	$8695.8

Lowland Beef Finishing

The farm is a beef only finishing unit with some store sales. The block grows a potential 8,132 kgDM/ha/yr of high quality pasture.

There are no breeding cows on farm, and both spring and autumn born Friesian bull calves are purchased pre-Christmas, as well as beef type steers and heifer weaners in March and May. 85% of beef is sold prime.

10 ha of chicory is sown annually in September and resown into new pasture 19 months later. Additional baleage is made in late spring and fed during winter feed deficit.

Key Performance Indicators	2025	
Effective area (ha)	235	
Species ratio (sheep: beef)	0:100	
Stocking rate (SU/ha)	12.1	
Nitrogen fertiliser summary (kgN/ha/yr)	25 kgN/ha to pasture + 84.5 kgN/ha to chicory crop	
Crop area (ha)	10 ha new chicory, 10 ha second year	
Production Summary		
Product per effective ha (kg)	276.3	
Opening MA ewes	0	
Opening MA cows	0	
Lambs sold	0	
Beef sold	338, 85% prime	
Emissions	kg/ha	Total (tonne)
Methane	146	34.3
Nitrous Oxide	2.8	0.67
CO$_2$e	4523	1,064
Financial		
Gross margin per kg product	$4.34	
Gross margin (per effective ha)	$1,199	
EFS ($/ha)	$648	

A.5Specific assumptions for Agroforestry systems

As the Agroforestry system is comprised of multiple components, further detail of the assumptions of how these have been modelled are below.

General Agroforestry assumptions compared to the baseline modelling:

- 50% pasture production
- 50% stocking rate
- 50% of income
- 50% greenhouse gas emissions and subsequent levy
- 50% of all variable costs, fixed costs remained as baseline.
- Forage crops removed from the system, 50% of the cost to produce the forage crop is added as bought in feed (50% to represent ½ the stock so ½ the crop required)
- Yield from pruning and thinning poplars not accounted for (1-5 kg/tree/yr) but assumed to mitigate any loss in DM between the forage crop cost and the supplementary feed purchased.
- N and P fertiliser is still applied to the Agroforestry system, at the same timings as the base for pasture N but at 50% of the rate (due to the 50% reduction in pasture grown). Where crop has been removed, crop fertiliser has been removed.
- No other system modifications, with same animal production timing and growth rates. It is assumed grazing is excluded for three years while young trees develop. During this period the assumption was that land would be leased to graze the livestock that would otherwise be grazing under the poplar forest. The assumed lease value for dairy land in the Wairoa catchment was on average $1400/ha/yr, while dry stock land around $550-600/ha (Pers. Comm. B. Aitken, ASB, Nov 2022). For simplification in the model, a lease rate of $1400 was used for all models due to the high profitability of the Agroforestry systems, and the change in lease value not having a significant impact on overall results.

Dairy specific assumptions

- The nitrogen fertiliser application is split into 4 applications of 15 kg N/ha per application. This is different to baseline modelling, due to crop removal. It is assumed the equivalent cost of cropping is to be spent on supplementary feed.
- The pasture silage is still made as per baseline modelling.
- Initial Dairy baseline for Wairoa had PKE fed above 3kg/hd/day, which Fonterra has a capped due to issues with milk fat composition. A model was developed as a sensitivity test by taking a copy of the baseline file and re-distributing PKE to meet the 3kg/hd/day cap. No additional feed was purchased, overall pasture cover and feed eaten was within 5% of the original, and milk solid production remained constant, the GHG impact and sub sequent levy was also negligible. The result provided confidence that there was no need to alter the information fed into the economics and NB models for the dairy base system.

Lowland Beef Finishing specific assumptions

- Lowland chicory in baseline modelling is removed and crop cost is put into purchasing supplementary feed.
- Pasture baleage is still made.
- Pasture N application has been increased to whole farm area (base model excludes pasture N application on crop area)
- Silage is still produced under the Agroforestry system. At 6x6 m planting spacing, tractors and machinery will fit down rows to allow pasture harvest to occur. Spacing is not correct

until year 10, but cost of conservation can be re-invested in imported feed (the actual cost difference has not been calculated or applied in the Agroforestry scenarios)

- As per baseline model, it is assumed 10 ha of new grass is sown annually with establishment N and P fertiliser (25 kg N/ha on 10 ha)

Hill Country Sheep and Beef specific assumptions

- No specific assumptions, only general Agroforestry assumptions apply.

Mixed Cropping specific assumptions

- It is assumed there is no practical method of integrating Agroforestry and a Mixed Cropping system. Therefore, in any sediment high-risk area that is currently Mixed Cropping, this will transition to an Agroforestry - Lowland system.

Pasture system assumptions

Within the Agroforestry system it is assumed that pasture production would reduce by 50%. This is a conservative number and most New Zealand literature indicates there is variation in the reduction in total pasture growth. The reduction in pasture growth depends on factors such as tree species, site, tree stocking rate, forest age, canopy fullness (%), and season, with more reduction in summer due to the leaf canopy, and less in winter when leaves have fallen. Most estimates sat around a 10-25% reduction from open pasture in formative years of a forest (10 years) and as the canopy closes, reductions around 40-50% were observed around year 20. (McElwee and Knowles, 2000; Guevara-Escobar, 1999; P&FR, 2022; Pers. Comm D. Satchell, 2022). McElwee and Knowles (2000) predicted the livestock carrying capacity farmed under a 200 stem/ha and 400 stem/ha forest levelled out at 60% and 40% of original livestock carrying capacity respectively, 15 years after planting. Leaf fall from mature trees can be up to 60 kgDM per tree (NZ Poplar and Willow trust, 2013), while estimated yields between 1-5 kgDM/prune/tree can be expected when pruning every two years (NZPC, 1995). This additional dry matter has not been accounted for in the model but is assumed to play an important role in meeting feed demand as canopy cover increases and pasture production decreases with forest age.

In light of the multiple factors mentioned above, based on the research and advice from industry experts, for the purpose of this thought exercise, a simple average reduction in pasture growth of 50% annually was used. Correspondingly, animal stocking rates were also reduced by 50% from the respective baseline FARMAX model.

A.6 Scenario 2A – N risk assumptions for Northern Wairoa

Dairy

2030 – 85kg N/ha/yr cap

- Removal of bulb turnips from the system, removal of N applications in July and reduction of April application from 30kgN/ha to 25kg N/ha
- Increased pasture silage area by 7 ha.
- + 20t maize silage (40t total) represented as feed crop, + 60 bales baleage (160 total) + 29 tonne pk (179 total), which are bought feeds.
- BCS in March/April dipped by .05, but was back to baseline in Dec/Jan
- Same milk solids per cow,
- 2% reduction in herd number (generic scaling not selective of older cows), breeding costs down 2% ($24,121 to $23,639)

Issues:

- Increased catchment demand for maize silage and baleage. If there are limited areas within the catchment of low risk for N loss, which can grow maize, then importing is likely which will drive up transport/feed cost and therefore production costs.
- Feed costs weren't calculated using the model. Solution, the proportional change in the feed cost predicted by FARMAX has been added to the Dairybase Northland average. ($52,500 to $61,203 = 16.58%). $83,285*1.1658 = $97,091.27
- Regressing from industry average – assumes regrassing continues even when turnips are removed.

2060 (compared to base)

- High winter covers, + Feb.
- Minimum application of N fertiliser @ 20kgN/ha – winter application removed. Rate dropped to 65kgN/ha/yr. Total N use 62 kg N/effective ha.
- Turnips removed, purchase 200 bales (+100 form baseline), + 35t maize silage (+15t form baseline) + 200t PKE (+50t from baseline). Increased supplement fed over all months.
- Drying off, 28th March – 2 weeks earlier. Heifers milked the same.
- 5% scaling down in herd size.
- Increase in silage area to 25 ha (+10)
- Natural optimization (less decay by 20kgDM/ha in 2060 system). N boost of 611 kgDM vs 1156 kgDM in original.
- Feed expenses (model = $73, 618. baseline= $52,500. Proportional increase = 40.22%. New feed cost = $83,285*1.402= $116,786.2.

Lowland Beef Finishing

2030 – 85kg N/ha/yr cap

- Chicory. Apply emergence fertiliser DAP at same rate (200kg or 35.2 kgN/ha), then reduce post grazing applications to 25kgN/ha (x2 in year one). not modelled in FARMAX directly.
- Chicory yield decreases from 13t/ha to 11.5 t/ha. (total =115 tDM). Second year crop receives the same annual fertiliser (as less than 85kgN/ha/yr).
- The 'N balance' was not re-added into the pasture block.
- Stock policy remains unchanged.
- Slightly improved pasture utilization.

Chicory fertiliser value change:

200kg DAP to 198 kg/ha= -2kg/ha * 10ha = 20kg DAP & $1800/t = 20*1.8 $36

Urea = 160 kg to 108 kg = -52 kg urea/ha. -52 * 10ha = -520 kg urea total. @ $984/tonne = $ 511 total.
Total $ savings = $548
New chicory establishment cost = $1250/ha (current) – 55 ($548/10) = $1,195/ha. Value manually changed in FARMAX.

2060 – 65 kg N/ha/yr cap

- Chicory replaced with pasture silage made on farm. Reduced summer cover + higher winter cover
- Regrassing plan needs to be considered ($6000 in current system, following chicory crop. With no crop, this will be missed from the model)
- Whole farm N increased to 25kgN/ha in March, from 15 kgN/ha.

Fert calc. All chicory removed (cost accounted in FARMAX). + additional urea added to pasture block (cost accounted for).

A.7 Emissions levy pricing pathways

Parameter	Unit	2025	2030	2035	2040	2045	2050	2055	2060
CH_4, low (95% discount in 2025, reduced by 1 pp yr-1)	$ per kgCH4	0.11	0.35	0.60	0.93	1.35	1.88	2.49	3.19
CH_4, medium	$ per kgCH4	0.49	1.00	1.39	1.89	2.50	3.27	4.13	5.10
CH_4, high (50% discount in 2025, reduced by 7.1 pp yr-1)	$ per kgCH4	1.06	1.97	2.58	3.32	4.24	5.36	6.60	7.97
N_2O/CO_2, low (95% discount in 2025, reduced by 1 pp yr-1)	$ per tCO2e	4.25	13.80	24.07	37.20	53.91	75.00	99.52	127.48
N_2O/CO_2, medium	$ per tCO2e	19.60	39.80	55.70	75.50	100.10	130.70	165.30	204.00
N_2O/CO_2, high (50% discount in 2025, reduced by 7.1 pp yr-1)	$ per tCO2e	42.50	78.86	103.16	132.87	169.44	214.29	264.04	318.70

Per hectare levy calculation equation: kgGas/farmed ha x $/kgGas = $/ha in levy

A.8 Total catchment estimated emissions and sequestration by land use (tonnes CO2-eq)

	1A			1B			2A			2B			2C		
	2025	2030	2060	2025	2030	2060	2025	2030	2060	2025	2030	2060	2025	2030	2060
Dairy	929,206	842,819	685,114	929,206	842,819	685,114	929,206	751,894	635,804	929,206	843,973	527,792	929,206	862,678	498,005
Hill Country Sheep and Beef	425,828	421,179	76,273	425,828	421,179	-	425,828	331,619	74,654	425,828	421,300	-	425,828	421,369	-
Lowland Beef Finishing	95,275	70,995	62,050	95,275	70,995	-	95,275	68,113	53,327	95,275	73,893	-	95,275	74,673	-
Mixed Cropping	7,251	6,866	6,866	7,251	6,866	6,866	7,251	6,818	6,818	7,251	6,867	6,867	7,251	6,867	6,867
Orchard (Avocado)	1,134	1,134	1,134	1,134	1,134	1,134	1,134	308	308	1,134	1,134	1,134	1,134	1,134	1,126
Exotic Forestry	-1,574,903	-2,035,845	-5,452,154	-1,574,903	-2,035,845	-6,479,885	-1,574,903	-2,639,923	-3,956,667	-1,574,903	-2,012,982	-4,040,351	-1,574,903	-1,950,091	-1,950,091
Totara Forestry															-580,228
Indigenous Vegetation	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,095	-234,062
Orchard (Macadamia)	-	-	-	-	-	-	-	-	-	-	-	5,671	-	-	5,671
Agroforestry - Dairy	-	-	-	-	-	-	-	22,321	22,321	-	-	-	-	-	-
Agroforestry - Lowland	-	-	-	-	-	-	-	3,350	6,697	-	-	30,468	-	-	29,800
Agroforestry - Hill	-	-	-	-	-	-	-	16,718	30,005	-	-	121,381	-	-	121,058
Net Emissions	-350,303	-926,946	-4,854,811	-350,303	-926,946	-6,020,866	-350,304	-1,672,877	-3,360,828	-350,304	-899,910	-3,581,132	-350,304	-817,465	-2,101,853

Negative (red) values indicate carbon sequestration in tonnes CO_2-eq.

A.9 A comparison of Nature Braid results for the Wairoa versus LAWA river observation measurements

Although the Nature Braid model on average "underpredicts" total N and P compared to observed values, this is expected, especially when it comes to total P. This is because although Nature Braid represents the impact of land management in detail and can infill missing localised parameters from more general regional, national, or international datasets where necessary, it needs explicit information on industrial discharge, sewage, number, and approximate locations of septic tanks etc to fully account for point source data inputs. Trends between observed and modelled predictions match well. These are presented for total N in Table A - 6 and Figure A - 1, and for total P in Table A - 7 and Figure A - 2.

Table A - 6: Comparing total N results between Nature Braid and LAWA annual average (mg/L).

LAWA site	Location	LAWA 5 year median	LAWA annual average 2006 - 2020	Nature Braid value
nrc-00006	Kaihu at Gorge	0.380	0.461	0.414
lawa-103474	Mangakahia at Titoki	0.270	0.429	0.260
nrc-00009	Mangakahia at Twin Bridges	0.200	0.316	0.145
nrc-00002	Manganui at Mititai Road	0.640	0.696	0.842
nrc-00001	Mangere at Knight Road	1.000	1.069	0.695
nrc-00012	Waiotu at SH1	0.460	0.668	0.606
nrc-00030	Waipao at Draffins Road	2.600	2.683	1.580
lawa-103475	Wairua at Purua	0.660	0.893	0.587
nrc-00013	Mangahahuru at Main Road	0.270	0.335	0.346
nrc-00008	Opouteke at Suspension Bridge	0.210	0.353	0.045

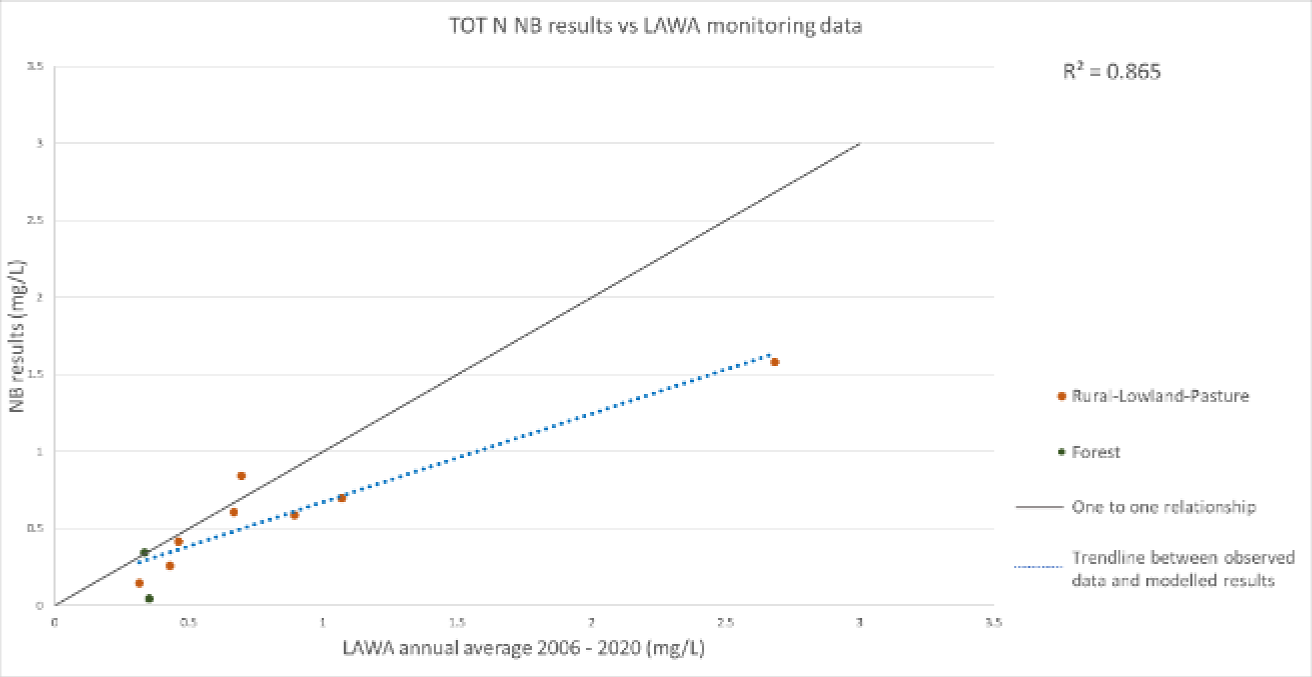


Figure A - 1: Total N results between Nature Braid and LAWA annual averages.

(Note underprediction is expected as data on sewage, septic tanks, industrial discharge was not available and not included, also driving rainfall and potential evaporation were on different timescales).

Table A - 7: Comparing total P results between Nature Braid and LAWA annual average (mg/L).

LAWA site	Location	LAWA 5 year median	LAWA annual average 2006 - 2020	Nature Braid value
nrc-00006	Kaihu at Gorge	0.0140	0.025	0.00125
lawa-103474	Mangakahia at Titoki	0.0240	0.032	0.000217
nrc-00009	Mangakahia at Twin Bridges	0.0285	0.049	0.002189
nrc-00002	Manganui at Mititai Road	0.0150	0.0295	0.000774
nrc-00001	Mangere at Knight Road	0.0800	0.0816	0.008693
nrc-00012	Waiotu at SH1	0.0890	0.1218	0.015923
nrc-00030	Waipao at Draffins Road	0.0130	0.0357	0.000317
lawa-103475	Wairua at Purua	0.0450	0.0625	0.006524
nrc-00013	Mangahahuru at Main Road	0.0450	0.0553	0.007209
nrc-00008	Opouteke at Suspension Bridge	0.0580	0.0810	0.004097

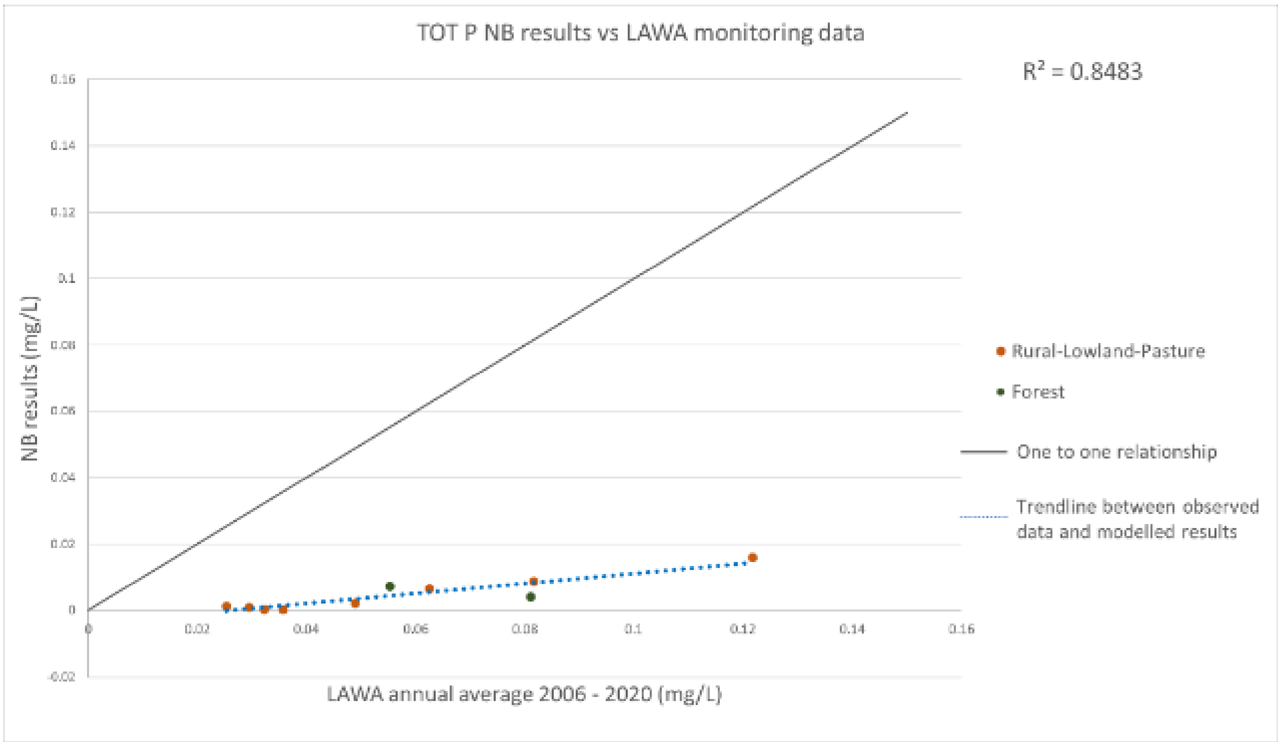


Figure A - 2: Total P results between Nature Braid and LAWA annual averages. (Note underprediction is expected as data on sewage, septic tanks, industrial discharge was not available and not included, also driving rainfall and potential evaporation were on different timescales).

A.10 Nature Braid NH_4-N, NO_3-N, particulate P and dissolved reactive P results for the baseline 2025 versus the scenario 2C 2060

The proportion of NO_3-N (nitrate) and NH_4-N (ammonium) was assumed to be 0.8:0.2 and the proportion of dissolved reactive phosphorus (DRP) and particulate phosphorus (PP) was assumed to be 0.3:0.7. The results of NH_4-N, NO_3-N, PP and DRP, however, are not simply obtained from multiplying the total N and total P using the assumed proportions. The proportion is just one of the input parameters for Nature Braid's N and P model and N and P species separation. The separation also considers other factors including topography, soil type, climate, land use and land management, requiring the Nature Braid nutrient models to be rerun to ensure impact of these factors and spatial configuration is maintained.

Thresholds for NO_3-N were based on National Objectives Framework (NOF) guidelines around toxicity (Ministry for the Environment, 2020); influenced by ANZG (2018) and various NIWA client reports, including Whitehead et al. (2022). Similarly, thresholds for NH_4-N were influenced by these guidelines, although the NOF guidelines on NH_4-N are less clear and based on quantile information; the information from ANZG (2018) was primarily used to consider thresholds at which NH_4-N has chronic to extreme toxicity effects on a range of aquatic species (Table A - 8). As both DRP and PP are generally not directly toxic to aquatic species, rather indirectly harmful when combined with other environmental factors contributing to eutrophication, thresholds for these remained as documented in Nature Braid, based on internationally accepted thresholds for where P contributes to eutrophication.

Table A - 8: Thresholds used to classify potential toxicity of nitrate and ammonium to aquatic stream species.

NO_3-N thresholds for stream concentration (mg/L)	Meaning
<1	Negligible toxicity
<2.4	Low chronic toxicity
<3.8	Some chronic toxicity
<6.9	High chronic toxicity as concerning chronic toxicity
<20	Some acute toxicity
>20	Highly acute toxicity
NH_4-N thresholds for stream concentration (mg/L)	Meaning
<0.01	Negligible toxicity
<0.05	Low toxicity
<0.1	Some toxicity
<0.5	Somewhat concerning toxicity
>0.5	High toxicity

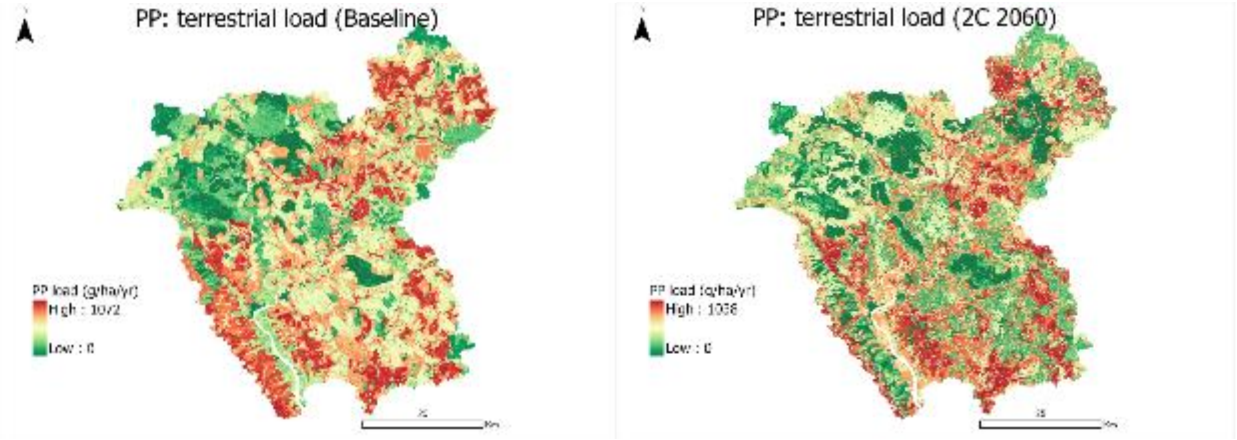


Figure A - 3: Particulate P terrestrial load changes between the baseline 2025 and scenario 2C 2060.

Table A - 9: Summary statistics for particulate phosphorus (PP) terrestrial load for the baseline 2025 and scenario 2C 2060.

PP load (g/ha/yr)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	252.1	122.06
Max	1072.4	1038.1

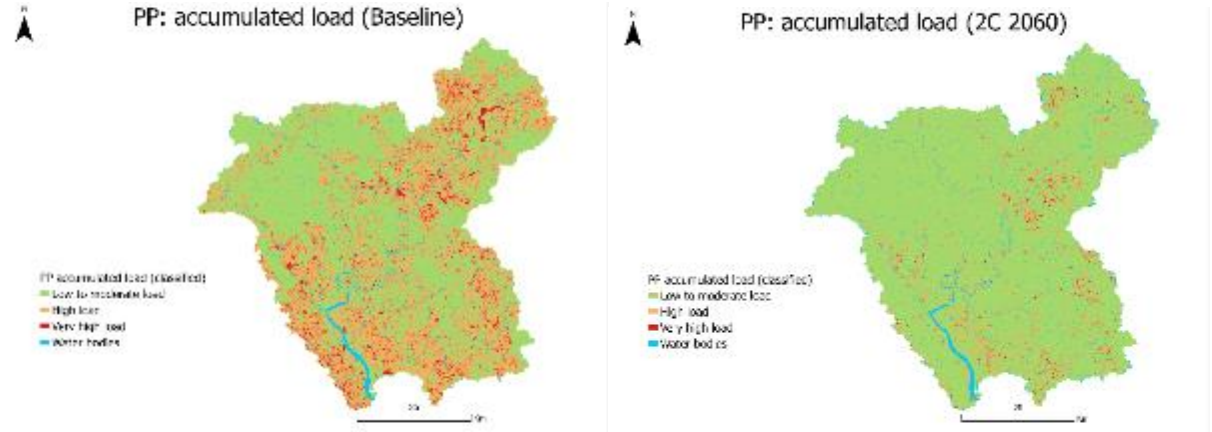


Figure A - 4: Particulate phosphorus (PP) accumulated load changes between the baseline 2025 and scenario 2C 2060.

Table A - 10: Summary statistics for particulate phosphorus (PP) stream concentration for the baseline 2025 and scenario 2C 2060.

PP stream concentration (mg/L)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	0.01	0.001
Max	15.5	0.07

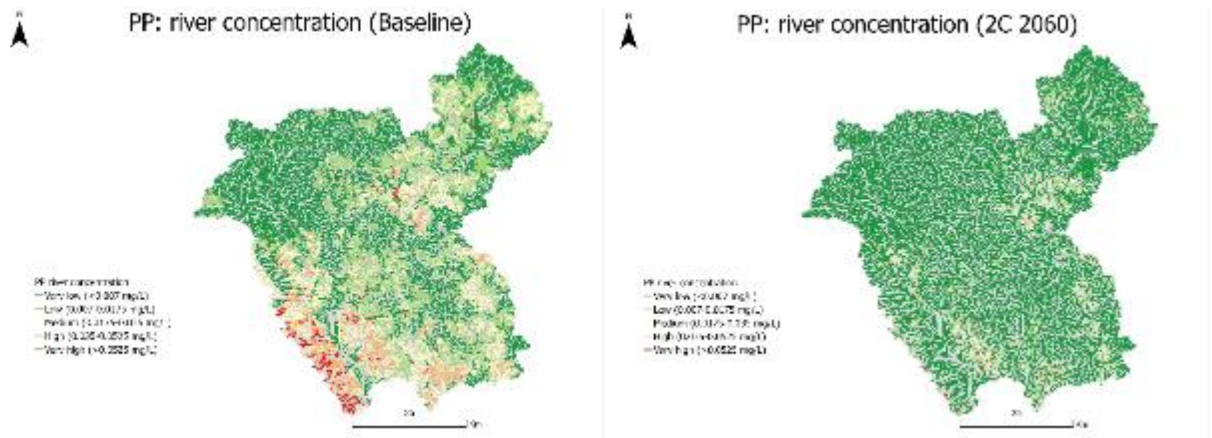


Figure A - 5: Particulate river concentration changes between the baseline 2025 and scenario 2C 2060.

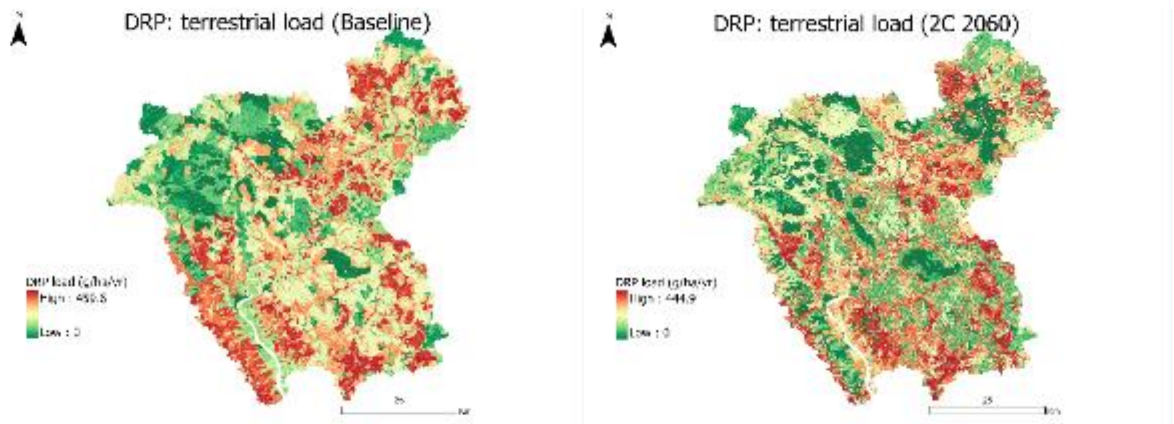


Figure A - 6: Dissolved P terrestrial load changes between the baseline 2025 and scenario 2C 2060.

Table A - 11: Summary statistics for dissolved reactive phosphorus (DRP) terrestrial load for the baseline 2025 and scenario 2C 2060.

DRP load (g/ha/yr)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	108.1	52.3
Max	459.6	444.9

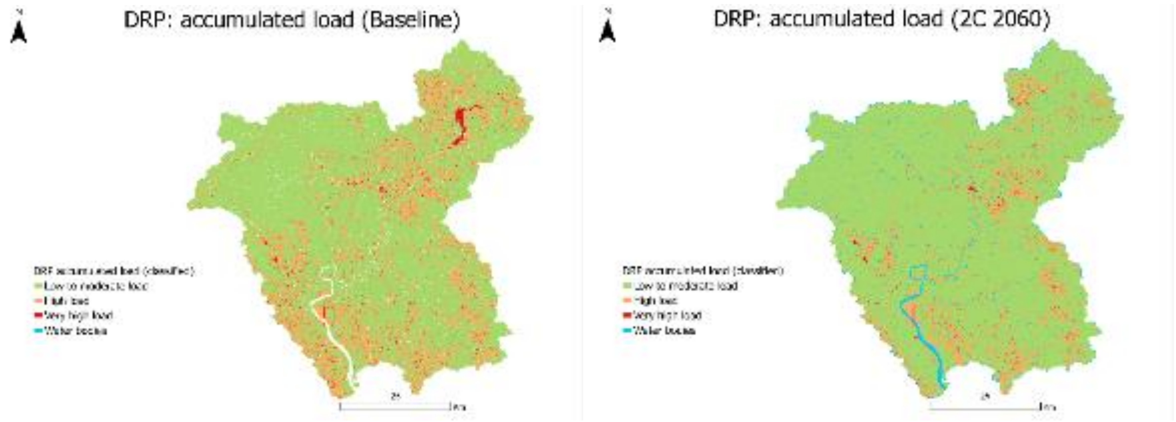


Figure A - 7: Dissolved reactive phosphorus (DRP) accumulated load changes between the baseline 2025 and scenario 2C 2060.

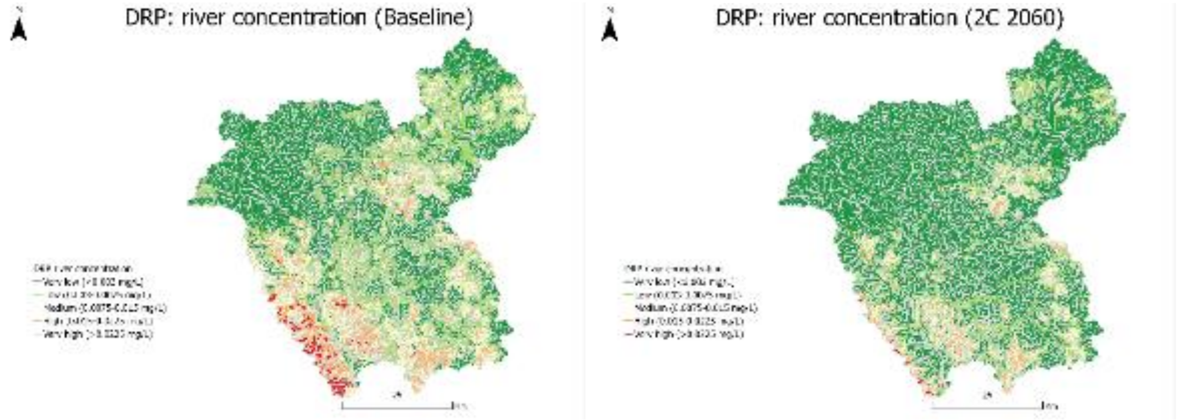


Figure A - 8: Dissolved reactive phosphorus (DRP) river concentration changes between the baseline 2025 and scenario 2C 2060.

Table A - 12: Summary statistics for dissolved reactive phosphorus (DRP) stream concentration for the baseline 2025 and scenario 2C 2060.

DRP stream concentration (mg/L)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	0.005	0.002
Max	0.08	0.03

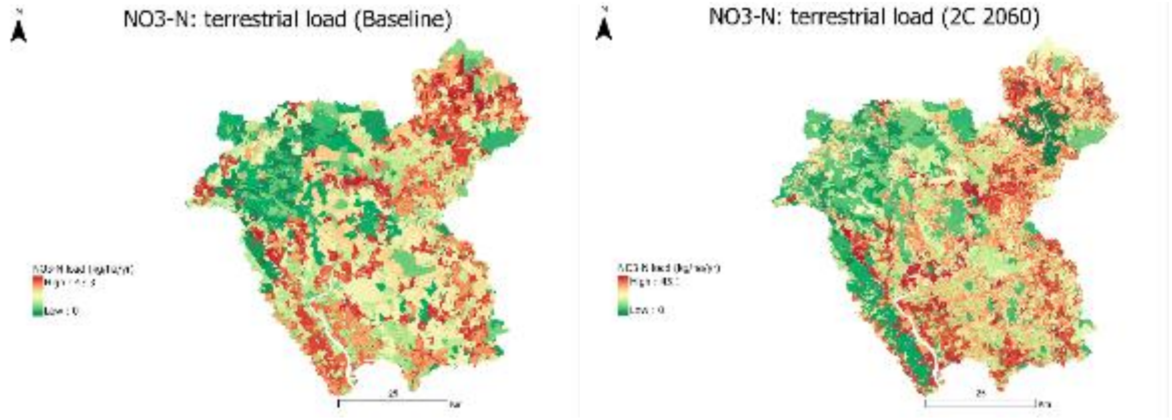


Figure A - 9: Nitrate nitrogen (NO_3-N) terrestrial load changes between the baseline 2025 and scenario 2C 2060.

Table A - 13: Summary statistics for nitrate nitrogen (NO_3-N) terrestrial load for the baseline 2025 and scenario 2C 2060.

NO_3-N load (kg/ha/yr)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	8.0	3.7
Max	43.3	43.1

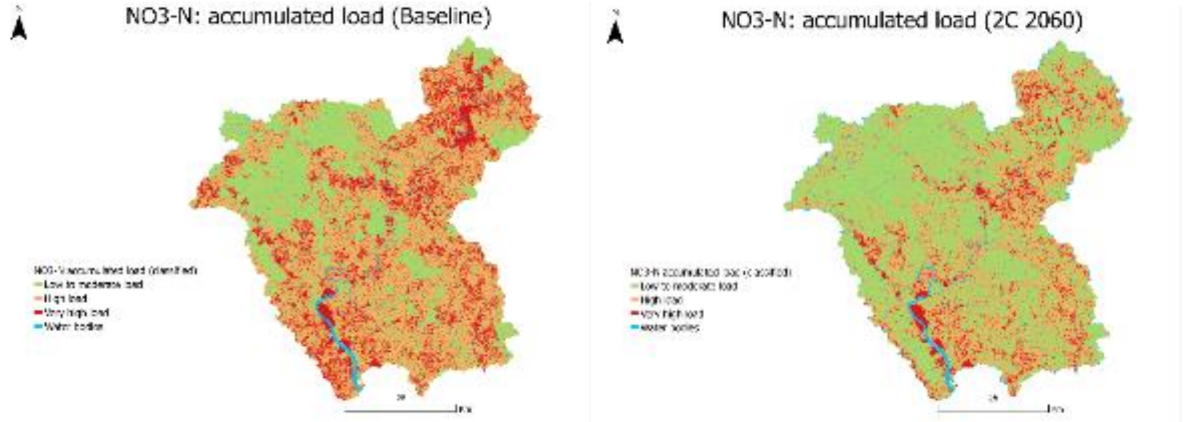


Figure A - 10: Nitrate nitrogen (NO_3-N) accumulated load changes between the baseline 2025 and scenario 2C 2060.

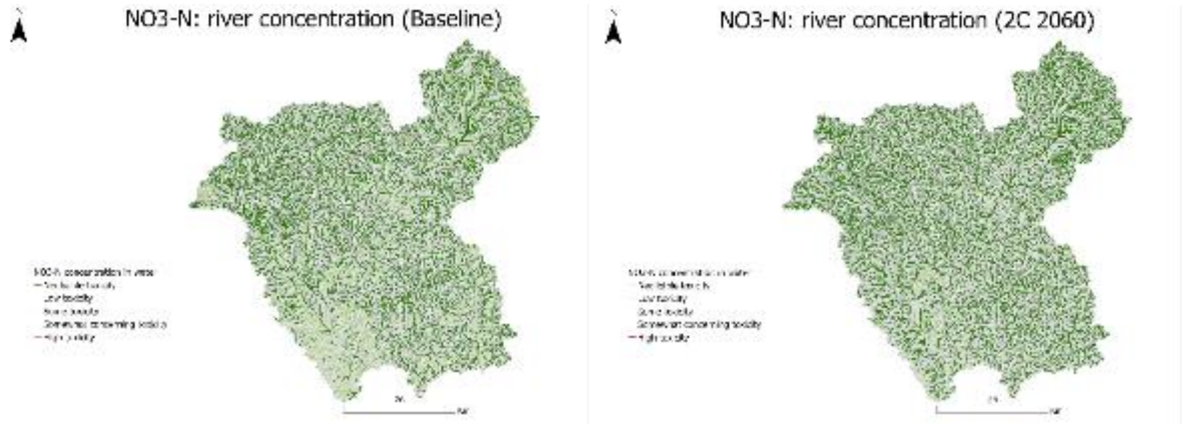


Figure A - 11: Nitrate nitrogen (NO_3-N) river concentration changes between the baseline 2025 and scenario 2C 2060.

Table A - 14: Summary statistics for nitrate nitrogen (NO_3-N) stream concentration for the baseline 2025 and scenario 2C 2060.

NO_3-N stream concentration (mg/L)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	0.5	0.2
Max	9.4	3.2

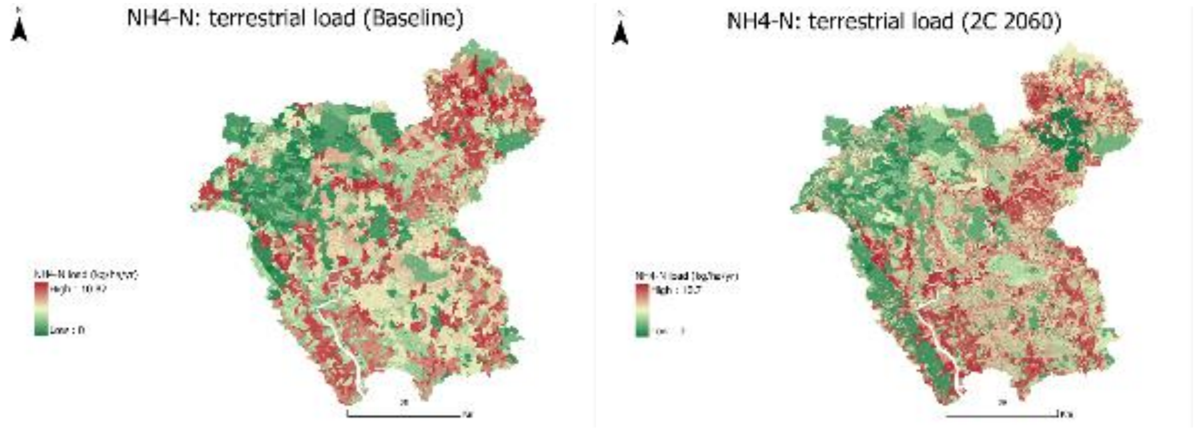


Figure A - 12: Ammonium (NH_4-N) terrestrial load changes between the baseline 2025 and scenario 2C 2060.

Table A - 15: Summary statistics for ammonium (NH_4-N) terrestrial load for the baseline 2025 and scenario 2C 2060.

NH_4-N load (kg/ha/yr)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	2.0	0.9
Max	10.8	1.5

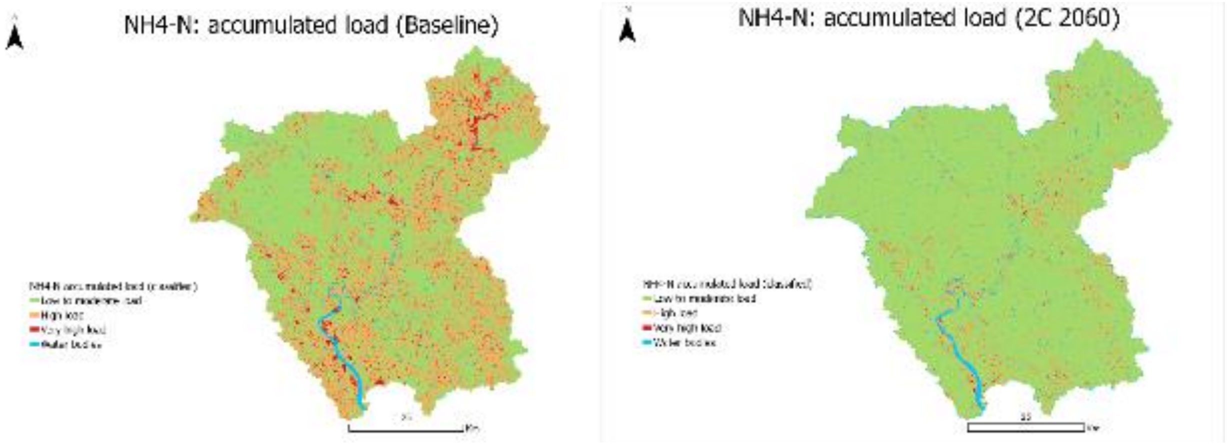


Figure A - 13: Ammonium (NH_4-N) accumulated load changes between the baseline 2025 and scenario 2C 2060.

Table A - 16: Summary statistics for ammonium (NH_4-N) stream concentration for the baseline 2025 and scenario 2C 2060.

NH_4-N stream concentration (mg/L)	Baseline 2025	Scenario 2C 2060
Min	0	0
Mean	0.1	0.01
Max	173.4	1.07

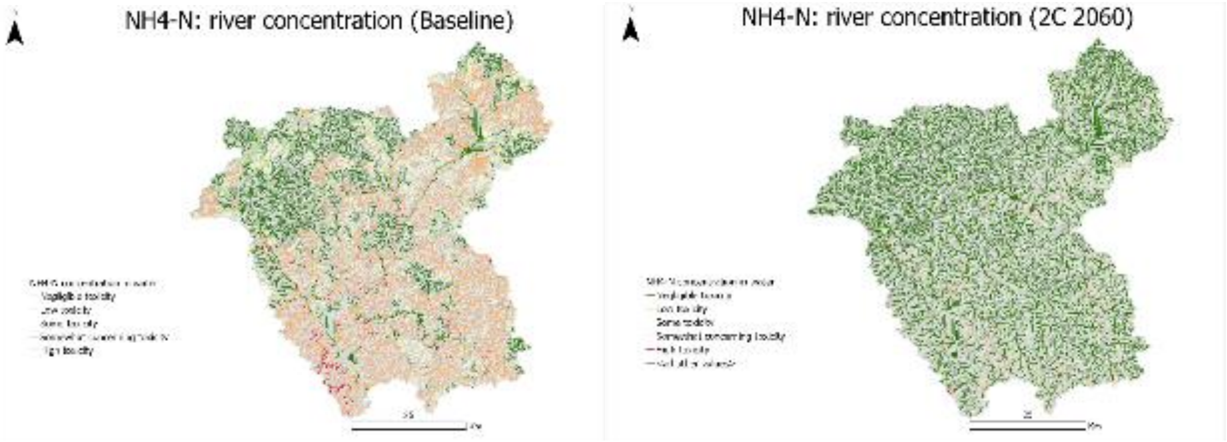


Figure A - 14: Ammonium (NH_4-N) river concentration changes between the baseline 2025 and scenario 2C 2060.

A.11 Additional Nature Braid Maps

Land use maps for the baseline 2025 and the five scenarios for 2030 and 2060, as well as land use maps for scenario 2A using LWS and Nature Braid sediment layers, are shown below in Figure A - 15 to Figure A - 22. The LWS-Nature Braid (NB) sediment high-risk areas and LWS N high-risk areas and the overlap area of both of these areas are shown in Figure A - 23.

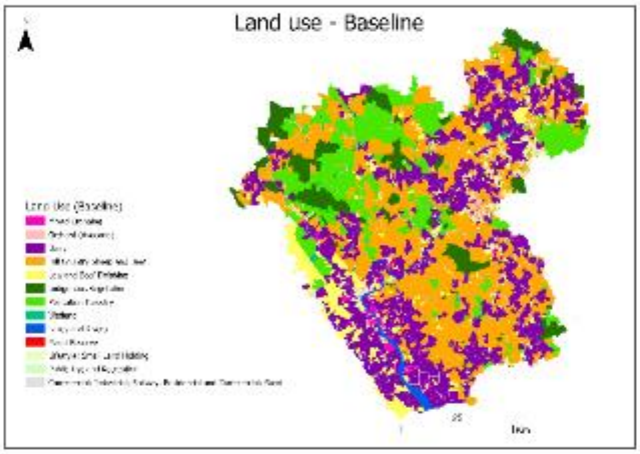


Figure A - 15: Land use map for the baseline 2025.

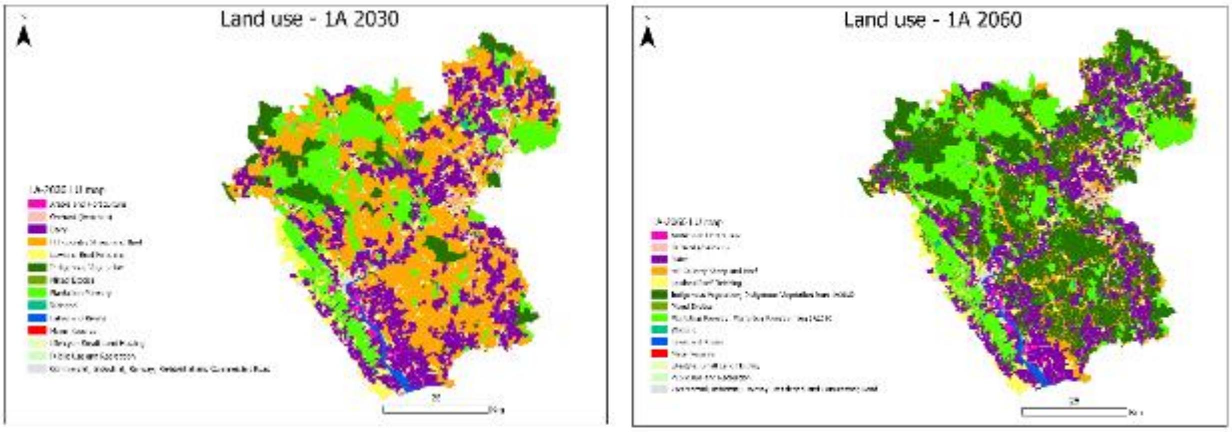


Figure A - 16: Land use maps for scenario 1A 2030 and 2060.

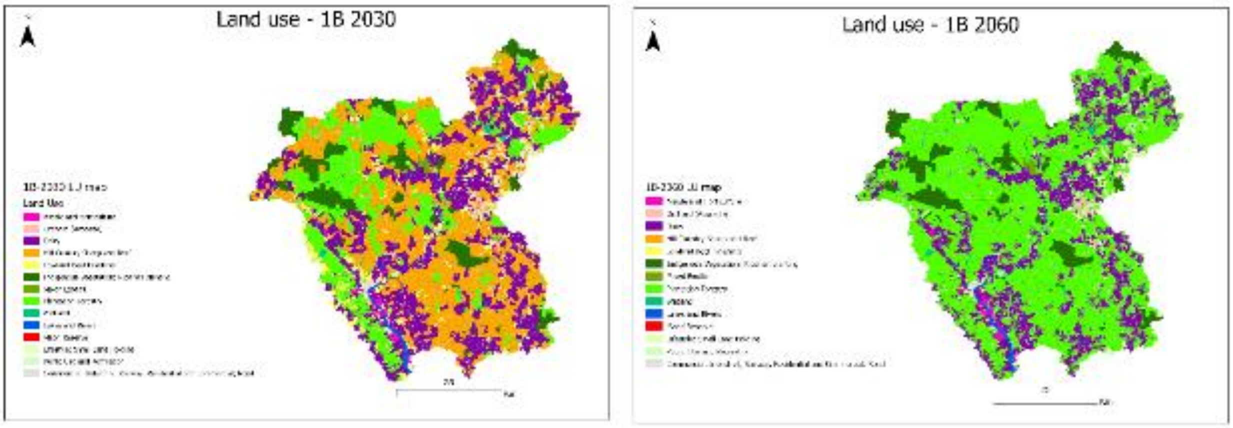


Figure A - 17: Land use maps for scenario 1B 2030 and 2060.

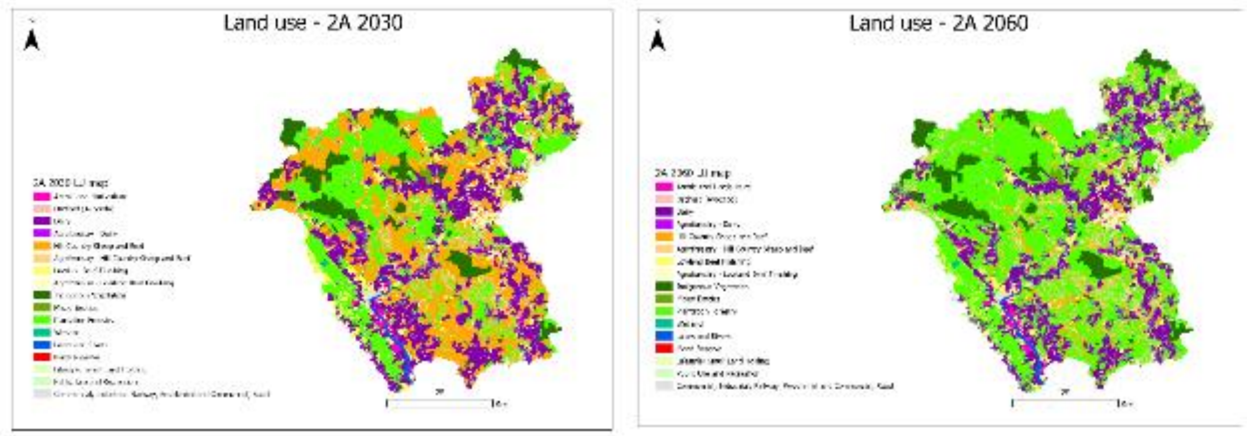


Figure A - 18: Land use maps for scenario 2A 2030 and 2060.

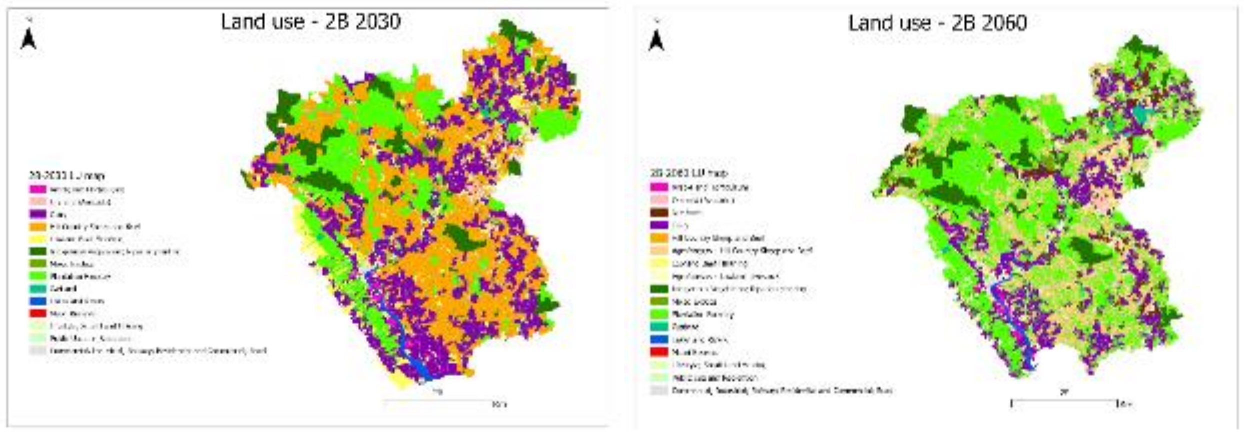


Figure A - 19: Land use maps for scenario 2B 2030 and 2060.

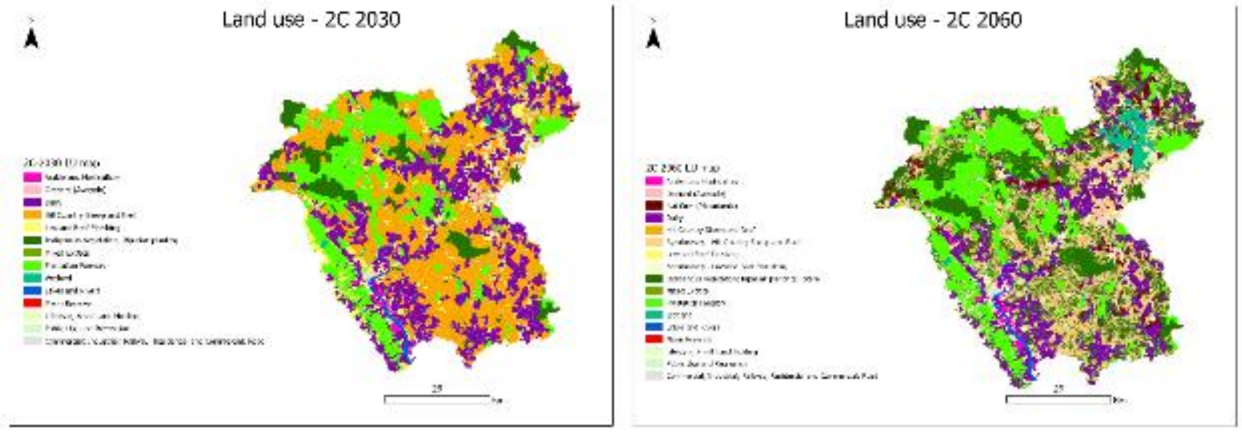


Figure A - 20: Land use maps for scenario 2C 2030 and 2060.

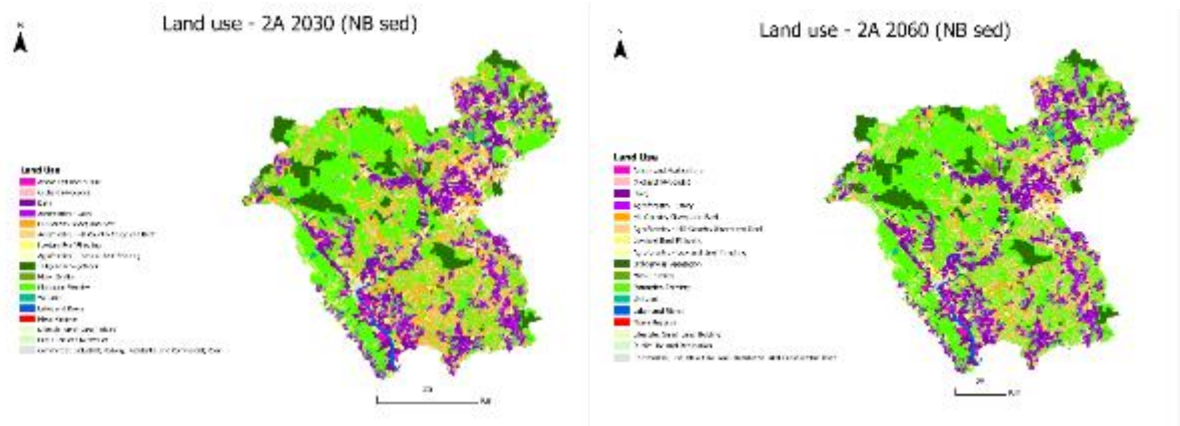


Figure A - 21: Land use maps for scenario 2A 2030 and 2060 using the Nature Braid sediment layer.

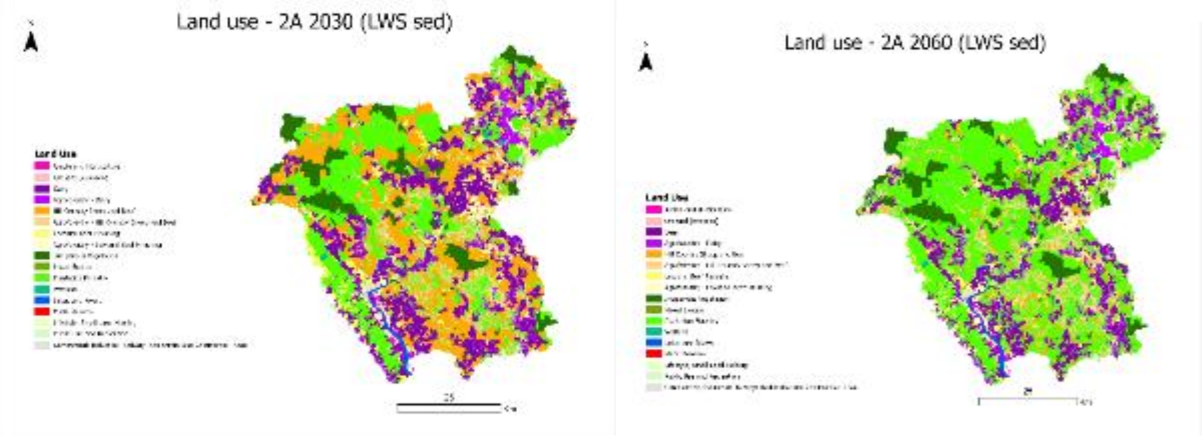


Figure A - 22: Land use maps for scenario 2A 2030 and 2060 using the LWS sediment layer.

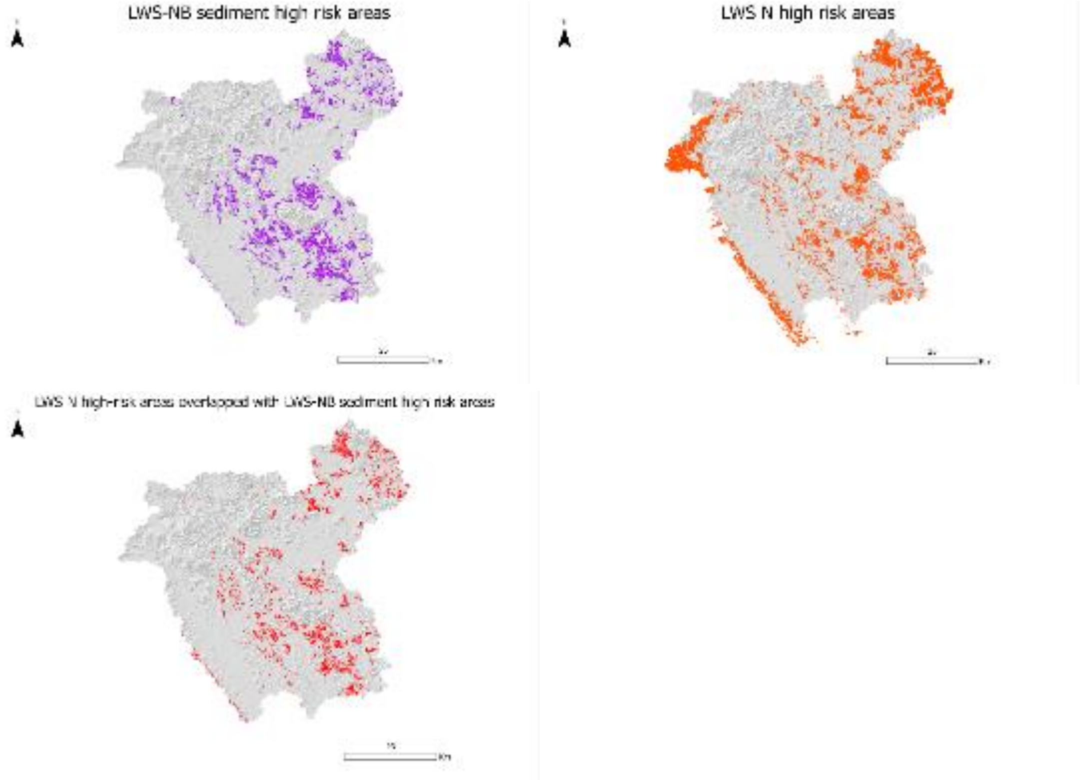


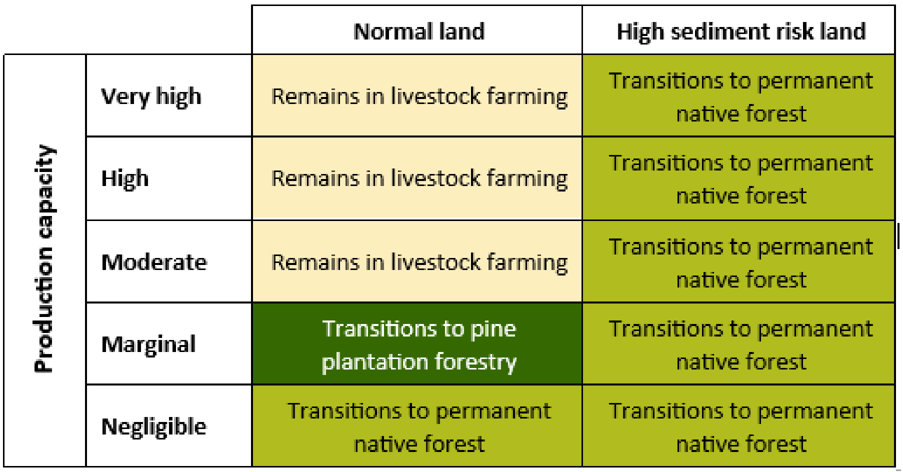
Figure A - 23: LWS-Nature Braid (NB) sediment high-risk areas and LWS N high-risk areas, and the overlap area of both

A.12 Scenario 1A (2060) - Variation: Conversion of marginal pastoral land to permanent native forest

Following consultation in the Wairoa, an additional scenario was requested by the Parliamentary Commissioner for the Environment to explore the impact of converting marginal land to indigenous vegetation.

This appendix describes the additional modelled scenario: *A scenario where marginal pastoral land is converted to permanent native forest instead of plantation forest in Wairoa for 2060*.

This scenario explores the effect of retiring livestock farming land to permanent native forest or pine plantation forestry, depending on sediment risk and production capacity according to Figure A - 24. For Wairoa, the areas of high sediment risk land were identified using the overlapping area of two layers: high sediment delivery (Nature Braid) and high sediment and pathogen susceptibility (Land and Water Science) as described in section 4.7 of this report (see figure 4 - 35). The predicted agricultural production capacity layer from Nature Braid was used to identify production capacity as per Figure A - 24. For modelling purposes, pine plantation forestry corresponds to 'Exotic Forestry' and permanent native forest to 'Indigenous Vegetation' in the Nature Braid model.



		Normal land	High sediment risk land
Production capacity	**Very high**	Remains in livestock farming	Transitions to permanent native forest
	High	Remains in livestock farming	Transitions to permanent native forest
	Moderate	Remains in livestock farming	Transitions to permanent native forest
	Marginal	Transitions to pine plantation forestry	Transitions to permanent native forest
	Negligible	Transitions to permanent native forest	Transitions to permanent native forest

Figure A - 24: Land transition rules for the mixed farm-forestry scenario as requested by PCE.

Following are the methods and assumptions made in this new scenario including parameterisation of Exotic Forestry and Indigenous Vegetation in Nature Braid (which are the same across the report but the parameters are explicitly presented here), the results of the economic analysis and environmental analysis.

Methods and Assumptions

- For the purpose of this scenario, land use change is considered to occur on the livestock land use classes as specified in the introduction. No other changes in land use or management occurs on any other land use classes in the Wairoa catchment. Therefore, the only land use classes that change from the baseline 2025 scenario are:
  - *Dairy*
  - *Hill Country Sheep and Beef*
  - *Lowland Beef Finishing*

- For the Dairy, Hill Country Sheep and Beef, and Lowland Beef Finishing areas that remain in livestock farming on land that has normal sediment risk and very high to moderate production capacity, there are no changes in management (e.g. stocking rate, fertiliser, etc).
- In this scenario, only land that combines normal sediment risk with marginal production capacity transitions to Exotic Forestry.
- Land that transitions to Indigenous Vegetation includes all high sediment risk land, regardless of production capacity, and land that combines normal sediment risk with negligible productive capacity.
- Erosion under Exotic Forestry (pine plantation) is modelled assuming a 28-year rotation wherein 6 years are considered "vulnerable" to soil erosion under extreme events such as landslides or heavy rainfall events (Baillie et al., 2015).
- The Indigenous Vegetation is not harvested and is assumed to be established and have continuous cover by 2060.
- The Nature Braid and Land and Water Science erosion and sediment layers were created using different models, data, and underlying assumptions and thus **only using the overlap of these layers will not capture other areas of high sediment risk identified only by the individual layers**.

Parameterisation of Exotic Forestry and Indigenous Vegetation within Nature Braid

The Nature Braid parameters for Exotic Forestry and Indigenous Vegetation used in this scenario are the same parameters used across all scenarios in this report, where either of these land uses are present. Parameterisation was based on previous literature, previous parameterisation of similar land covers within Nature Braid, and consultation with experts. Table A - 17 below shows an overview of these values, followed by justification in the bullet points below.

Table A - 17: Parameterisation table within Nature Braid for Exotic Forestry and Indigenous Vegetation

Land use	Flow mitigating ability (classified)	Agricultural production (classified)	C-factor	Ideal habitat for kererū?	Resistance to kererū (classified)	Nitrogen multiplier (1 = arable land, conventional agriculture, deer, beef)	Phosphorus multiplier (1 = arable land, conventional agriculture, deer, beef)
Exotic Forestry (LUcode = 200)	2	5	0.325	0 (No)	1	0.054545	1.692308
Indigenous Vegetation (LUcode = 203)	2	5	0.002	1 (Yes)	1	0.131818	0.2115385

- Flow mitigating ability = 2, as these land uses (when established) can mitigate flow
- Agricultural production = 5
  - *Considered non-productive (i.e. cannot support stock grazing)*
- C-factor:

  - *Exotic Forestry value based on weighted average of values the same as Indigenous Vegetation (0.002 to represent established vegetation) and extreme value (1.5) to represent the vulnerability of the Wairoa to erosion events*
  - *Indigenous Vegetation value based on previous literature around established native forests*
- Ideal habitat for kererū:
  - *No for Exotic Forestry*
  - *Yes for Indigenous Vegetation*
- Resistance to kererū = 1
  - *Both land uses are assumed to be easy for kererū to fly through*
- Nutrient parameterisation:
  - *Since we are assuming no grazing, we have assumed the nitrogen and phosphorus parameterisation value to be the national average used in the default Nature Braid for Indigenous Vegetation and Exotic Forestry.*

Results

Economics results

For the economic analysis in this Scenario 1A - Variation:

1. All land exposed to high sediment risk and all negligible production capacity livestock land has been prioritised to transition to Indigenous Vegetation, and all marginal production capacity livestock land has transitioned to Exotic Forestry.
2. All moderate, high, and very high production capacity livestock land that has normal or low sediment risk remains in the existing use.

Table A - 18 below shows the land areas exposed to high sediment risk. All this land is transitioned to Indigenous Vegetation (as per point 1 above).

Table A - 18: Land exposed to high sediment risk in the Wairoa to transition to Indigenous Vegetation.

Land area exposed to high sediment risk 2060	Very high production capacity	High production capacity	Moderate production capacity	Marginal production capacity	Negligible production capacity	Total
Dairy	279	293	4,206	4,539	63	9,381
Hill Country Sheep and Beef	285	200	9,267	16,294	114	26,160
Lowland Sheep and Beef	111	47	288	187	10	644
Total	675	541	13,762	21,020	188	36,186

Land that is not exposed to high sediment risk but has marginal or negligible production capacity will also be transitioned per the scenario rules (point 1 above) is set out in Table A - 19. A comparison of the land use change under Scenario 1A – Variation compared to Scenario 1A is provided in Table A - 20.

Table A - 19: Other land transitions in the Wairoa by 2060.

Other transitions (ha)	Marginal production capacity	Negligible production capacity	Total
Dairy	12,382	9,206	21,588
Hill Country Sheep and Beef	35,697	1,241	36,938
Lowland Sheep and Beef	1,787	5,349	7,137
Mixed Cropping	10	133	142
Orchard (Avocado)	35	4	38
Exotic Forestry	34,195	2,509	36,705
Indigenous Vegetation	17,799	1,445	19,244
Wetland	45	432	476
Total	101,950	20,319	122,269

Table A - 20: Land use change in the Wairoa under Scenario 1A - Variation compared to Scenario 1A.

	Baseline (2025)	Change	2060
Dairy	99,700	-30,969	68,731
Hill Country Sheep and Beef	124,148	-63,099	61,049
Lowland Sheep and Beef	21,032	-7,781	13,251
Mixed Cropping	2,500	-133	2,368
Orchard (Avocado)	1,418	0	1,418
Exotic Forestry	55,067	49,999	105,066
Indigenous Vegetation	28,598	51,983	80,581
Wetland	993	0	993
Total	333,456	0	333,456

- All agricultural land uses decline in profitability as a result of reduced land use and the increase in the emissions levy over time.
- The move to more Exotic Forestry increases overall catchment profitability (Table A - 21).

Table A - 21: Profitability change in the Wairoa under Scenario 1A - Variation compared with the baseline 2025.

	Baseline (2025)	Catchment profitability change	Scenario 1A (2060) - Variation
Dairy	$181,292,042	-$91,948,953	$89,343,090
Hill Country Sheep and Beef	$44,251,747	-$42,757,358	$1,494,389
Lowland Sheep and Beef	$13,139,612	-$8,984,469	$4,155,143
Mixed Cropping	$21,706,214	-$867,699	$20,838,516
Orchard (Avocado)	$29,788,703	$0	$29,788,703
Exotic Forestry	$83,659,374	$653,288,518	$736,947,892
Indigenous Vegetation	$0	$0	$0
Wetlands	$0	$0	$0
Total	$373,837,693	$508,730,039	$882,567,732

Environmental results

The Nature Braid model showed the following overall results:

- By 2060, the mixed farm-forestry scenario had large decreases in the mean terrestrial nitrogen (10.7 kg N/ha/yr to 6.9 kg N/ha/yr) and phosphorus (401.52 g P/ha/yr to 255.39 g P/ha/yr) loads. Both nitrogen and phosphorus in-stream concentrations decreased in terms of the mean values (0.7 mg N/L to 0.4 mg N/L; 0.016 mg P/L to 0.007 mg P/L) and greatly decreased in maximum values (191 mg N/L to 42 mg N/L; 17.3 mg P/L to 3.6 mg P/L).

- The addition of Indigenous Vegetation and Exotic Forestry presented large increases in the amount of flood mitigating features (+101,335ha), potential habitat for kererū (+51,688ha), and the area of matrix where kererū can fly through more easily (+143,980ha).

- The mean terrestrial soil loss increased with the addition of Exotic Forestry (83.62 tonnes/ha/yr to 90.58 tonnes/ha/yr), and the 2060 results show other areas of high sediment risk that were not picked up by the overlap of the Nature Braid and Land and Water Science results which are potential hotspots for management interventions. However, the median soil loss decreased compared to the baseline (16.18 tonnes/ha/yr to 3.87 tonnes/ha/yr).

The updated land use map is shown in Figure A - 25, showing large transitions to Indigenous Vegetation and Exotic Forestry around the catchment as assumed in this scenario.

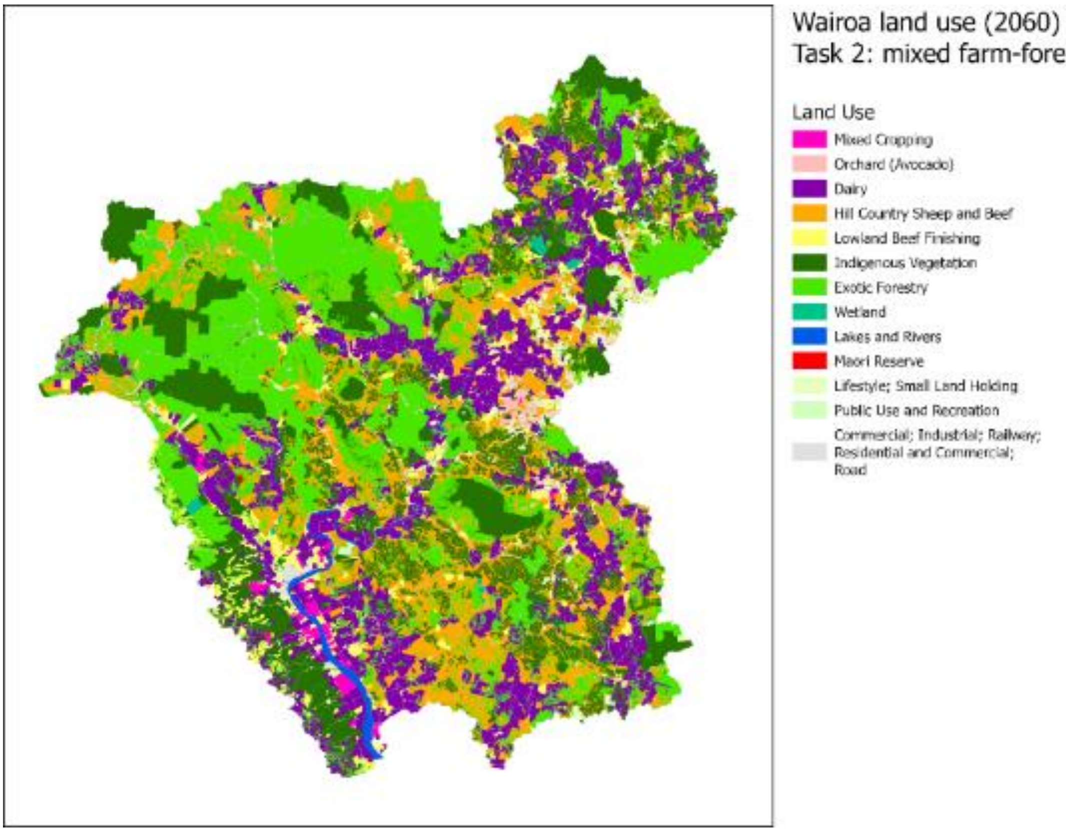


Figure A - 25: Land use map for 2060 under Scenario 1A – Variation.

Agricultural productivity

The predicted optimal agricultural utilisation is the same as the baseline, as this is driven by underlying soil, climate, topography, etc. Retiring livestock farming to Indigenous Vegetation and Exotic Forestry reduced the amount of land considered to have high production (71.83% to 42.87%) and land considered to have very high utilisation that is potentially over-utilised (25.3% to 0.47%; Figure A - 26 and Table A - 22).

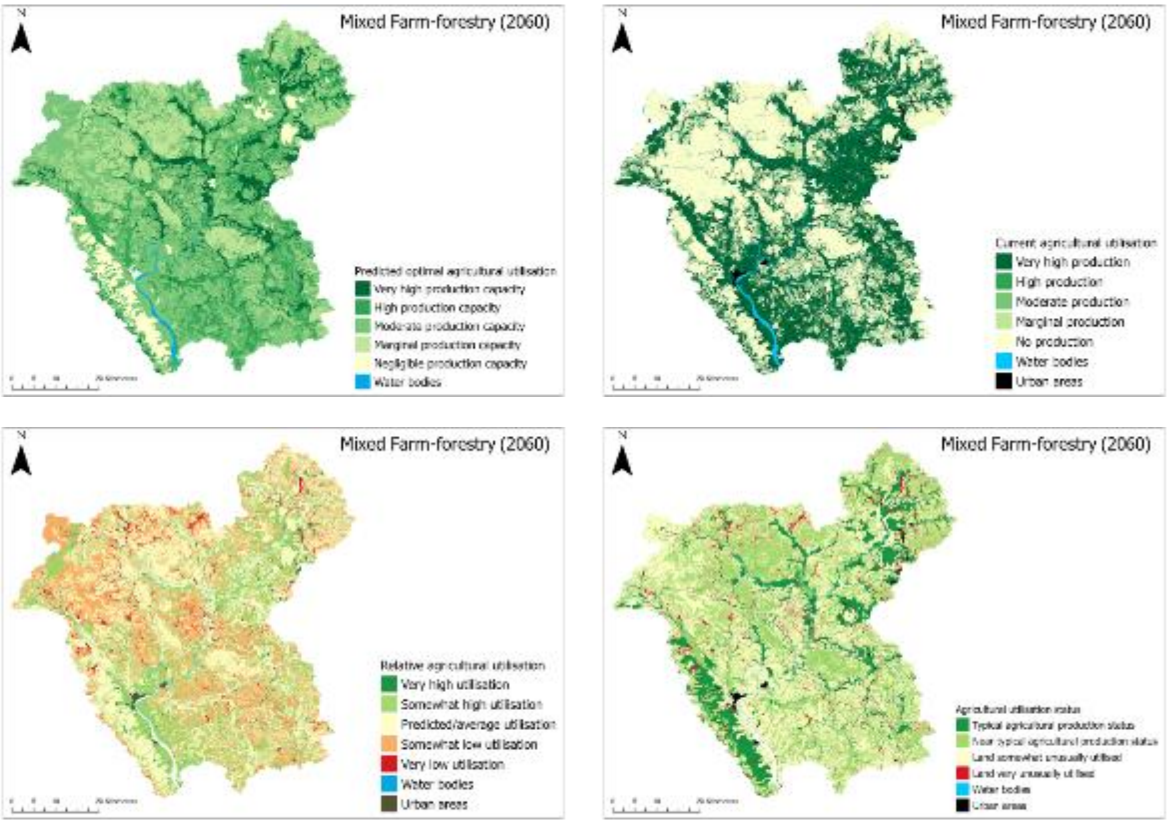


Figure A - 26: Results of agricultural productivity: predicted agricultural utilisation, current agricultural utilisation, agricultural utilisation status and relative agricultural utilisation.

Table A - 22: Current agricultural utilisation percentages for the baseline 2025 and 2060 scenario.

Current agricultural utilisation	Baseline 2025 (%)	Mixed farm-forestry 2060 (%)
Very high production	71.83	42.87
High production	0	0
Moderate production	0.27	0.27
Marginal production	0.22	0.22
No production	22.97	51.47
Water bodies	2.93	2.94
Urban areas	2.24	2.24

Table A - 23: Relative agricultural utilisation percentages for the baseline 2025 and 2060.

Relative agricultural utilisation	Baseline 2025 (%)	Mixed farm-forestry 2060 (%)
Very high utilisation	25.3	0.47
Somewhat high utilisation	29.57	22.14
Predicted/average utilisation	33.07	45.76
Somewhat low utilisation	6.25	24.44
Very low utilisation	1.29	2.65
Water bodies	2.23	2.24
Urban areas	2.29	2.29

Nitrogen

Retiring livestock farming shows large decreases in the mean terrestrial nitrogen load (-3.8 kg/ha/yr) compared to the baseline 2025 (Figure A - 27 and Table A - 24). The additional effect of these changes can be seen in the in-stream nitrogen concentrations, with the mean concentration being halved (-0.32 mg/L) and the maximum concentration being 22% of the baseline 2025 value (Figure A - 27 and Table A - 25).

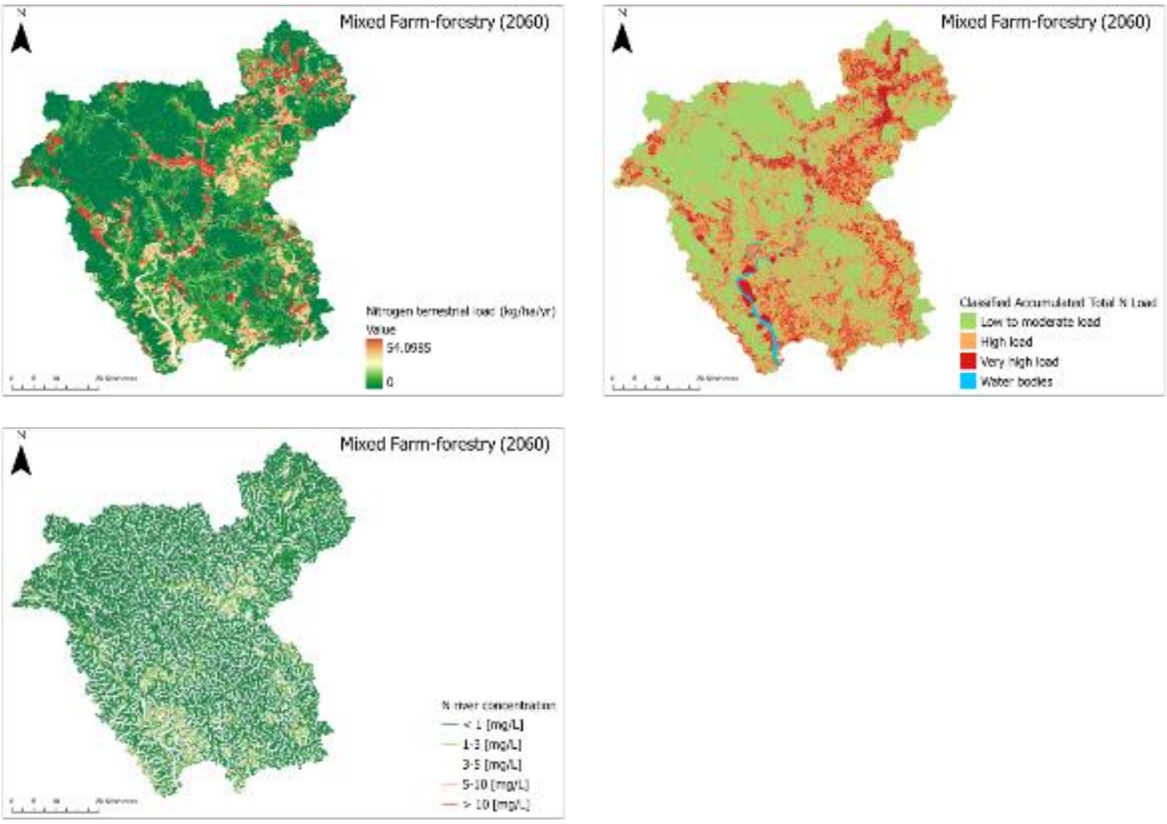


Figure A - 27: Results of nitrogen (N): terrestrial load, accumulated load classification and in-stream concentration for 2060.

Table A - 24: Summary statistics of nitrogen terrestrial loads for the baseline 2025 and 2060 scenario.

Nitrogen terrestrial load (kg/ha/yr)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to Baseline 2025 (%)
Min	0.00	0.00	0.00	0.00
Median	7.45	0.70	-6.74	-90.55
Mean	10.71	6.93	-3.78	-35.26
95th percentile	36.06	35.24	-0.82	-2.27
Max	54.10	54.10	0.00	0.00

Table A - 25: Summary statistics of in-stream nitrogen concentration for the baseline 2025 and 2060 scenario.

Nitrogen stream concentration (mg/L)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Min	0.00	0.00	0.00	0.00
Median	0.51	0.19	-0.32	-63.07
Mean	0.68	0.36	-0.32	-47.58
95th percentile	2.09	1.32	-0.77	-36.86
Max	190.97	42.20	-148.77	-77.90

Phosphorus

The results for phosphorus are similar to the nitrogen outcomes, with mean terrestrial load decreasing (-146.14 g/ha/yr) from the baseline 2025 value (Figure A - 28 and Table A - 26). Both the mean (-0.009 mg/L) and maximum values of in-stream phosphorus concentration (-13.6mg/L) decrease significantly (Figure A - 28 and Table A - 27).

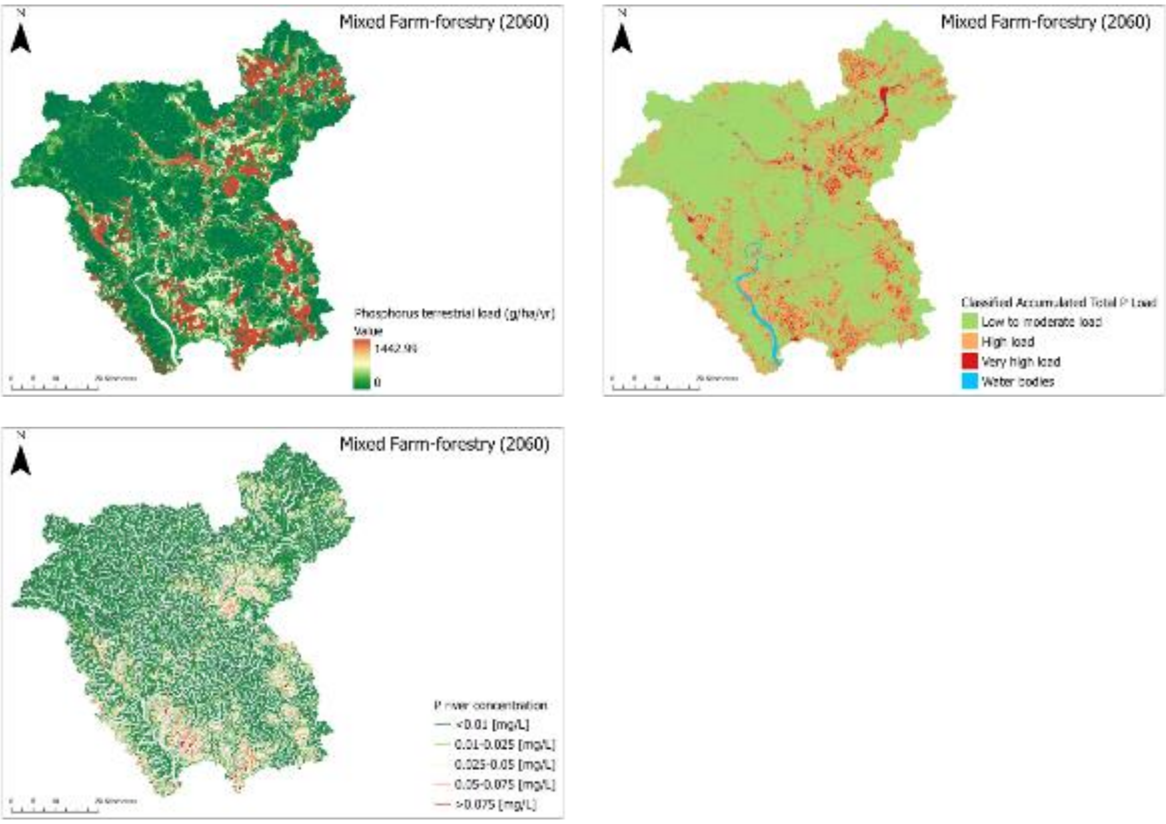


Figure A - 28: Results of phosphorus (P): terrestrial load, accumulated load classification and in-stream concentration for 2060.

Table A - 26: Summary statistics of phosphorus terrestrial loads for the baseline 2025 and 2060 scenario.

Phosphorus terrestrial load (g/ha/yr)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Min	0.00	0.00	0.00	0.00
Median	182.32	32.46	-149.86	-82.20
Mean	401.52	255.39	-146.14	-36.40
95th percentile	1,359.13	1,336.89	-22.25	-1.64
Max	1,531.98	1,442.99	-88.99	-5.81

Table A - 27: Summary statistics of in-stream phosphorus concentration for the baseline 2025 and 2060 scenario.

Phosphorus stream concentration (mg/L)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Min	0.00	0.00	0.00	0.00
Median	0.008	0.002	-0.01	-79.23
Mean	0.016	0.007	-0.01	-59.08
95th percentile	0.062	0.031	-0.03	-49.59
Max	17.276	3.644	-13.63	-78.91

Flood mitigation

The additions of Indigenous Vegetation and Exotic Forestry increase the area considered mitigating in 2060 by 101,335ha (Figure A - 29 and Table A - 28), meaning that more of the Wairoa catchment is able to capture flows of mass, water, associated sediments, and nutrients when there is a greater area of the catchment transitioned to mature, established forest.

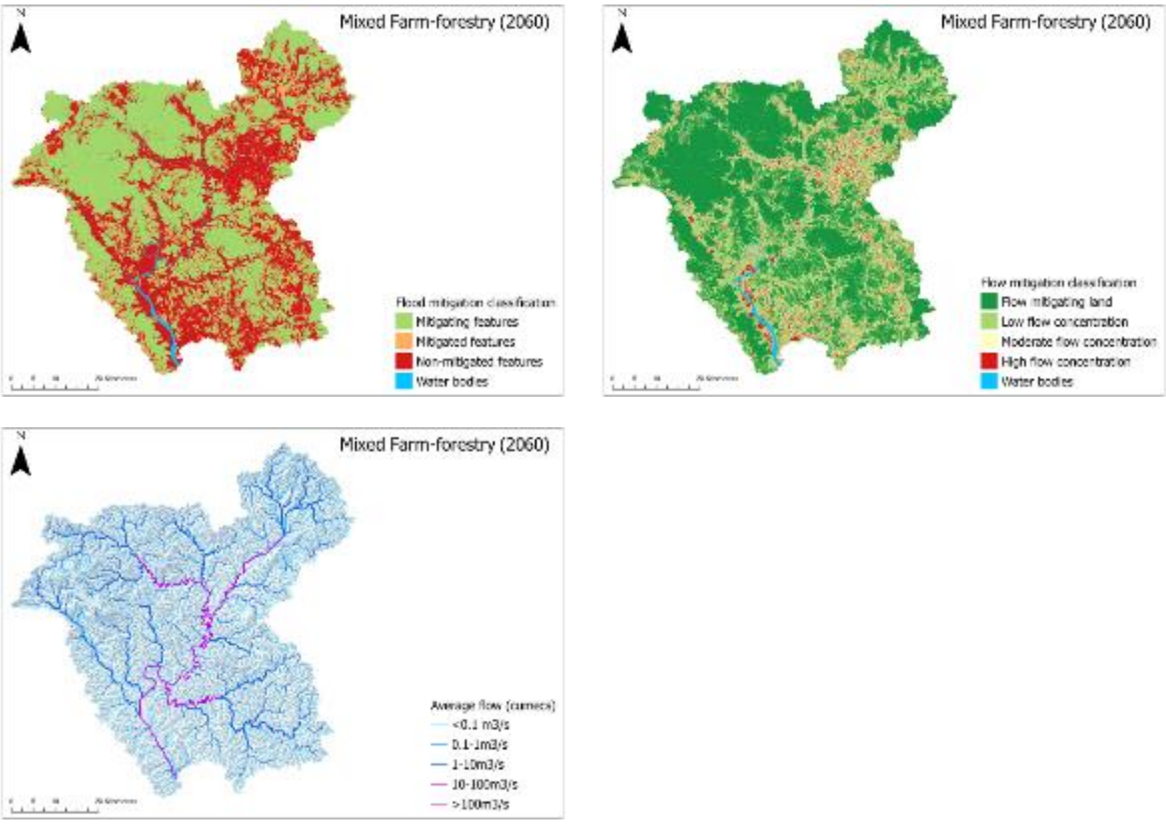


Figure A - 29: Results of flood mitigation: flood mitigation, flow mitigation and average flow for 2060.

Table A - 28: Results of the flood mitigation tool for the baseline 2025 and 2060 scenario.

Flood mitigation classification (ha)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Mitigating features	85,300	186,635	101,335	119
Mitigated features	7,110	37,587	30,477	429
Non-mitigated features	253,150	121,324	-131,826	-52
Water bodies	10,110	10,117	7	0

RUSLE

Retiring livestock grazing on marginal land (lower fertility, steeper slopes) outside of the high sediment risk area defined by the overlap of the Nature Braid and Land and Water Science layers to Exotic Forestry results in a mean soil loss increase of 6.96 tonnes/ha/yr (Figure A - 30 and Table A - 29). The Wairoa catchment is vulnerable to extreme rainfall events that cause landslides and slips, and the model assumes that there are periods of higher soil loss within a 28-year Exotic Forestry rotation. These vulnerable periods are during the initial stages while the forest is establishing, during clear-fell harvesting, and post-harvesting before the next cycle begins. The sediment delivery map shows other areas of the catchment vulnerable to soil losses that are potential hotspots for management interventions.

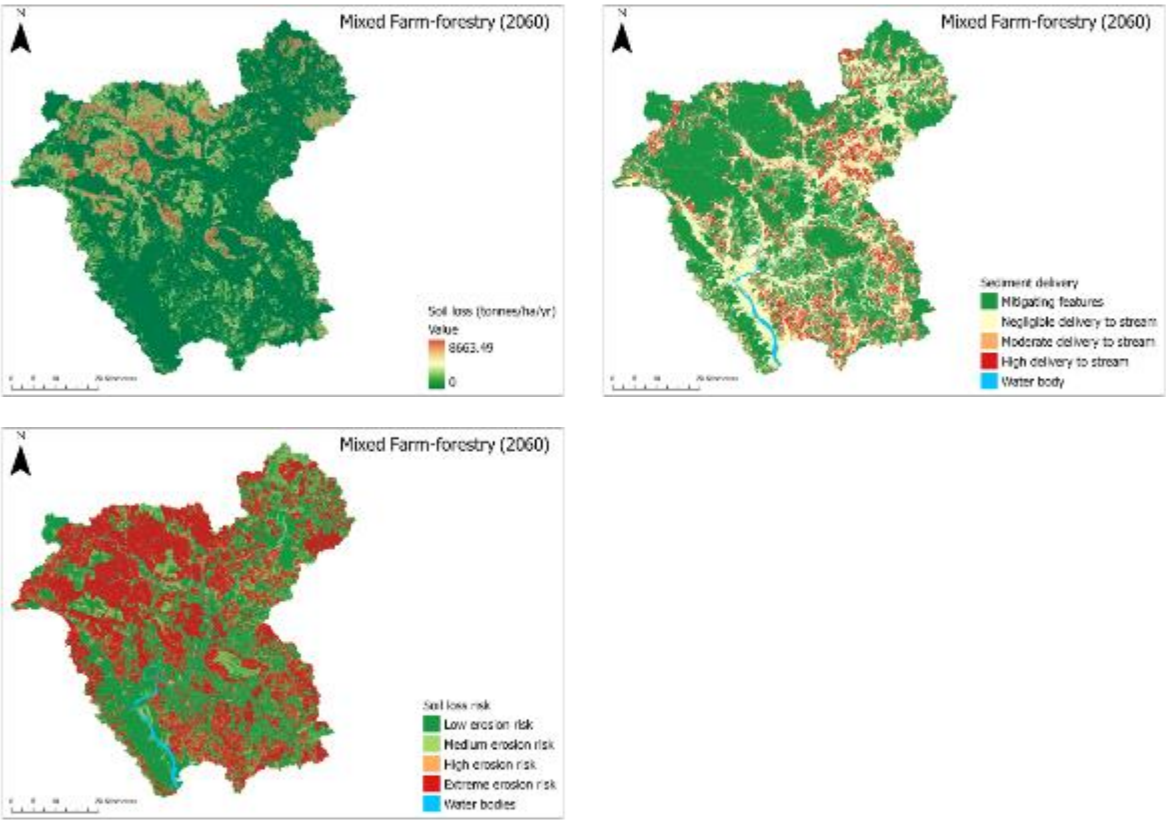


Figure A - 30: Results relating to both "point"-scale soil loss: (soil loss (tonnes/ha/yr and a categorisation of risk), and risk of this soil being delivered to waterways ("sediment delivery").

Table A - 29: Summary statistics for terrestrial soil loss for the baseline 2025 and 2060 scenario.

Soil loss (tonnes/ha/yr)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Min	0.00	0.00	0.00	0.00
Median	16.18	3.87	-12.32	-76.11
Mean	83.62	90.58	6.96	8.33
95th percentile	448.13	471.84	23.72	5.29
Max	8,663.90	8,663.49	-0.41	0.00

Habitat connectivity

The increase in the area of Indigenous Vegetation across the Wairoa catchment increases the amount of ideal habitat for the kererū, in patches of varying sizes across the catchment (a total increase of 51,688ha; Table A - 30). In between these patches, the red areas in Figure A - 31 show the corridors that kererū can fly through as they move between ideal habitat patches, which increases by 143,980ha from the baseline 2025. The woody biomass of established Exotic Forestry allows kererū to utilise these areas as stepping-stones despite this land use not being the ideal habitat for them.

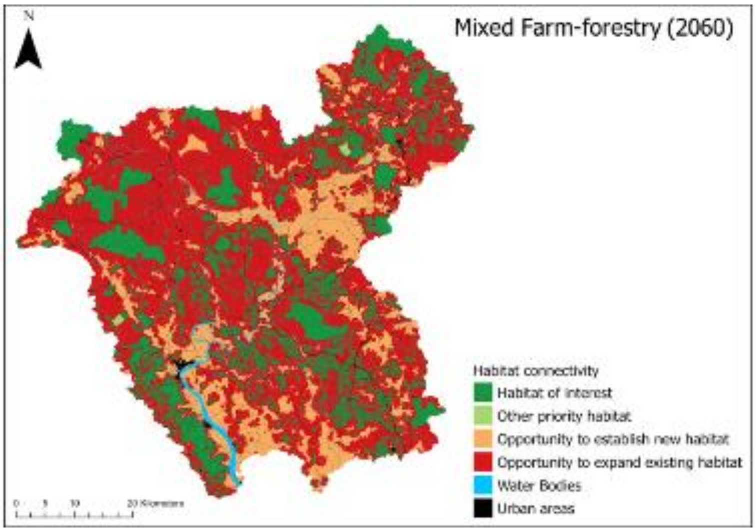


Figure A - 31: Results of habitat connectivity for kererū.

Table A - 30: Results of the habitat connectivity tool for kererū for the baseline 2025 and 2060 scenario.

Habitat classification (ha)	Baseline 2025	Mixed farm-forestry 2060	Change in 2060	Change relative to baseline 2025 (%)
Habitat of interest	28,210	79,898	51,688	183
Other priority habitat	960	961	1	0
Opportunity to establish new habitat	254,190	58,480	-195,710	-77
Opportunity to expand existing habitat (areas where kererū can easily fly through)	54,430	198,410	143,980	265

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