Manaaki Whenua
Landcare Research

Climate Resilient Māori Land

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Climate Resilient Māori Land

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Project and Client

The *Climate Resilient Māori Land* project is funded through the Deep South National Science Challenge, Vision Mātauranga Programme.

- We address Theme 3 (Programme 2) of the Deep South NSC Research and Business Plan. Our aim is to help enhance the future prosperity of Māori by incorporating potential climate change impacts into land investment decisions and providing holistic approaches for managing climate-sensitive catchments.

Objectives

The objective of this research was to identify future land investment opportunities for the Waiapu River catchment that accounted for climate change. These investment opportunities focused on afforestation. Specifically, the research project:

- confirmed the core values, goals and objectives of the iwi/hapū in the catchment
- used the latest NIWA downscaled climate impacts layers to assess climate implications in the catchment under a range of future climate scenarios
- incorporated these climate impacts into the NZFARM model to assess the economic viability of afforestation opportunities under the different climate scenarios for the catchment
- assessed the bio-economic risk and uncertainty resulting from different climate scenarios and mitigation/adaptation strategies to estimate yield/price variability associated with the afforestation scenarios
- identified the impacts of climate change on Māori land to assist Māori landowners with catchment-level decisions on future investment opportunities
- demonstrated how this type of analysis can be benefit Māori organisations facing land investment decisions, both in the Waiapu River Catchment and other similar areas.

The research was conducted through a partnership between Manaaki Whenua Landcare Research (LCR), SCION and the He Oranga mō ngā Uri Tuku Iho Trust.

Methods

A step-by-step process was used to discuss and evaluate afforestation scenarios utilising: a kaupapa Māori assessment, a bio-physical assessment, and an economic assessment. The process consisted of:

- Step 1: *Landowner aspirations* were identified through a series of wānanga in Ruatōrea.
- Step 2: *Climate Change Modelling* based on the baseline erosion rates from the New Zealand Empirical Erosion Model (NZEEM) were used to derive empirical distributions of climate change uncertainty.

- Step 3: *Afforestation Scenarios* were primarily identified through wānanga (workshops). Wānanga were mostly held on marae with site visits to the catchment.
- Step 4: *Economic Modelling* was undertaken using New Zealand Farm and Agriculture Regional Model (NZFARM) to assess the profitability of the afforestation scenarios. The afforestation scenarios included:

  i mānuka only

  ii mānuka and tōtara

  iii mānuka, tōtara, and kawakawa.

  NZFARM identified the optimal sheep and beef farming areas to afforest under 3 erosion reduction targets – low, medium and high.

  Uncertainty analysis was undertaken to assess the effect on profitability from policy, market, climate change and profitability uncertainty. The efficiency of the Erosion Control Funding Programme (ECFP) was also assessed to help policymakers determine if ECFP would realise the expected public benefits of the programme where there was climate uncertainty.
- Step 5: *Kaupapa Māori assessment* of the afforestation scenarios for three Māori land parcels was undertaken using a Kaupapa Māori evaluation tool. The afforestation scenarios included the three scenarios outlined above and the afforestation 3 scenario plus horticultural options (hemp, olives, macadamias, lemons).
- Step 7: *On-site Wānanga* were used to discuss with landowners on-site climate mitigation approaches for the catchment. The mitigation approaches focused on retiring land from production and fencing with tree planting.

Results

- We estimated that if current land use practices continue, mean aggregate erosion could increase by 41% by the end of the century. These potential impacts, coupled with an already extremely high erosion rate, have driven national and local agencies to consider policy options and incentives to reduce erosion and their impacts to the economy and ecosystem. This has been primarily through afforestation programmes.
- Our analysis found that between 16,700 and 41,900 hectares of pasture would have to be afforested to achieve various erosion reduction targets, equivalent to 19–48% of the current area of sheep-beef farming in the catchment.
- We found that there were marked improvements in Kaitiakitanga (sustainable resource management) on the three land blocks with afforestation scenarios that include podocarps like tōtara. This was due to the long-term, intergenerational yields of these species. In comparison to the baseline scenario (sheep and beef farming), afforesting parts of the farms was less likely to impact negatively on Māori values as there was reduced sediment run-off into waterways.
- In terms of Manaakitanga (reciprocal obligations), the afforestation scenarios provide relatively more opportunities to improve connections between the farm, farm beneficiaries, and the local community than the existing land use.
- In terms of Whakatipu Rawa (growing the asset base), the benefits from investing in options, i.e. afforestation scenarios, that reduce erosion bodes well for future

generations. The long-term benefits of improved water quality and enhanced terrestrial ecosystems through riparian planting and management along with the reduced erosion are more likely to be realised by future generations.

- The mānuka-tōtara-kawakawa afforestation scenario, having the most uncertain profitability, became the preferred alternative only under a very low discount rate (1%). The relatively high revenues obtained far in the future are disadvantaged with higher discount rates. The profitability uncertainty comes from the uncertainty of future kawakawa and tōtara product prices. This scenario is plausible, however, for Te Tairāwhiti, as the iwi/hapū values like kaitiakitanga, manaakitanga, and whakatipu rawa reflect intergenerational aspirations.
- ECFP is unlikely to achieve the expected benefits as climatic uncertainty negatively impacts the flow of benefits. This may incentivise the Ministry for Primary Industries (MPI) and the Gisborne District Council (GDC) to re-evaluate the benefits (e.g. economic, social, environmental, etc.) from the programme in light of our estimated effects of climate change for the Waiapu catchment.

Limitations

The limitations of our assessment of investment opportunities for the Waiapu catchment under climate change are:

- *Land use*: Land use data, while generally accurate at the catchment level, was not sufficiently refined for smaller scales. For instance, exotic forest was sometimes classified as indigenous forest, and vice versa. Therefore, the land use data for farm and block scale has to be refined with input from landowners and stakeholders.
- *Lack of productivity data*: The economic modelling was unable to incorporate any productivity effects of climate change on the tree/crop species included in the modelling. The assessment initially considered using radiata pine data as a surrogate for indigenous forest species but, due to the high variability in indigenous tree species and their responses to climate change compared to pine, we decided the pine results are not likely to be representative for indigenous forest. Future research ought to investigate the impacts of climate change on the productivity of indigenous tree species, particularly those species with economic and kaupapa Māori potential.
- *Mean annualised returns*: While the NPVs for the land use options on the flatter areas suggest that the crops are profitable, there is an establishment period for some crops, like apples and olives. This means, in the short term, there will be an initial financial burden for investors.

Recommendations

Some governance recommendations for the Waiapu catchment are:

- The findings and learnings from the Climate Resilient Māori Land project should be considered in future decision-making and policy development by Waiapu Kōkā Huhua in the catchment.

- Greater benefits for the Waiapu catchments could be achieved through greater coordination in the implementation of erosion management and mitigation actions, for example, between ECFP and Waiapu Kōkā Huhua.

Some policy recommendations are:

- To encourage the development of strategies, policies and processes by key governance and policy institutions in Te Tairāwhiti to support further afforestation in the Waiapu catchment, in line with the options assessed in this report.
- For the Ministry for Primary Industries and the Gisborne District Council to re-evaluate the likely benefits for the Waiapu catchment of the ECFP (as it is currently designed) so that it incorporates the impacts of climate change.
- To develop and implement a succession programme to the ECFP ensuring there is accountability for achieving the shared vision for Waiapu Kōkā Huhua on the part of the Crown.
- To continue supporting local and central government on several issues, e.g. governance training for Māori land institutions, capability development for local entrepreneurs/Māori landowners, and entrepreneurial efficacy for local entrepreneurs/Māori landowners. This support is required for the successful implementation of afforestation approaches to reduce the impacts of climate change.

Some recommendations for Māori landowners are:

- To further invest in the implementation of programmes that support capability development of Māori institutions governing Māori land, e.g. governance training.
- To further invest in developing the capability of whanau/hapū/iwi in the Waiapu catchment to realise the investment opportunities necessary to mitigate the effects of climate change in the catchment.
- To identify local champions and provide them with necessary policy and enterprise assistance to invest in opportunities like afforestation to help to mitigate the effects of and to adapt to climate change.

Some recommendations for working with Māori to address climate issues are:

- Kaupapa Māori assessments should be conducted alongside economic modelling to provide a fuller representation of aspirations and values from a Kaupapa Māori perspective.
- Future Kaupapa Māori assessments should include an assessment of wāhi tapu/taonga. However, this requires knowledge of wāhi tapu/taonga by local people. We recommend that when there are gaps in knowledge, wānanga are used to rediscover and share this knowledge.
- Assessments of the benefits from erosion control practices (e.g. afforestation) should consider using an ecosystem services evaluation and a Kaupapa Māori assessment to provide a more holistic and robust assessment of potential benefits.
- Future studies should include climate change projections to account for the possibility of public underinvestment. Estimating the benefits in the catchment under climate

change uncertainty not only supports investments to achieve specific erosion reduction targets but also supports identifying more beneficial investments.

- Landscape data generally provide reliable and accurate data for landscape-level analysis but needs to be refined with input from landowners and stakeholders when assessing afforestation scenarios at a farm or block scale.
- Future research is required to explore the impact of temperature changes on a wider range of tree/crop species.

1 Introduction

Climate change is expected to have major implications for future and existing investment in New Zealand. Māori not only have long-term interests in the land they own and/or manage but are also heavily invested in primary industries, which are exposed to a range of vulnerabilities from both present and future projected climatic conditions (Reisinger et al. 2014). More than 60% of Māori-owned land is steep and hilly, making it highly susceptible to damage from high intensity rain events and erosion. Conversely, their land on the plains is susceptible to flooding and sedimentation (Harmsworth et al. 2006; King et al. 2010). While many Māori organisations have the institutional capacity to manage their land and adapt to climate change (Reisinger et al. 2014), information and approaches to understand the implications of climate change for land investment decisions are often not available or have not been clearly demonstrated. To enable more enduring decisions by Māori organisations, a clearer understanding is needed of climate change impacts and their implications for investment decisions. This will improve the ability of Māori landowners to mitigate or avoid the potential consequences of climate change, thereby improving the resilience of their investments and the prosperity of their communities.

1.1 Project aim

We address Theme 3 (Programme 2) of the Deep South NSC Research and Business Plan. Our aim is to help enhance the future prosperity of Māori by incorporating potential climate change impacts into land investment decisions and providing holistic approaches for managing climate-sensitive catchments.

This proposed research encompasses both developed and undeveloped Māori land as it strives to improve the resilience of land management decisions and investment in the face of changing climate. There has already been significant investment, and new investments will be made in the future, on Māori land that is likely to be adversely impacted by climate change (or potentially benefit from it). It is vital to ensure existing and future ventures consider these impacts and benefits.

The East Coast of New Zealand’s North Island is already suffering from the repercussions of previous land management decisions that have led, in particular, to high rates of erosion. This is likely to be exacerbated by climate change through extreme rain events generating higher erosion losses, and drought events being more profoundly felt due to degraded soil resources. The Waiapu catchment has been the focus of previous studies (Harmsworth et al. 2002; Funk et al. 2014; Warmenhoven et al. 2014) as well as Ministry for Primary Industries and Gisborne District Council initiatives such as the Erosion Control Funding Programme (Ministry of Primary Industries 2015a), Restoring the Waiapu Catchment: “Healthy land, healthy rivers, healthy people” (Warmenhoven et al. 2014) and Sustainable Hill Country Projects (Ministry of Primary Industries 2015b).

This project supports these previous initiatives, in particular the aspirations for restoring the Waiapu Catchment (Ngāti Porou), to incorporate climate change implications into the investment decisions by Māori landowners.

The current project will explore alternative forestry under various climate change scenarios and extend the promotion of indigenous forestry and alternative forestry for erosion susceptible land in the Waiapu catchment.

1.1.1 Objectives

The objective of this research was to identify future land investment opportunities for the Waiapu River catchment that accounted for climate change. These investment opportunities focused on afforestation. Specifically, the research project:

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The research was conducted through a Manaaki Whenua Landcare Research (LCR), SCION and the He Oranga mō ngā Uri Tuku Iho Trust partnership.

2 Background

2.1 Case study area: The Waiapu River Catchment

The current study took place in the East Coast region of the North island of New Zealand, namely the Waiapu catchment in the Gisborne district (Fig. 1). The Waiapu catchment covers an area of 175,800 ha in the north of the Gisborne–East Coast region near East Cape. It is centred on the township of Ruatōrea, with a population inside the catchment boundaries of about 1500. The highest point in the catchment is the culturally significant Maunga Hikurangi (Mount) at 1752 m a.s.l., flanked on the east and north-east by Aorangi (1272 m), Wharekia (965 m), and Taitai (677 m), and on the north-west by Whanakao (1618 m). In the middle to upper part of the catchment, hill country rises steeply from numerous incised valleys to heights between 100 and 600 metres, bounded in the west by the Raukumara ranges, between 500 and 1500 metres. The Waiapu River is formed by the joining of the Mata and Tapuaeroa Rivers, which originate in the headwaters of the steep Raukumara range. The rivers flow east and northeast to the Pacific Ocean. The Waiapu catchment shares the southwest catchment divide with the Waipaoa River, which runs southwards towards Gisborne. The Waiapu River provides the lifeblood of Ngāti Porou, the primary iwi of the catchment, and is of great cultural and spiritual significance to them.

The Waiapu Catchment is a relevant case study for four major reasons: (1) Current Global Climate Models and Earth System Models often poorly represent some physical processes in the region; (2) the East Coast is one of the most erosion-prone regions in New Zealand; (3) the existence of two environmental policies rewarding regulating services from forests (carbon sequestration payments and erosion mitigation subsidies); and (4) the region's predominant indigenous Māori population and the growing preference of native forestry products informed by intrinsic and holistic shared values such as mauri (life-force). These four points are expanded on below.

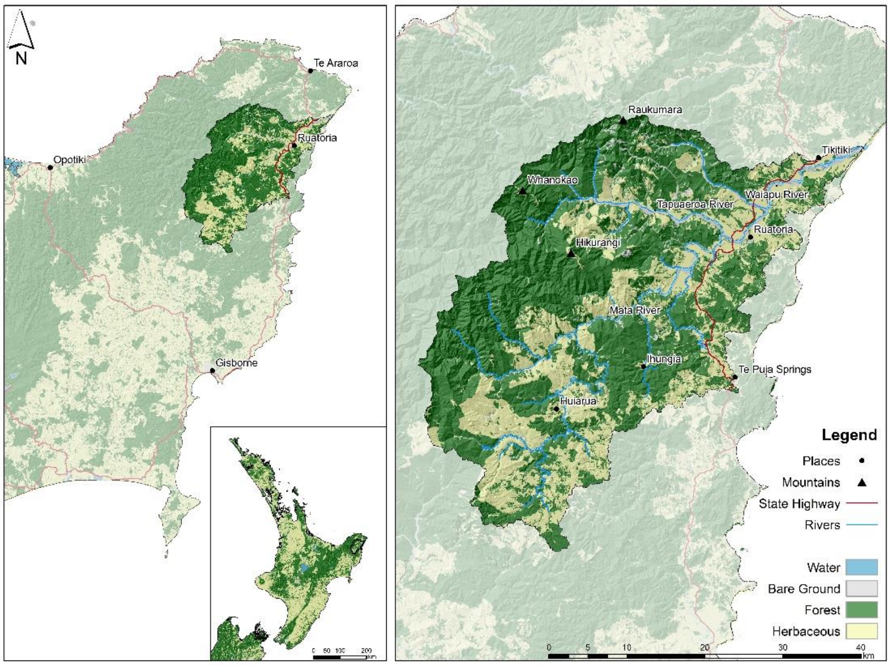

Figure 1: Location of the Waiapu catchment in the North island of New Zealand.

There is currently a National Science Challenge in New Zealand to properly model the climate processes in the Southern Ocean and Antarctica, namely the "Deep South" region.[1] The core objective of the Challenge is to assemble the first New Zealand Earth System Model (NZESM) to properly model physical processes of atmospheric and oceanic circulation in the region. However, the relatively recent launch of the Challenge precludes the use of the potentially more refined results from the NZESM. Hence, such lack of data presents an opportunity to use sparse GCM-downscaled spatial data from previous projects (Tait et al. 2016) and statistical techniques that do not require large datasets to fit a probability distribution function, namely the use of non-parametric empirical distribution functions.

In 1840, before deforestation of the native forest, at least 80% of the Waiapu catchment was covered with mainly podocarp broadleaf and beech. The ecosystem was healthy and vibrant with a flourishing mauri (life force). Deforestation and the establishment of pastoral farming by European settlers started about 1890 and initiated a phase of greatly increased erosion and sediment transfer. The main period of deforestation and burning was between 1890 and 1920. As a consequence, the present-day catchment exhibits an extensive and serious erosion problem due, in part, to the number of subsequent storm events and floods in 1916, 1918, 1938, and Cyclone Bola in 1988 (Harmsworth et al. 2002). Nowadays, the East Coast is one of the most erosion-prone regions of New Zealand and in the world (Cumberland et al. 1980; Glade et al. 2006). Frequent and extensive flooding occurs throughout the catchment but has always had a particularly devastating effect on the highly productive floodplains and low terraces in the lower parts of the catchment, from Ruatōrea to the Waiapu river mouth.

Planting of exotic forest to control erosion began in the late 1960s. In the headwaters of the most highly eroded subcatchment, the Tapuaeroa, conversion of eroded pasture to exotic forest began in 1969. Due to increasing costs for on-site mitigation strategies, the New Zealand government acquired large areas of farmland, mainly located in the headwaters of the three major river catchments in this region, and successively reforested these areas during the 1960s to late 1980s (Marden et al. 2011). Major storm events in the 1980s caused massive damage and initiated new gullies, particularly on pastoral farm land. In response to that, the New Zealand government initiated the East Coast Forestry Project to provide grants for establishing an effective tree cover on erosion-prone farm land. These catchments have moved towards a sustainable land use regime in the last 30 years, with increased protection of native forest and widespread and targeted exotic forestry planting (i.e. *Pinus radiata*) on erosion-prone land. Exotic forest now accounts for about 26% of the Waiapu catchment area, ~37% remains in pasture, of which about half is located on marginal steep hill country and is regarded as unsustainable. Native forest (Lowland and Highland beech, broadleaved and some podocarp) still makes up about 21% of the catchment and is mostly restricted to the steep mountainous headwaters with

[1] http://www.deepsouthchallenge.co.nz/

smaller patches of remnant native vegetation occurring near lowland rivers. Shrublands comprising mainly kānuka (*Kunzea ericoides*) and mānuka (*Leptospermum scoparium*) cover about 12% of the middle and lower parts of the catchment. Much of the lower part of the catchment consists of alluvial floodplain and terraces where the soils are considered to be some of the most versatile (LUC Class II and III) in New Zealand and are currently utilised for pastoral farming and fodder cropping.

Many exotic forests are presently being felled, and there is concern among the community and some stakeholders that the projected increase in the rate of clear-felling will again lead to high levels of erosion and sediment transfer. Most exotic forests are planted and felled to the edge of rivers and streams which after the completion of harvesting have little remaining riparian protection. Some selective clear-felling of native forest still occurs on both private land and in the DOC estate. Any clearing of scrub on erosion-prone land will also lead to greater erosion, increased sediment transfer and flooding. Most areas of scrub are not fenced and remain open to livestock and feral animals (Harmsworth et al. 2002).

The vulnerability of the land to erosion has negatively impacted the productivity potential of the land – and hence its profitability – and the future economic growth prospects of the region. These impacts, coupled with comparatively lower socio-economic statistics, including some of the lowest household incomes in New Zealand, and the greater likelihood of being unemployed (Smith et al. 2017), present additional challenges to improving the productivity and economic well-being of this catchment. The Waiapu catchment also comprises relatively large areas of Māori land in multiple ownership. While most of this area is used for pastoral farming and forestry, large tracts of land remain undeveloped and covered in shrubland and indigenous forest. About 70% of farms are in hill country, thus many Māori are involved in pastoral farming, mainly beef and sheep, and grow maize and other fodder crops on and adjacent to floodplains; most Māori, however, live near or on the floodplains.

The degradation of Māori environmental and social values can be attributed to forest clearance over a century ago and to the impacts of repeated storm and flood events on the landscape since then (Warmenhoven et al. 2014). Because of these events, the lives, economic status, and general well-being of people living in the Waiapu area have been greatly affected. Māori have had to adjust to this rapid transformation of their landscape and adapt to an environment with greatly heightened erosion and flooding risks that continue to cause the loss of large tracts of cultural resources, such as native forest that comprises culturally significant flora and fauna, ongoing damage to utilities including power and the road infrastructure, as well as damage to housing and loss of productive farmland. The highly degraded state of the Waiapu Awa is linked to the loss and decline of Mātauranga Māori (indigenous knowledge) and the mauri (life force) of the catchment. The poor health of the Waiapu River catchment is therefore of great concern.

Steps to address the loss of well-being or mauri is being addressed by Waiapu Kōkā Huhua – Waiapu Restoration Programme, a collaborative programme between the Ministry for Primary Industries, Te Rūnanganui o Ngāti Porou (TRONPnui) (the tribal authority representing the primary iwi in the Waiapu river catchment – Ngāti Porou), and the Gisborne District Council (GDC). The programme is a result of the Waiapu Accord, a post-settlement, co-governance partnership between Ngāti Porou and Crown entities. The vision for the 100-year programme is: "Healthy land, healthy rivers, healthy people – Ko te mana: Ko te Hauora o te whenua, Ko te Hauora o nga awa; Ko te Hauora o te iwi". The programme aims to treat erosion, stop greater physical damage to the catchment, and bring social and economic gains to iwi and landowners.

These inter-generational aspirations inform Ngāti Porou's preferences for productive forest systems consisting of native tree species, rather than the predominant exotic species in the region, namely radiata pine (*Pinus radiata* D. Don). Native species with the potential to contribute to productive planted forest systems analysed here are mānuka (*Leptospermum scoparium*), tōtara (*Podocarpus tōtara*) and kawakawa (*Piper excelsum*). These species have been chosen for this study because of their high cultural significance and potential high profitability, which is conditioned on the uncertain niche markets where their products would be traded due to their uniqueness.

The Waiapu River catchment provides an ideal location for this study due to the existence of environmental policies incentivising two important regulating services from forestry: climate change mitigation (i.e. carbon sequestration) and erosion control. The New Zealand Emissions Trading Scheme (NZ ETS) is a domestic national policy implemented to meet the nation's international climate change obligations. Through the NZ ETS a price is assigned to a tonne of CO_2e sequestered, or a New Zealand Unit (NZU), creating an incentive to plant trees (Ministry for the Environment 2017). The ECFP is a regional initiative, led by the Gisborne District Council and the Ministry for Primary Industries, that grants landowners funding to control erosion on the worst eroding or erosion-prone land in the district. Eligible treatments include the establishment of indigenous forestry in retired grazing land (Ministry for Primary Industries 2017b).

Due to their design and the effects of climate change, the uncertain benefits obtained from such policies have important implications for landowners and governments alike. Previous modifications of the NZ ETS resulted in highly uncertain carbon price signals that affected landowners' trust and, hence, enrolment numbers.[2] The ECFP has been designed as an incentive mechanism (i.e. early lump-sum payments) to promote land use change to control for erosion. However, due to the uncertain erosion forecasts under climate change, it would be worthwhile to assess the effectiveness of such policy in reaching the expected public benefits.

[2] A modification of the NZ ETS back in 2009 permitted the surrendering of international Kyoto carbon units. Due to an oversupply of international units coupled with a low demand from the EU, such modification resulted in a drastic NZU drop to a record low of $2/NZU in 2013. See Richter & Chambers (2014).

3 Methodology

We recognise that a collaborative research approach provides more useful outcomes for Māori than a standard desktop analysis or the rollout of a spreadsheet or GIS application. Interacting with farm managers on the ground using kaupapa Māori research practices of whanaungatanga and kanohi ki te kanohi along with collaborative workshops were essential parts of our research approach. A collaborative process was established to work closely with selected Māori land owners in the Waiapu Catchment, Ruatōrea. A series of hui were carried out to identify, consider, and evaluate investment scenarios like afforestation. Several project meetings (4) and site visits (2) with the trustees and farm management took place at Taumata o Mihi Marae (Rauru), Ruatōrea. The meetings, a mixture of informal conversations with technical experts and formal presentations along with semi-structured questions, helped provide direction to the research team and offered an opportunity for the trustees/management to provide input into the research process.

A step-by-step process was used to discuss and evaluate afforestation scenarios utilising: a kaupapa Māori assessment, a bio-physical assessment and an economic assessment (see Figure 2). The process consisted of:

- Step 1: Landowner aspirations – A series of wānanga in Ruatōrea were carried out to identify landowner aspirations for the catchment. The research team met with owners of Māori land in the Waiapu catchment and listened to the landowner aspirations for their whenua.
- Step 2: Climate Change Modelling – based on baseline erosion rates developed with the New Zealand Empirical Erosion Model (NZEEM) were used to derive empirical distributions of climate change. In this study, we estimated annual erosion for all 286 sheep-beef land parcels in the catchment and a combination of 6 Global Climate Change Models (GCM) for the 4 Representative Concentration Pathways (RCP) scenarios for year 2100.[3]
- Step 3: Afforestation Scenarios were primarily identified through wānanga (workshops). Wānanga were mostly held on marae with site visits to the catchment. Identification of tree/shrub species by project team (indigenous and non-indigenous): the project team identified a list of potential tree/shrub species and combinations for afforestation scenarios (20–30 plus), drawing on the existing work by Landcare Research and SCION. The afforestation scenarios were reviewed by Ngāti Porou Māori landowners during the first wānanga. The project team refined the list of potential tree/shrub species and combinations to three indigenous afforestation scenarios for economic modelling and Kaupapa Māori assessment. The afforestation scenarios were validated by Māori land owners at the second wānanga.

[3] The 6 best-performing GCMs for the New Zealand region were selected, based on comparisons with observations over the historical data period of the models, namely the HadGEM2-ES (UK), CESM1-CAM5 (USA), NorESM1-M (Norway), GFDL-CM3 (USA), GISS-E2-R (USA) and BCC-CSM1.1 (China). See Tait et al. (2016).

- Step 4: Economic Modelling was undertaken using New Zealand Farm and Agriculture Regional Model (NZFARM) to assess profitability of the afforestation scenarios. NZFARM is an economic land-use model that has been used to explore the impacts of water and climate policy and resource constraints, climate impacts, and opportunities to improve land-based productivity and profitability in other catchments in New Zealand. A simplified list of afforestation scenarios was selected for this step. The afforestation scenarios included:

  (i) mānuka only: chosen as a resilient crop suitable for growing conditions on the East Coast of New Zealand, providing revenues from the sale of honey

  (ii) mānuka and tōtara: mānuka was used as a nurse crop providing shelter to aid in the establishment of tōtara, using the latter as a long-term high-value alternative

  (iii) mānuka, tōtara, and kawakawa: similar to the previous scenario with the addition of kawakawa as a high-value understory crop. Kawakawa is of high cultural value and produces a specialized product for use in pharmaceuticals.

- Step 5: Kaupapa Māori assessment of the afforestation scenarios for three Māori land parcels was carried out using a Kaupapa Māori evaluation tool. A simplified list of afforestation scenarios was selected for this step. The afforestation scenarios included: afforestation 1 (mānuka only), afforestation 2 (mānuka and tōtara), afforestation 3 (mānuka, tōtara, and kawakawa), afforestation 3 plus horticultural options (hemp, olives, macadamias, lemons). Using the methodology described below, the benefits from each afforestation scenario were ranked by the project team.
- Step 6: On-site Wānanga were used to discuss on-site climate mitigation approaches for the catchment. The mitigation approaches focused on, retiring land from production and fencing with tree planting. The training also included the practical steps required to carry out these types of mitigation approaches.

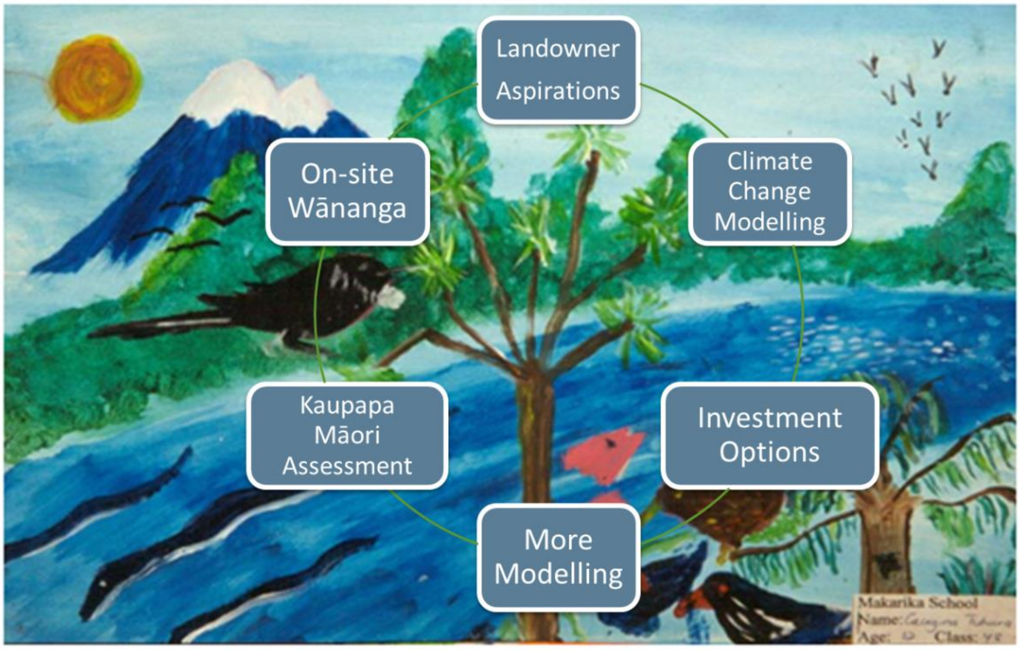

Figure 2: Research approach for the Climate Resilient Māori Land project.

Pluralistic methods from quantitative economic analysis to qualitative wānanga were utilised for this study. Economic modelling was used to assess the returns from a diverse group of afforestation scenarios; the GCS model was downscaled for the Waiapu catchment with a focus on erosion; and a Kaupapa Māori approach was used to assess the benefits of each afforestation scenario from a Māori perspective. A description of the Kaupapa Māori assessment is provided first, followed by the econometric methods and models (NZFARM and Uncertainty) and finally a description of the process (wānanga/workshops) for eliciting the preferred afforestation scenario by Māori landowners in the Waiapu catchment.

3.1 Kaupapa Māori assessment

Mātauranga Māori can inform all aspects of policy and strategic planning for collective assets. It is essential to create a robust, consistent, and replicable process to support the engagement of iwi/hapū/beneficiaries in the management, decision-making, planning, and policy development for collective assets. This ensures tangata whenua values and interests are identified and reflected in planning and management of collective assets from the outcome setting through to the goal setting, decision-making and evaluation stages.

Māori values, derived from the traditional belief system, are part of the wider Māori knowledge system, and can be defined as instruments through which Māori make sense of, experience, and interpret the environment. Māori values can be represented in many forms:

- in the environment as places or sites of significance: the basis for recognising Māori treasures (taonga), such as iconic flora and fauna species, significant biodiversity, mahinga kai and environmental issues
- in the language: through relationships between people or organisations; and the intrinsic cultural basis for controlling or modifying human behaviour, forming the principles and ethics by which we live and advance.

Using a kaupapa Māori assessment, each afforestation scenario was assessed from the perspective of Ngā Pou Herenga (Core Values and Principles). These core values and principles were identified by Awatere (Awatere et al. 2014):

- *Kaitiakitanga* – Māori sustainable resource management (not the same as guardianship as there is an element of active use based on whakapapa and the ability of securing an access and use right to the resource)
- *Manaakitanga* – reflects reciprocity of actions to the environment, the wider community, to iwi/hapū, and other people
- *Whakatipu Rawa* – concerned with growing the asset base, retention of Māori owned resources and effective use of these resources for beneficiaries and future generations.

These principles align with but are not proxies for economic, social, and environmental well-being. They represent alternative ideologies for well-being, are used in natural resource management planning, and have been adapted here for collective asset management (Tāmaki Regional Mana Whenua Forum 2007; Jefferies et al. 2009; Awatere et al. 2012, 2013; Harmsworth et al. 2013)). There is potential for including wairuatanga (spiritual well-being), where narrative descriptions are provided alongside the modelling to provide further explanation or to support the outcomes from the modelling.

A kaupapa Māori assessment can be used to measure and assess the benefits of afforestation scenarios. An assessment tool helps the assessor(s) of any investment (e.g. trustees of a Māori land incorporation or trust) evaluate any investment or activity against Ngā Pou Herenga (Core Values and Principles). These core Māori values, principles, and criteria/indicators for measurement are described next along with a statement for how they could assess an investment:

He Pou Herenga (Guiding Principle): Kaitiakitanga

The attributes for Kaitiakitanga are:

- *Wāhi tapu/taonga*: The mauri of culturally significant sites. How well does the investment enhance the mauri of culturally significant sites? and
- *Mahinga kai*: The mauri (life-force principle) of food-gathering areas. How well does the investment provide for traditional food-gathering areas?
- *Ngā Otaota Māori*: The mauri of culturally significant plants. How well does the investment enhance the mauri of native flora and fauna?
- *Ngā Wai Tipuna*: The mauri of culturally significant waterways. How well does the investment enhance the mauri of significant waterways?

Tables 1–4 below provide a description of the indicators and measures for Kaitiakitanga.

Table 1: Wāhi Tapu/Taonga (significant sites) descriptors and variables

Wāhi Tapu/Taonga (significant sites): Does the investment protect and enhance significant sites?	
PAI RAWA 4	All wāhi tapu/taonga are protected and enhanced
PAI 3	Most wāhi tapu/taonga are protected and enhanced
ĀHUA PAI 2	Some wāhi tapu/taonga are protected and enhanced
PŌHARA 1	Few wāhi tapu/taonga are protected and enhanced
AUE 0	No wāhi tapu/taonga are protected and enhanced

Table 2: Mahinga Kai (food-gathering areas) descriptors and variables

Mahinga Kai (food-gathering areas): Does the investment improve the well-being of food-gathering areas through restoration and enhancement activities?	
PAI RAWA 4	All mahinga kai are protected and enhanced
PAI 3	Most mahinga kai are protected and enhanced
ĀHUA PAI 2	Some mahinga kai are protected and enhanced
PŌHARA 1	Few mahinga kai are protected and enhanced
AUE 0	No mahinga kai are protected and enhanced

Table 3: Ngā Otaota Māori (indigenous flora and fauna) descriptors and variables

Ngā Otaota Māori (indigenous flora and fauna): Does the investment protect and/or enhance native flora, fauna, habitats, ecosystems, and biodiversity?	
PAI RAWA 4	Full protection of ecosystems and enhancement of biodiversity; landscaping and riparian zones plant all native plants
PAI 3	Moderate protection ecosystems and enhancement biodiversity, landscaping and riparian zones plant mostly native plants
ĀHUA PAI 2	Occasional protection of ecosystems and enhancement of biodiversity, landscaping and riparian zones plant some native plants
PŌHARA 1	Few protections of ecosystems and enhancement of biodiversity, landscaping and riparian zones plant few native plants
AUE 0	No protection of ecosystems and enhancement of biodiversity, landscaping and riparian zones plant no native plants

Table 4: Ngā Wai Tipuna (natural waterways) descriptors and variables

Ngā Wai Tipuna (natural waterways): Does the investment protect and/or enhance natural waterways, and consider the appropriate use/reuse, treatment and disposal of water?	
PAI RAWA 4	Full protection and enhancement of natural waterways, water use is sustainable and there is no discharge into waterways
PAI 3	Moderate protection and enhancement of natural waterways, water use is mostly sustainable and there is little discharge into waterways
ĀHUA PAI 2	Occasional protection and enhancement of natural waterways, water use is somewhat sustainable and some discharge into waterways
PŌHARA 1	Few protections and enhancement of natural waterways, water use is not very sustainable and significant discharge into waterways
AUE 0	No protection and enhancement of natural waterways, water use is unsustainable and very significant discharge into waterways

He Pou Herenga (Guiding Principle): Manaakitanga

The attributes for Manaakitanga are:

- *Akoranga*: Mātauranga Māori is enhanced. How well does the investment provide for education opportunities with iwi/hapū beneficiaries and the wider community?
- *Whanaungatanga*: Community connectedness. How well does the investment provide work and business environments and practices that are uniquely iwi/hapū based, and places where iwi/hapū and manuhiri alike are welcome, encouraged, and proud to be involved?
- Iwi/hapū outcomes – The mauri of the iwi/hapū is enhanced
- Whānau hapori – The mauri of the wider community is enhanced.
- *Kia Mahi Ngātahi*: Inter-iwi and intra-community commercial relationships are maintained. How well does the investment provide for opportunities to work with other iwi/hapū and the wider community?

Tables 5–7 below provide a description of the indicators and measures for Manaakitanga.

Table 5: Akoranga (education goals) descriptor and indicators

Akoranga (education goals): Does the investment protect and enhance Mātauranga Māori and help grow Māori entrepreneurship capability?	
PAI RAWA 4	Tikanga (values and principles) are practised, maintained or shared amongst whanau; Māori entrepreneurship capability development is fully supported
PAI 3	Most tikanga are practised, maintained or shared amongst whanau; Māori entrepreneurship capability development is mostly supported
ĀHUA PAI 2	Some tikanga practised or shared amongst whanau; Māori entrepreneurship capability development is sometimes supported
PŌHARA 1	Few tikanga practised or shared amongst whanau; Māori entrepreneurship capability development is rarely supported
AUE 0	Tikanga are not practised or shared amongst whanau; Māori entrepreneurship capability development is not supported

Table 6: Whanaungatanga (community development) descriptors and variables

Whanaungatanga (community development): Does the investment provide jobs for local people and promote iwi/hapū/whanau identity?	
PAI RAWA 4	Always utilises the local labour force, iwi/hapū/whanau identity is fully recognised, and whanaungatanga is flourishing
PAI 3	Mostly utilises the local labour force, iwi/hapū/whanau identity is mostly recognised, and whanaungatanga is engaged
ĀHUA PAI 2	Sometimes utilises the local labour force, iwi/hapū/whanau identity is occasionally recognised, and whanaungatanga is activated
PŌHARA 1	Rarely utilises the local labour force, iwi/hapū/whanau identity is rarely recognised, and whanaungatanga is awakened
AUE 0	The local labour force is not utilised, iwi/hapū/whanau identity is not recognised, and whanaungatanga is dormant

Table 7: Kia Mahi Ngātahi (partnerships) descriptors and variables

Kia Mahi Ngātahi (partnerships): Does the investment help grow inter-iwi and intra-community commercial relationships?	
PAI RAWA 4	Iwi/hapū/whanau are full active partners in the development, local businesses are always preferred retailers and suppliers, and local entrepreneurs are flourishing
PAI 3	Iwi/hapū/whanau are moderately active partners in the development, local businesses are mostly preferred retailers and suppliers, and local entrepreneurs are engaged
ĀHUA PAI 2	Iwi/hapū/whanau are occasionally partners in the development, local businesses are sometimes preferred retailers and suppliers, and local entrepreneurs are active
PŌHARA 1	Iwi/hapū/whanau are almost never partners in the development, local businesses are rarely preferred retailers and suppliers, and local entrepreneurs are awakened
AUE 0	Iwi/hapū/whanau are not active partners in the development, local businesses are never preferred retailers and suppliers, and local entrepreneurs are dormant

He Pou Herenga (Guiding Principle): Whakatipu Rawa

The attributes for Whakatipu Rawa are:

- *Intergenerational investment*: Distribution among members and future generations. How well does the investment provide for equitable shared benefits across generations?
- *Whakapūmautanga*: Retention and accumulation of fixed assets to generate increased equity. How well does the investment provide for the retention of fixed assets?
- *Labour FTEs*: Labour Full Time Equivalents are enhanced. How well does the investment provide for full-time equivalent employees from iwi/hapū and the wider community?

Tables 8-10 below provide a description of the indicators and measures for Whakatipu Rawa.

Table 8: Whakapūmautanga (perpetuity) descriptors and variables

Whakapūmautanga (perpetuity): How well does the investment grow the accumulation of strategic assets?	
PAI RAWA 4	Assets like whenua/ngahere/wai are always accumulated and retained, and growth in the asset base is flourishing
PAI 3	Assets like whenua/ngahere/wai are mostly accumulated and mostly retained, and growth in the asset base is growing
ĀHUA PAI 2	Assets like whenua/ngahere/wai are occasionally accumulated and sometimes retained, and the asset base is consolidated
PŌHARA 1	Assets like whenua/ngahere/wai are rarely accumulated and almost never retained, and growth in the asset base is dormant
AUE 0	Assets like whenua/ngahere/wai are never accumulated and never retained, and growth in the asset base is in decline

Table 9: Mana Taurite (intergenerational equity) descriptors and variables

Mana Taurite (intergenerational equity): Does the investment provide for equitable distribution amongst beneficiaries and future generations?	
PAI RAWA 4	Benefits are always distributed equitably amongst beneficiaries, the well-being of future generations is always considered, and whanau well-being is flourishing
PAI 3	Benefits are mostly distributed equitably amongst beneficiaries, the well-being of future generations is mostly considered, and whanau well-being is engaged
ĀHUA PAI 2	Benefits are occasionally distributed equitably amongst beneficiaries, the well-being of future generations is sometimes considered, and whanau well-being is activated
PŌHARA 1	Benefits are almost never distributed equitably amongst beneficiaries, the well-being of future generations is rarely considered, and whanau well-being is awakened
AUE 0	Benefits are never distributed equitably amongst beneficiaries, the well-being of future generations is never considered, and whanau well-being is dormant

Table 10: Labour FTEs (labour full time equivalents)

Labour FTEs: Labour Full Time Equivalents are enhanced. How well does the investment provide for full-time equivalent employees from iwi/hapū/whanau and the wider community?	
PAI RAWA 4	Substantial FTEs for iwi/hapū/whanau and the wider community
PAI 3	Some FTEs for iwi/hapū/whanau and the wider community
ĀHUA PAI 2	A few FTEs for iwi/hapū/whanau and the wider community
PŌHARA 1	Very few FTEs for iwi/hapū/whanau and the wider community
AUE 0	No FTEs for iwi/hapū/whanau and the wider community

Mauri (life-force principle) is a considerable part of the assessment criteria for the goals and objectives. This study utilises similar methods for assessing mauri/well-being that were developed by earlier studies (Tipa et al. 2003; Morgan 2007; Harmsworth et al. 2009). Qualitative rankings such as low, medium and high were assigned for each mauri-based criterion. For the purposes of Māori collective asset management, mauri is a culturally appropriate measure of well-being because it is derived from kaupapa Māori ideology. Likewise, qualitative rankings (pōhara, āhua pai, pai and pai rawa) were assigned to other criteria like: intergenerational investment, sustainable return, labour FTEs, education goals, and partnerships.

As the type of evaluation required is qualitative and based on subjective assessment, assessment of each attribute requires determination of the relative size or degree of difference between the value judgements of each assessor. The Likert-type scale would be appropriate in this case because it converts subjective assessment into relative scores. However, it can be difficult to aggregate quantitative measures based on subjectivity and values judgement. This can be overcome to some degree by achieving consistency in standards, particularly in the way each proposal is measured and evaluated. This relies on improving the skills and experience of each assessor and promoting professional standards. If such a process and evaluation system were adopted, each assessor could use a scoring system, such as that based on the Likert-type scale (aue = 0, pōhara = 1, āhua pai = 2, pai =3, pai rawa = 4), which gives rating categories. Each investment can then be assessed against key principles to indicate which elements of the investment are seen positively or negatively from a Māori perspective.

It is also possible to explore the development of an index or aggregation of indicators for each sub-category from the assessment tool based on Ngā Pou Herenga (Guiding Principles), e.g. a Kaitiakitanga index, a Manaakitanga index, and a Whakatipu Rawa index. Aggregation of measures provides a useful way for summarising information and for benchmarking the performance or non-performance of an investment in relation to a core value. For example, the maximum aggregate performance score for an investment based on the Kaitiakitanga index with 4 sub-categories would be 16 (with 4 being assigned to a ranking of "pai rawa"). Alternatively, a mid-high-performance score would be 12 (with 3 being assigned to a ranking of "pai"), a mid-range performance score would be 8 (with 2 being assigned to a ranking of "āhua pai"), and a minimum performance score would be 0 (with 0 being assigned to a ranking of "aue").

Care should be taken with relying too much on quantitative measures. The purpose of these measures is to promote dialogue between trustees and beneficiaries through the explicit recognition of core Māori values and principles in the decision-making process for collective assets. Narrative comment can further enhance the quantitative assessment through the addition of contextual information to provide decision-makers with a more holistic data set. There is a rich historical and spiritual narrative that can add value to the decision-making process. The intention of making explicit measures considering mauri will hopefully engender further dialogue about the potential impact a collective asset investment may have on the overall and holistic well-being of the beneficiaries.

3.2 Identifying afforestation scenarios through wānanga (workshops)

This research used economic analysis of potential afforestation scenarios under different climate scenarios as well as assessing the potential of catchment-level ecosystem-based interventions to mitigate climate risks. Downscaled climate impacts have recently become available through the Climate Change Implications and Impacts (CCII) programme, making this kind of analysis timely and relevant to Māori land investment decisions. The economic modelling used the New Zealand Farm and Agriculture Regional Model (NZFARM). NZFARM is an economic land use model that has been used to explore the impacts of water and climate policy and resource constraints, climate impacts, and opportunities to improve land-based productivity and profitability in other catchments in New Zealand. It has also formed the basis for other economic assessments on Māori-owned land (e.g. for Maniapoto Māori Trust Board and Makirikiri Aggregated Trust). Key to carrying out economic modelling on Māori-owned land has been the co-development of afforestation scenarios. We wanted to collaboratively identify potential solutions to climate change with the landowners who will bear the impacts from climate change. The primary method for identifying the afforestation scenarios were wānanga (workshops). Wānanga were mostly held on marae and were sometimes accompanied by site visits to the catchment where land use activity is being carried out.

In consultation with Māori landowners in the Waiapu catchment, we identified a number of afforestation and horticultural scenarios to consider for economic modelling:

- 9 preferred land uses consisting of 5 afforestation scenarios of intercropped species and 4 horticultural scenarios:
    - mānuka, kānuka – honey and erosion control
    - mānuka, kānuka, tōtara – honey, timber, and erosion control
    - mānuka, kānuka, tōtara, mataī, pūriri – honey, timber, and erosion control
    - mānuka, kānuka, tōtara, mataī, pūriri, harakeke, kawakawa – honey, erosion control, medicinal/cosmetic, fibre, kaupapa Māori, timber, and oil
    - mānuka only – honey, oil, and erosion control
- Horticultural scenarios include:
    - Olive Orchards – olives and olive oil
    - Lemon Orchards – lemons
    - Hemp plantation – fibre and seeds
    - Macadamia plantation – nuts and oil

A comparative Net Present Value analysis of the above scenarios is presented in Appendix 1. For the purposes of this study, we refined the scenarios for the risk and certainty analysis along with the Kaupapa Māori assessment. The following afforestation scenarios were explored alongside the baseline scenario of sheep and beef:

- mānuka only
- mānuka and tōtara, and
- mānuka, tōtara, and kawakawa.

The Kaupapa Māori assessment focuses on the above scenarios along with the addition of a horticultural scenario including.

- Olive Orchards – olives and olive oil
- Lemon Orchards – lemons
- Hemp – fibre and seeds
- Blueberries – frozen

The following section provides more details on where the wānanga were held, their primary purpose, and some of the key outcomes that helped inform the current study.

3.3 Wānanga (Workshops)

Wānanga (workshops) were used for several purposes including: socialisation of the project with Māori land-owners in the Waiapu catchment; identification of key priorities and values; and identification of afforestation scenarios within the context of climate change. Three wānanga were held: the first presented the kaupapa to landowners and identified some preliminary values and priorities; the second identified afforestation scenarios and reaffirmed the priority for the catchment from a landowner perspective; and the third wānanga presented the results of the bio-physical and economic modelling and discussed the afforestation scenarios for managing land within the context of climate change.

3.3.1 Wānanga tuatahi

The first wānanga/workshop for Māori land-owners was held on 12 August 2016 at Taumata o Mihi Marae (Rauru), Ruatōrea. The hui was opened with a karakia (prayer) and mihi (welcoming speech). Participants also engaged in whanaungatanga, an exercise to develop a shared connection through experiences and working together.

The wānanga, was attended by five Māori land-owners and hosted by the principal co-investigators Shaun Awatere (Landcare Research), Tui Warmenhoven (HOMINUTI), and Duncan Harrison (Scion). The hui presented the research kaupapa to Māori land-owners.

Through a free-flowing discussion key themes emerged. Participants expressed the desire to manaaki their beneficiaries and other members of Ngāti Porou through the promotion of programmes that helped build capability. To realise investment opportunities, people require essential skills including forestry skills, governance, entrepreneurship, financial and leadership. Of utmost importance for most land owners was the concept of **whakapūmautanga (te whenua) ma ngā uri tuku iho – retention of assets for the benefit of future generations**. Participants at the wānanga supported afforestation scenarios that provided some financial benefits but more importantly were aligned to the ethic of kaitiekitanga (sustainable resource use for future generations). These themes provided a clear direction to the project team to focus on alternative forestry or indigenous afforestation scenarios.

Before the wānanga, the project team brainstormed a list of potential afforestation scenarios from horticultural such as lemons and olives through to alternative forestry such as mānuka. The afforestation scenarios were informed from previous work (see for example, Daigneault et.al. (2015b)). A list of 30–40 options was presented to participants. Based on feedback from participants, the focus of the project was refined to alternative forestry, including indigenous forestry:

- Rationale: climate change could potentially increase the erosion risk for the Waiapu catchment. Forestry would help mitigate the risk from erosion. The Waiapu catchment is approximately 158,000 ha and the area suitable for forestry is 145,365 ha or 92% of the catchment.
- The current project realigned to alternative forestry scenarios under various climate change scenarios and extended the promotion of indigenous forestry and alternative forestry for erosion susceptible land in the Waiapu catchment. Afforestation scenarios focused on availability of data for economic analysis and alignment to addressing erosion susceptibility. Horticultural options focused on crops currently succeeding economically for the region and avoided crops that had realised their potential in the past.

The wānanga also discussed some management/mitigation strategies. The need for a coordinated and informed effort for the implementation of management/mitigation actions was identified, e.g. improved co-ordination by the Erosion Control Funding Programme and The Waiapu Accord. In terms of capability development, the need for indigenous tree-planting specialists, i.e. beyond willow and poplars, was identified. The requirement for incentives to energise current capability was identified. There are challenges trying to get all owners and trustees from a Māori land institution present to discuss approaches for improving Māori land development, therefore projects and programmes supporting land development are reliant on local champions to develop capability.

TRONPnui and MPI appointed a relationship manager in mid-2014 to foster connections between Ngāti Porou land-owners in the Waiapu district for Waiapu Kōkā Huhua. These land owners are the focus of efforts by relationship managers due to the co-governance arrangement between Ngāti Porou, central and local government authorities – the Waiapu River Accord. The Accord enables Ngāti Porou to provide input into government investment decisions with respect to infrastructure management including erosion control, roading, energy, and communications. MPI provides funding through the ECFP to Gisborne district landholders and community groups to help reduce wide-scale erosion problems in the Gisborne district. The programme can be utilised to achieve land owner aspirations. The ECFP terminates in 2020 with $30 million to be distributed by that date.

The focus of the WCRP is erosion treatment uptake on priority blocks. The relationship manager attended the wānanga on 28 April and identified a primary issue for the uptake of any results from the current research project is engagement with governance members of Māori land blocks. Many of the blocks in the Waiapu district are unincorporated or are managed through trusts under Te Ture Whenua Māori Act. The relationship manager identified that relationships and trust take time to develop for the successful uptake of solutions.

The wānanga also identified priority catchments such as the Mangawhariki Catchment because of complex issues such as susceptibility to high levels of erosion, multiple land-blocks, and diverse governance issues. The wānanga was closed with a poroporoaki (farewell ceremony) and a karakia.

3.3.2 Wānanga tuarua

The second wānanga/workshop for Māori land-owners was held on 12 October 2016 at Kariaka Marae, Ruatōrea. The hui was opened with a karakia (prayer) and mihi (welcoming speech). The wānanga, was attended by 14 Māori land-owners, hosted by the principal investigator Tui Warmenhoven (He Oranga), and supported by Pia Pohatu (He Oranga) and Duncan Harrison (SCION). An additional ZOOM meeting was also held with 5 Māori land-owners. The wānanga was held adjacent to SCION's *Weaving the korowai* MBIE project hui.

Participants at the wānanga reaffirmed their support for the current project to explore alternative forestry scenarios under various climate change scenarios and extend the promotion of indigenous forestry and alternative forestry for erosion susceptible land in the Waiapu catchment. Discussion covered the risk of relying on limited capability for expert advice, e.g. from community and hapū champions. Participants expressed their desire for government agencies to improve information dissemination, utilisation of online resources, and the promotion of more collaboration between hapū and government agencies that are more focused on community-based outcomes.

It was clear from the wānanga that there was a desire to invest in afforestation. The participants at the wānanga refined the list of 30–40 land use opportunities presented at the previous wānanga in August 2016 to approximately 9 preferred land uses, consisting of 5 alternative forestry scenarios, and 4 horticultural scenarios. Alternative forestry scenarios of intercropped species with associated benefits included the following:

- mānuka, kānuka – honey and erosion control
- mānuka, kānuka, tōtara – honey, timber, and erosion control
- mānuka, kānuka, tōtara, mataī, pūriri – honey, timber, and erosion control
- mānuka, kānuka, tōtara, mataī, pūriri, harakeke, kawakawa –honey, erosion control, medicinal/cosmetic, fibre, kaupapa Māori, timber, and oil
- mānuka – honey, oil, and erosion control

Horticultural scenarios include:

- Olive Orchards – olives and olive oil
- Lemon Orchards – lemons
- Hemp plantation – fibre and seeds
- Macadamia plantation – nuts

The wānanga was closed with a poroporoaki (farewell ceremony) and a karakia.

3.3.3 Wānanga tuatoru

The final wānanga/workshop with Māori land-owners was held on 28 April 2017 at Taumata o Mihi Marae (Rauru), Ruatōrea. The hui was opened with a karakia (prayer) and mihi (welcoming speech). The primary aim of wānanga tuatoru was to present back to land-owners the results from the economic analysis. The results were well-received, with participants confirming that the proposed mitigation approaches (afforestation scenarios) are consistent with their aspirations for long-term investment in afforestation such as through the Waiapu Catchment Restoration Project (WCRP), an approach that considers those socio-economic benefits, particularly the improvement in the health of the awa (river), that will lead to improvements in the health of the whenua and its people. The wānanga also helped:

- identify the most useful ways to visualise and interpret data and outputs from the economic modelling
- develop a Kaupapa Māori assessment approach for each of the land use scenarios to accompany the economic modelling, utilising Kaupapa Māori measures such as impact on mahinga kai and impact on wāhi tapu/taonga river, etc. The assessment tool is informed by earlier work by Manaaki Whenua (see, for example: Hainsworth S, Daigneault A, Samarasinghe O, Awatere S 2016. Assessment and evaluation of opportunities for Arai-Matawai Incorporation. Ngā Pae o te Māramatanga project. Landcare Research Contract Report LC 2636. 30 p.)
- identify catchment-scale mitigation/adaptation approaches for afforestation
- identify farm-scale mitigation/adaptation approaches for afforestation.

A capability field trip that included training for landowners was also held on 28 April. The training involved:

- an on-site assessment of landform/s and LUC, overlay 3 and 3A identified by the mapping information, access to block, prevailing wind and rain information, hazard risk assessment
- discussion of land use and/or treatment options that align with landowner aspirations
- matching land use with the eligibility for ECFP and other support programmes
- a planning session on the phased application of treatment/land use within the landblock/site and development of the associated resource/support. For example, where reforestation was an aspiration, appropriate forest species were identified for specific areas of the land block. In the case of the Ahikouka block this was mānuka for treating erosion prone land and crop/nut trees to support landowner aspirations for a papakainga and orchard. Papakainga area was confirmed based on the stability of

land block and mapping information. This assessment will have significant implications on the dwelling designs and capacity for whanau housing.

Landowners were briefed on understanding the problems with different parts of the river system to identify what and where to plant trees for erosion mitigation. Some areas were identified as unsuitable for tree planting such as areas currently in gully erosion and the immediate margins of some rivers. The team, supported by Mike Marden, discussed on-site mitigation approaches, primarily retiring land from production and carrying out fencing along with tree planting, with the land-owners of Ahikouka, Tikapa, and Tapuaeroa. The training also included the practical steps required to carry out these types of mitigation approaches. The wānanga was closed with a poroporoaki (farewell ceremony) and a karakia.

3.4 Economic methods and models

Overall methodology

Figure 3 summarises the overall method by graphically representing the linear flow of data (averages and distributions) and models used in the two complementary approaches: (1) the deterministic optimisation (i.e. no uncertainty) routine using NZFARM; and (2) the post-optimisation uncertainty analysis. The detailed descriptions of the data sources, methods and models used are developed in the following sub-sections.

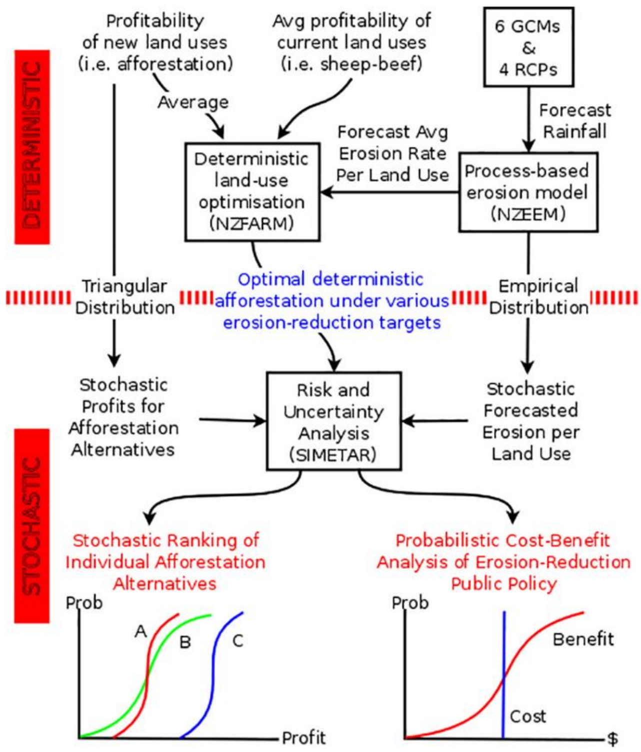

Figure 3. Graphical representation of the flow of the coupled and complementary approaches.

New Zealand Forest and Agriculture Regional Model (NZFARM)

A spatially explicit economic optimisation model was used to contrast the *deterministic* profitability of native tree species with that of the predominant land use in the region (i.e. sheep-beef) enabling the identification of the areas that would need to be afforested (i.e. erosion hotspots) under various *deterministic* future erosion-reduction goals. The model used was the New Zealand Forest and Agriculture Regional Model (NZFARM), a widely used non-linear mathematical programming model of New Zealand land use that is spatially delineated at the farm-parcel level (Daigneault et al. 2016). The model has been parameterised to assess how changes in climatic conditions, technology, market drivers, resource constraints, or environmental policies will affect a host of economic or environmental performance indicators that are important to decision-makers and rural landowners (Daigneault et al. 2015a, 2017b; Fernandez et al. 2017). For a more detailed description of the model's mathematical formulation and calibration procedure, refer to the second section of Appendix 2.

Cash flows of afforestation scenarios

A highly simplified version of the NZFARM model was used for this study to quantify and track changes in land cover and soil erosion, which was then used to estimate impacts on a wider range of ecosystem services. For replication purposes, any linear (or non-linear) programming model that maximises overall profits across land uses in a specific region, considers area allocation among land uses as the main decision variable, together with a constraint equation that tracks erosion rates per land use and limits total erosion in the region, could be used as a substitute for the version of NZFARM used for this study (e.g. Doole 2015).

For the specific case of the Waiapu catchment, baseline land use and enterprise areas are based on a GIS-based land use map created in 2014 using the latest information from Agribase and the NZ Land Cover Database version 4 (LCDBv4).[4] Production yields, stocking rates, input costs, and output prices for sheep-beef farms come primarily from the literature (Newsome et al. 2008; Lincoln University 2013; Ministry for Primary Industries 2013a, b), and have been verified with agricultural consultants and enterprise experts. Erosion and soil loss figures are based on methods from Ausseil et al. (2013) and on the New Zealand Empirical Erosion Model (NZEEM) (Dymond et al. 2010).

Since the establishment of indigenous forestry in retired grazing land is an eligible erosion treatment under the ECFP, three indigenous tree species were chosen through a set of consultations with community representatives, namely mānuka, tōtara, and kawakawa. Three continuous-cover forest management scenarios were designed for this analysis by

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[4] Available at https://www.asurequality.com/our-solutions/agribase/ and https://lris.scinfo.org.nz/layer/412-lcdb-v40-land-coverdatabase-version-40/

combining these tree species. Refer to Figure 4 for a graphical representation of the transitions. All scenarios started with mānuka, based on its potential to provide: (1) shelter for the establishment of tōtara and kawakawa; (2) early revenue from honey sales; (3) a thick canopy for rain interception; and (4) a solid rooting system for erosion reduction. The afforestation scenarios are:

1 **Mānuka only**: Chosen as a resilient crop suitable for growing conditions on the East Coast of New Zealand, providing revenues from the sale of honey. Productivity was assumed to start at 10 kg/ha of honey from year 4, building up to 30 kg/ha from year 6, and reducing to 20kg/ha from year 28 into perpetuity (ANZ Research 2015).

2 **Mānuka and tōtara**: mānuka was used as a nurse crop providing shelter to help the establishment of tōtara, using the latter as a long-term high-value alternative. Honey production from mānuka was assumed to stop due to shading as the canopy transitioned to tōtara. Sustainable recoverable volumes were assumed to increase slowly over seven selective harvests, each 10 years apart, starting at 100 m^3/ha in year 88 and finishing at 107 m^3/ha in year 148 (Bergin et al. 2003).

3 **Mānuka, tōtara, and kawakawa**: Similar to the previous scenario, with the addition of kawakawa as a high-value understory crop. Kawakawa is of high cultural value and produces a specialized product for use in pharmaceuticals. In this scenario, it was assumed kawakawa planting would start from year 25 after tōtara canopy closure. Kawakawa harvesting was assumed to start one year after the first planting, initially providing 100 kg of dried kawakawa leaves per hectare, and increasing to 900 kg/ha by year 32 (Heaphy et al. 2013).

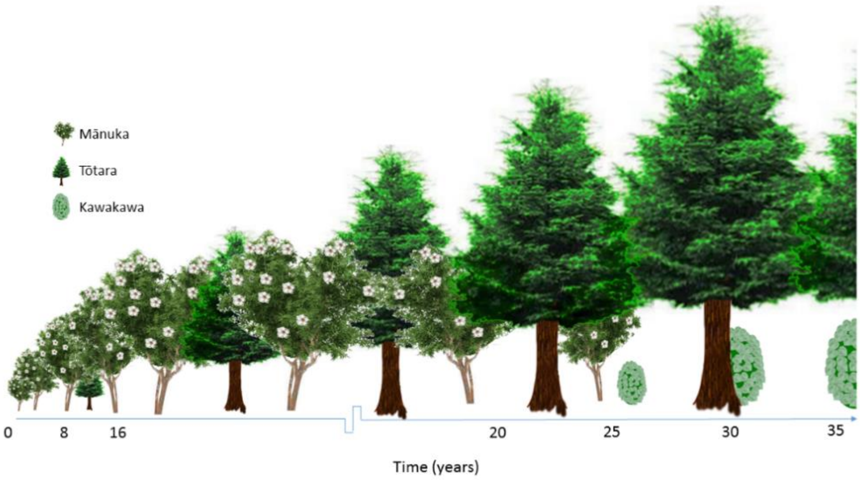

Figure 4: Afforestation transitions through time.

To assess the profitability of the three afforestation scenarios, a discounted cash flow approach was used. Operational costs were calculated in line with common practices of radiata pine plantations in New Zealand assuming high hindrance from slope and understorey. In scenarios where, multiple operations occurred within the same year, an adjustment factor was used to avoid double counting the cost of time spent accessing trees. The range in prices assumed for the various products are listed in Table 11 below.

The variability of these prices was specified based on the best information available in the literature. For more details on the assumptions for costs, productivities and silvicultural practices, refer to the first section of Appendix 2.

Sources of profitability uncertainty

Since the optimisation exercise using NZFARM was of a deterministic nature (i.e. not considering uncertainty), a simple and replicable Monte Carlo approach was used as a complement to represent probabilistically the uncertainty expected from various sources. There are various specialised software packages (e.g. @Risk, Crystal Ball, SIMETAR, etc.) and routines in popular programming languages (R, Python, Matlab, GAMS, etc.) that can perform such Monte Carlo simulations. The stochastic modelling process is explained below to encourage others replicate such procedures in their preferred tools.

Various sources of uncertainty (e.g. policy, market and climate change) have been considered that will affect the impact of the generation of ecosystem services on landowners' and policymakers' decision-making processes. The following sections list the uncertain parameters considered with their respective data and methods. Table 11 lists the parameters considered for the various sources of uncertainty.

Market uncertainty: The forest products considered (e.g. mānuka honey, tōtara timber and kawakawa dry leaves for pharmaceuticals) are for niche markets where there is a high demand uncertainty. Due to the novel nature of such products, there is no appropriate price time series to calibrate a parametric distribution (e.g. normal). Hence, for practical purposes the uncertainty around expected prices was modelled using a symmetric triangular distribution where the uncertainty is expressed as a percentage (μ) around the mean (β) as shown in Figure 5. The uncertainty (μ) is relative to the level of market development for the niche product and is based on price ranges obtained from literature (Heaphy et al. 2013; Steward et al. 2014; ANZ Research 2015).

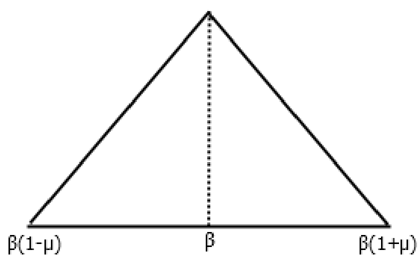

Figure 5: Triangular distribution function with respective parameters.

Table 11: Parameters for triangular distributions to represent uncertainty for the profitability of the native tree species used as afforestation scenarios

Uncertainty type	Parameter	Unit	Uncertainty in %	Exp price in $/unit	Min price in $/unit	Max price in $/unit
			μ	β	β*(1μ)	β*(1+μ)
Market	Mānuka price	$/kg honey	10	35	31.5	38.5
	Tōtara price	$/m^3 timber	40	350	210	490
	Kawakawa price	$/kg dry leaves	40	110	66	154
Policy	Carbon price	$/NZU	50	17	8.5	25.5
Ecosyst. Service	Carbon sequest.	tCO2e/ha/yr		7.6	7	9.2

Policy uncertainty: The carbon price signal created by the NZ ETS has been so erratic in the last 5 years due to the relatively young market and policy changes. Because of such high uncertainty there is no sensible way to calibrate any existing price series to a parametric distribution. Hence, a symmetric triangular distribution was also adopted where uncertainty is expressed as a percentage around an expected price of $17/CO2e, which is the current price, and an uncertainty factor of 50% resulting in a minimum and a maximum price of $8.5/CO2e and $25.5/CO2e, respectively. The resulting minimum and maximum reflect historical price ranges (Funk et al. 2014; CommTrade 2017).

Carbon sequestration uncertainty: The expected sequestration rate is defined by a set of lookup tables that the Ministry for Primary Industries in New Zealand has developed. Despite being derived from areas of regenerating indigenous shrublands dominated by mānuka/kānuka, such estimates account for about 70% of the total regenerating indigenous area in New Zealand (Ministry for Primary Industries 2017a).[5] Trotter et al. (2005) defined a national carbon sequestration range for mānuka and kānuka, which was used to define the minimum and maximum sequestration rates for an asymmetric triangular distribution (last row of Table 11). Although carbon sequestration was modelled for a 150-year time horizon, the uncertainty was based on the average annual sequestration rates for a 40-year timespan. The time horizon of 150 years was chosen to consider a full transition from mānuka to tōtara.

Profitability uncertainty: All the previous sources of uncertainty (except for climate change) were encapsulated in the following profitability measures for the three afforestation scenarios:

[5] Forest owners have two options to quantify changes in carbon stocks: the default lookup tables and the field measurement approach. The former is used for participants with less than 100 hectares of post-1989 forest land in the NZ ETS and is based on default lookup tables publicly available and published by the government. The latter is used for participants with more than 100 hectares who need tailored growth curves for their specific blocks to minimise under- or over-reporting carbon stocks. We have used the lookup tables for practical purposes.

$$\tilde{\pi}_s = \sum_{t}^{150} \frac{\left(\widetilde{tp_{t,s}} * tq_{t,s}\right) + \left(\widetilde{cp_{t,s}} * \widetilde{cq_{t,s}}\right) + ECFP_{r\in t} - c_{t,s}}{(1+i)^t}$$

where the ~ sign identifies stochastic variables, *s* is the afforestation alternative, *t* represents every year of the 150-year time horizon, r is a subset of time including the periods when the ECFP payments take place,6 $\tilde{\pi}_{l,s}$ represents the net present value (NPV), tp is the product price (e.g. mānuka honey, tōtara timber and kawakawa dry leaves), tq is the quantity of the product, cp is the price of carbon, cq is the annual carbon sequestration rate, c represents costs, i is the private discount rate of 5%, and ECFP is the payment granted by the government to control erosion.

Stochastic dominance to rank afforestation scenarios

Various stochastic dominance tests were used to rank the afforestation alternatives. These are outlined in detail with the purpose of giving readers plenty of options to be implemented in their preferred packages. Since the various tests are based on comparing the cumulative distributions functions (CDF) of the afforestation scenarios, 500 Monte Carlo simulations were first performed for each scenario to obtain the CDFs for the NPV variables.[7] The results would allow land owners and managers to compare afforestation options.

The tests used in this study were: first degree dominance (FDD), second degree dominance (SDD), Stochastic Dominance with Respect to a Function (SDRF) and Stochastic Efficiency with Respect to a Function (SERF). The first two (FDD and SDD) are widely available tests in various software packages (e.g. R, Matlab, @Risk, SIMETAR, etc.) and rely on a small set of assumptions about the decision-maker's utility function.[8] The last two are only available in SIMETAR to the best of our knowledge, rely on a larger set of assumptions and identify tipping points (i.e. thresholds) across a range of risk aversion coefficients.[9] Denoting the cumulative distribution functions (CDF) of the NPVs of the mānuka-only (MO) and mānuka-tōtara (MT) scenarios as *MO(π)* and *MT(π)*, respectively, then MO would dominate MT:

[6] ECFP payments have been assumed to take effect in three instalments: First 50% in t=0, an additional 30% in t=1, and the final 20% in t=5. The total undiscounted payment sums up to $1,500/ha.

[7] The simulations and stochastic dominance tests were performed with the Excel Add-in SIMETAR Richardson et al. 2008. The simulations were performed using the Latin Hypercube sampling method of McKay et al. (1979) and the Mersenne Twister random number generator Matsumotu & Nishimura (1998).

[8] FDD assumes that all decision makers are non-satiated (i.e. non-decreasing utility function) (Hadar J, Russell WR 1969. Rules for ordering uncertain prospects. The American Economic Review 59: 25–34). SDD additionally assumes that all decision makers are risk averse.

[9] SDRF ranks alternatives for decision makers whose utility functions are defined by lower and upper risk aversion coefficients (Meyer 1977). SERF relies on a utility function specification (Hardaker JB, Richardson JW, Lien G, Schumann KD 2004. Stochastic efficiency analysis with risk aversion bounds: a simplified approach. Australian Journal of Agricultural and Resource Economics 48: 253–270).

- By FDD if the CDF of the MO scenario is entirely to the right of the CDF of the MT scenario or $MO(\pi) - MT(\pi) \geq 0 \quad \forall\pi$
- By SDD if the CDF of both alternatives cross each other and the CDF of the MT scenario is a mean-preserving spread of the MO scenario or $\int_{-\infty}^{\pi}[MO(\pi) - MT(\pi)]\,d\pi \geq 0 \quad \forall\pi$
- By SDRF if the MO scenario is the dominant alternative for the two limiting cases represented by a lower (r_1) and upper (r_2) risk aversion coefficient or $\int_{r_1}^{r_2}[MO(\pi) - MT(\pi)]U'(\pi)d\pi \geq 0 \quad \forall\pi$
- By SERF if the certainty equivalent of the MO scenario (CE_{MO}) is higher than the one from the MT (CE_{MT}) scenario or $CE_{MO} > CE_{MT}$ evaluated at a specific risk aversion coefficient.[10]

The stochastic dominance tests were performed under various private discount rates. The latter was considered important as low discount rates could make long-rotation alternatives (e.g. tōtara) preferable than the obvious short-term alternatives. In this specific case involving a Māori community, low discount rates could be justified on the grounds that investments are made for the community's intergenerational benefit.[11] The theoretical grounds to justify low discount rates to assess investments affecting generations to come have been a topic of discussion among the most prominent economists in the world (Weitzman 1998; Arrow et al. 2013; Knoke et al. 2017). However, the purpose of the sensitivity analysis is more descriptive, rather than prescriptive, to show the interactions between uncertainty and discount rates.

[10] The certainty equivalent is the minimum fixed monetary payment that an individual would be willing to accept to be indifferent between forgoing or accepting an uncertain alternative.

[11] The structure of Māori businesses differs from conventional businesses (e.g. sole trader or company) as they involve large groups of stakeholders defined by family or tribal relationships.

(A) (B)

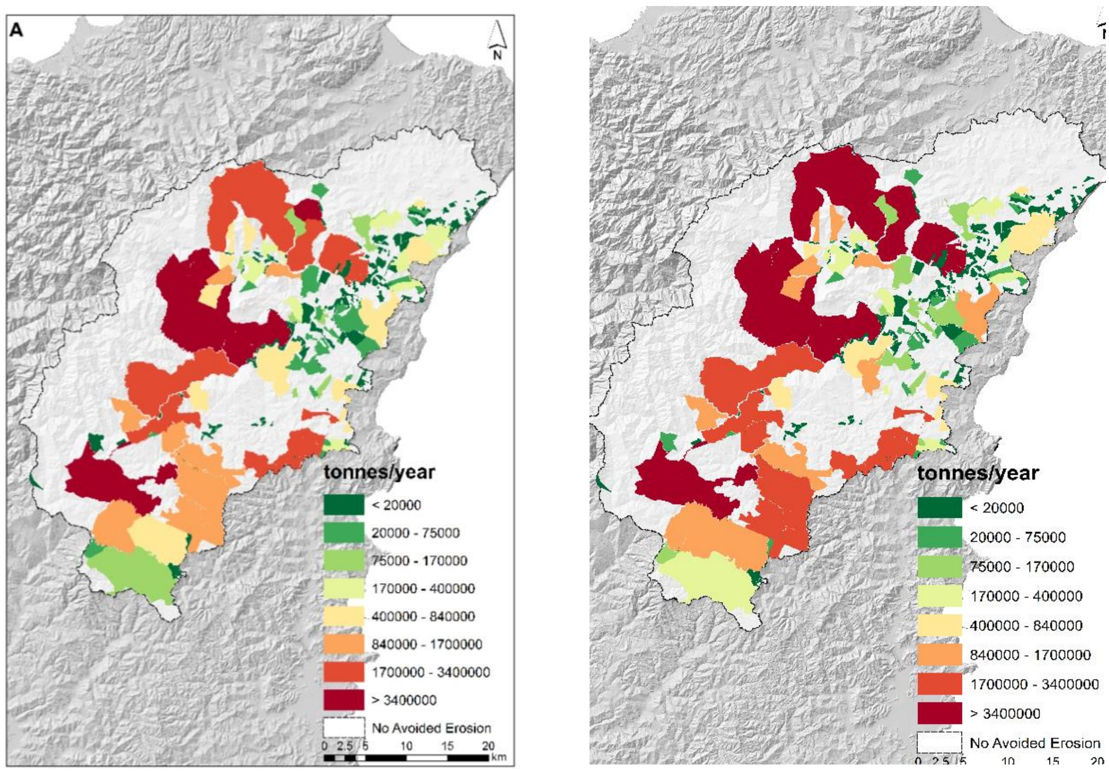

Figure 6: Total baseline erosion from sheep-beef parcels in the Waiapu catchment: (A) registered erosion in year 2015, and (B) forecasted erosion in year 2100 using the average of a suite of 6 global circulation models and 4 representative concentration pathways.

Probabilistic cost-benefit analysis of ECFP under uncertain climate change

Using the forecasted erosion estimates under uncertain climate change, a simple probabilistic cost-benefit analysis was developed to help policymakers determine the efficiency of the ECFP in reaching the expected public benefits under an uncertain future. Three erosion-reduction targets were determined: low, medium and high (e). The targets are listed in Table 12.

Table 12. Forecasted erosion, avoided erosion and afforestation under various erosion-reduction targets in the Waiapu Catchment for all land uses and sheep-beef farms (S-B) only

Erosion reduction targets	Erosion (million t/yr)		Avoided erosion (million t/yr)		Change from 2100 baseline (%)		Afforested S-B area (ha)
	All	S-B	All	S-B	All	S-B	
2015-Baseline	51.1	46.1	N/A	N/A	–30%	–30%	N/A
2100-Baseline	72.6	65.8	N/A	N/A	0%	0%	N/A
2100-Low	45.9	39.2	26.6	26.6	–40%	–37%	16,704
2100-Medium	35.7	28.9	36.8	36.8	–56%	–51%	27,699
2100-High	25.5	18.7	47.0	47.0	–71%	–65%	41,875

For this, NZFARM was used to evaluate the impact of imposing a wide range of erosion reduction targets. Since 90% of the total erosion in 2015 was from sheep-beef farms (i.e. ~46 million tonnes/year), NZFARM identified the optimal sheep and beef farming areas to afforest under 3 erosion reduction targets – low, medium and high. The three afforestation scenarios, and respective expected NPVs, were used as potential land use scenarios.

The following formulas were used to represent stochastic benefits, fixed ECFP payments and perform the probabilistic cost-benefit analysis. Since the ECFP is a fixed per-hectare payment, the total cost of achieving the various erosion-reduction goals was estimated with the second term of the right-hand side expression of the following formula. The value of the benefits (*pe*) were modelled as unitary annual benefits or $ per tonne of avoided erosion per year as shown in the first term of the right-hand side expression in the following formula:[12]

$$\widetilde{Benefit}_e - Cost_e = \left[\sum_{l}^{286}\sum_{t}^{89}\frac{\widetilde{\tau_{l,t}} * pe_{t,e}}{(1+j)^t} * ha_{l,e}\right] - \left[\sum_{l}^{286}\sum_{r\in t}\frac{ECFP_r}{(1+j)^r} * ha_{l,e}\right]$$

where *t* represents time for a forecasted horizon of 89 until year 2100, *l* represents the 286 sheep-beef parcels in the catchment, *e* the erosion-reduction scenarios, *Benefit* represents total benefits, *Cost* represents total public investment, τ is the avoided erosion (in tonnes/ha/yr), *j* the public discount rate of 2%, *pe* is the value attached to avoided erosion (in $/tonne/yr), and *ha* are the afforested hectares identified by NZFARM under various erosion-reduction goals. Since the avoided erosion parameter (τ) is uncertain, the variable *Benefit* is stochastic, while *Cost* is a deterministic parameter.

Avoided erosion (τ) was modelled as a fixed 90% reduction from the stochastic baseline erosion ($erosion^{s\&b}$) achieved through afforestation as suggested by Dymond et al. (2006) and Marden (2012) and as shown in the following formula:

$$\widetilde{\tau_{l,t}} = \widetilde{erosion}_{l,t}^{s\&b} * 0.90$$

Due to the stochastic nature of the benefits, the following formula shows a probabilistic representation of the cost-benefit analysis. The key output variable would be the probabilities of obtaining a benefit-cost ratio greater or equal to 1:

$$Prob\left(\widetilde{Benefit}_e \geq Cost_e\right) = Prob\left(\frac{\widetilde{Benefit}_e}{Cost_e} \geq 1\right)$$

The ultimate purpose of the probabilistic cost-benefit analysis is to identify the “threshold public benefit” or the public benefit that would need to be achieved to compensate the government’s investment in the ECFP (i.e. benefit-cost ratio greater than 1) under various levels of certainty considering uncertain avoided erosion under climate change. It is expected that such threshold benefit will need to be higher as the levels of certainty

[12] This was done to contrast the results from this study to other national or regional studies that have tried to tag a value to avoided erosion in New Zealand.

increase to compensate for the probabilities of underestimating (i.e. low-tail or downside uncertainty) avoided erosion. Hence, assuming that the discounted threshold benefits (in $/tonne) are represented by ρ for the different erosion-reduction scenarios *(e)*, the aim is to identify the levels of the threshold benefit that would result in high probabilities of obtaining a benefit-cost ratio higher or equal to 1:

$$\rho_e = \sum_{t}^{89} \frac{pe_{t,e}}{(1+j)^t}$$

$$\rho_e \overset{?}{\Rightarrow} Prob\left(\frac{Benefit_e}{Cost_e} > 1\right) = 50\%, 75\% \;\&\; 100\%$$

4 Results

The three afforestation scenarios along with the horticulture scenario are analysed in the following sections utilising a Kaupapa Māori assessment and Economic Modelling. The results from the Kaupapa Māori assessment are presented first.

4.1 Kaupapa Māori assessment

Indigenous forestry provides a diverse range of Kaupapa Māori benefits from recreational, economic and spiritual. Indigenous forestry also mitigates the impact from erosion and is a useful option for erosion treatment under the ECFP. Three indigenous tree species were identified as significant species for the community of the Waiapu catchment, namely mānuka, tōtara, and kawakawa. Three continuous-cover forest management scenarios were designed for this analysis by combining these tree species along with a number of high value horticultural scenarios. All scenarios started with mānuka, based on its potential to provide: (1) shelter for the establishment of tōtara and kawakawa; (2) early revenue from honey sales; (3) a thick canopy for rain interception; and (4) a solid rooting system for erosion reduction.

The kaupapa Māori assessment tool assessed the following afforestation scenarios primarily focused on afforestation:

- *Baseline* – refers to current land utilisation including agriculture (sheep and beef) and forestry (*pinus radiata*).
- *Mānuka* – chosen as a resilient crop suitable for growing conditions on the East Coast of New Zealand, providing revenues from the sale of honey.
- *Mānuka plus tōtara* – Mānuka was used as a nurse crop providing shelter to aid in the establishment of tōtara, using the latter as a long-term high-value alternative. Honey production from mānuka was assumed to stop due to shading as the canopy transitioned to tōtara.

- *Mānuka, tōtara, plus kawakawa* – Similar to the previous scenario, with the addition of kawakawa as a high-value understory crop. Kawakawa is of high cultural value and produces specialised products for use in pharmaceuticals.
- *Afforestation + Horticulture* – Similar to the previous scenario, with the addition of a Horticultural scenario that included land use options such as macadamia nuts, hemp, olives, and lemons.

We assessed each of the afforestation scenarios for the Māori land blocks that participated in the project. The rankings for each attribute are as follows:

Pōhara	Āhua Pai	Pai	Pai Rawa

Pseudonyms are used here to maintain confidentiality. We have named each Māori land block as follows: Ahikouka, Tapuaeroa, and Tikapa. Each Māori land block has unique characteristics. For example, Ahikouka is classed as LUC 7, suitable for forestry; Tapuaeroa is a majority of LUC 7 with a small proportion of land suitable for horticulture on the river valley (LUC 2); Tikapa is a coastal block with an equal mix of river valley land suitable for cropping and horticulture (LUC 1), land with moderate limitations for horticulture but suitable for cultivated crops, pasture or forestry (LUC 3) and land with some limitations more suitable for forestry (LUC6 and 7). Figures 7–9 below provide a visual representation of our assessment. No assessments were carried out for Wāhi Tapu/Taonga (significant sites) due to a lack of data.

	Criteria	Baseline	Mānuka	Mānuka + Tōtara	Mānuka + Tōtara + Kawakawa	Afforestation +Horticulture
Kaitiakitanga	Mahinga Kai	1	3	3	3	4
	Ngā Wai Tipuna	1	2	3	3	3
	Wāhi Tapu/Taonga		2	3	4	4
	Ngā Otaota Māori	2	3	4	4	4
Manaakitanga	Whanaungatanga	3	4	4	4	4
	Akoranga	1	3	3	4	4
	Kia Mahi Ngātahi	2	3	3	4	4
Whakatipu Rawa	Mana Taurite	1	4	4	4	4
	Labour FTEs	2	3	3	3	4
	Whakapūmautanga	2	4	4	4	4

Figure 7: Kaupapa Māori assessment for Ahikouka.

Criteria		Baseline	Mānuka	Mānuka + Tōtara	Mānuka + Tōtara + Kawakawa	Afforestation +Horticulture
Kaitiakitanga	Mahinga/ Kai	2	3	4	4	4
	Ngā Wai Tipuna	1	3	3	3	3
	Wāhi Tapu/Taonga		3	4	4	4
	Ngā Otaota Māori	2	3	4	4	4
Manaakitanga	Whanaungatanga	1	3	4	4	4
	Akoranga	1	3	4	4	4
	Kia Mahi Ngātahi	1	3	3	3	4
Whakatipu Rawa	Mana Taurite	2	3	4	4	4
	Labour FTEs	1	3	3	4	4
	Whakapūmautanga	1	3	4	4	4

Figure 8: Kaupapa Māori assessment for Tapuaeroa.

Criteria		Baseline	Mānuka	Mānuka + Tōtara	Mānuka + Tōtara + Kawakawa	Afforestation +Horticulture
Kaitiakitanga	Mahinga/Maara Kai	2	3	4	4	4
	Ngā Wai Tipuna	2	3	3	3	3
	Wāhi Tapu/Taonga		3	4	4	4
	Ngā Otaota Māori	2	3	4	4	4
Manaakitanga	Whanaungatanga	1	3	4	4	4
	Akoranga	1	3	4	4	4
	Kia Mahi Ngātahi	1	3	3	3	4
Whakatipu Rawa	Mana Taurite	1	3	4	4	4
	Labour FTEs	1	3	3	3	4
	Whakapūmautanga	1	3	4	4	4

Figure 9: Kaupapa Māori assessment for Tikapa.

Ahikouka Assessment

At the low range was the Baseline afforestation scenario. We assessed the benefits from the current land use activity as being relatively low: 4/12 for Kaitiakitanga; 6/12 for Manaakitanga; and 5/12 for Whakatipu Rawa. At the mid-range is the mānuka only afforestation scenario: 10/16 for Kaitiakitanga; 9/12 for Manaakitanga; and 9/12 for Whakatipu Rawa). At the high end is the Afforestation + Horticulture scenario: 15/16 for Kaitiakitanga; 12/12 for Manaakitanga; and 12/12 for Whakatipu Rawa).

Tapuaeroa Assessment

At the low range was the Baseline scenario. We assessed the benefits from the current land use activity as being relatively low: 5/12 for Kaitiakitanga; 3/12 for Manaakitanga; and 4/12 for Whakatipu Rawa. At the mid-range is the mānuka only afforestation scenario: 12/16 for Kaitiakitanga; 9/12 for Manaakitanga; and 9/12 for Whakatipu Rawa. At the high end is the Afforestation + Horticulture scenario: 15/16 for Kaitiakitanga; 12/12 for Manaakitanga; and 12/12 for Whakatipu Rawa.

Tikapa Assessment

At the low range was the Baseline scenario. We assessed the benefits from the current land use activity as being relatively low: 4/12 for Kaitiakitanga; 3/12 for Manaakitanga; and 3/12 for Whakatipu Rawa. At the mid-range is the mānuka only afforestation scenario: 12/16 for Kaitiakitanga; 9/12 for Manaakitanga; and 9/12 for Whakatipu Rawa. At the high end is the Afforestation + Horticulture scenario: 12/16 for Kaitiakitanga; 12/12 for Manaakitanga; and 12/12 for Whakatipu Rawa.

Overall Assessment

We found that there were marked improvements in Kaitiakitanga (sustainable resource management) on the three land blocks with afforestation scenarios that include podocarps like tōtara. This was due to the long-term, intergenerational yields of these species. In comparison to the baseline scenario (sheep and beef farming), afforesting parts of the farm was less likely to impact negatively on Māori values as there was reduced sediment run-off into waterways. Afforestation results in an improved habitat for taonga species like tuna (eels) and īnanga (whitebait). Furthermore, planting riparian zones with indigenous vegetation provides opportunities for beneficiaries to access sites for rongoā (medicines) and mahinga kai (food-gathering). Access by tangata kaitiaki (sustainable resource managers) to these potential sites (mahinga kai and mahinga rongoā) would need to be managed to minimise the impact on current land use.

In terms of Manaakitanga (reciprocal obligations), the afforestation scenarios provide relatively more opportunities to improve connections between the farm, farm beneficiaries, and the local community than with existing land use. These opportunities can be realised through initiatives such as open days with beneficiaries, and visits by the local kura kaupapa schools and tertiary training institutions to learn more about indigenous forestry practices.

In terms of Whakatipu Rawa (growing the asset base), the benefits from investing in options, i.e. afforestation scenarios, that reduce erosion bodes well for future generations. The long-term benefits of improved water quality and enhanced terrestrial ecosystems through riparian planting and management along with the reduced erosion are more likely to be realised by future generations. Investment in afforestation would also provide the opportunity to grow the capability of younger workforce participants through for example cadetships, leading to enhanced intergenerational investment. Afforestation plus horticulture yielded the largest benefits for Whakatipu Rawa out of all the afforestation/horticulture scenarios for each of the three land blocks assessed.

4.2 Climate change modelling

4.2.1 Spatial optimisation and forecasted uncertain erosion under climate change

The Waiapu catchment has a land area of approximately 158,000 hectares, comprised mainly of sheep-beef farming (54%), plantation forestry (25%), and native bush (19%). The modelled baseline estimate of total net revenue is $20.4 million/yr, which equates to about $126/ha/yr. The majority of income is earned from plantation forestry (83%), followed by sheep-beef (11%) and horticulture and arable cropping (5%). The 2015 baseline soil erosion is estimated to be 51.1 million tonnes/yr, or 316 tonnes/ha/yr, which is one of the highest average erosion rates in New Zealand (Cumberland et al. 1980). The 2100 baseline erosion under climate change for all farms is estimated to be 72.6 million tonnes/yr, of which more than 90% is estimated to be sourced from sheep-beef farms, i.e. 65.8 million tonnes/yr (see Figs 10 and 11).

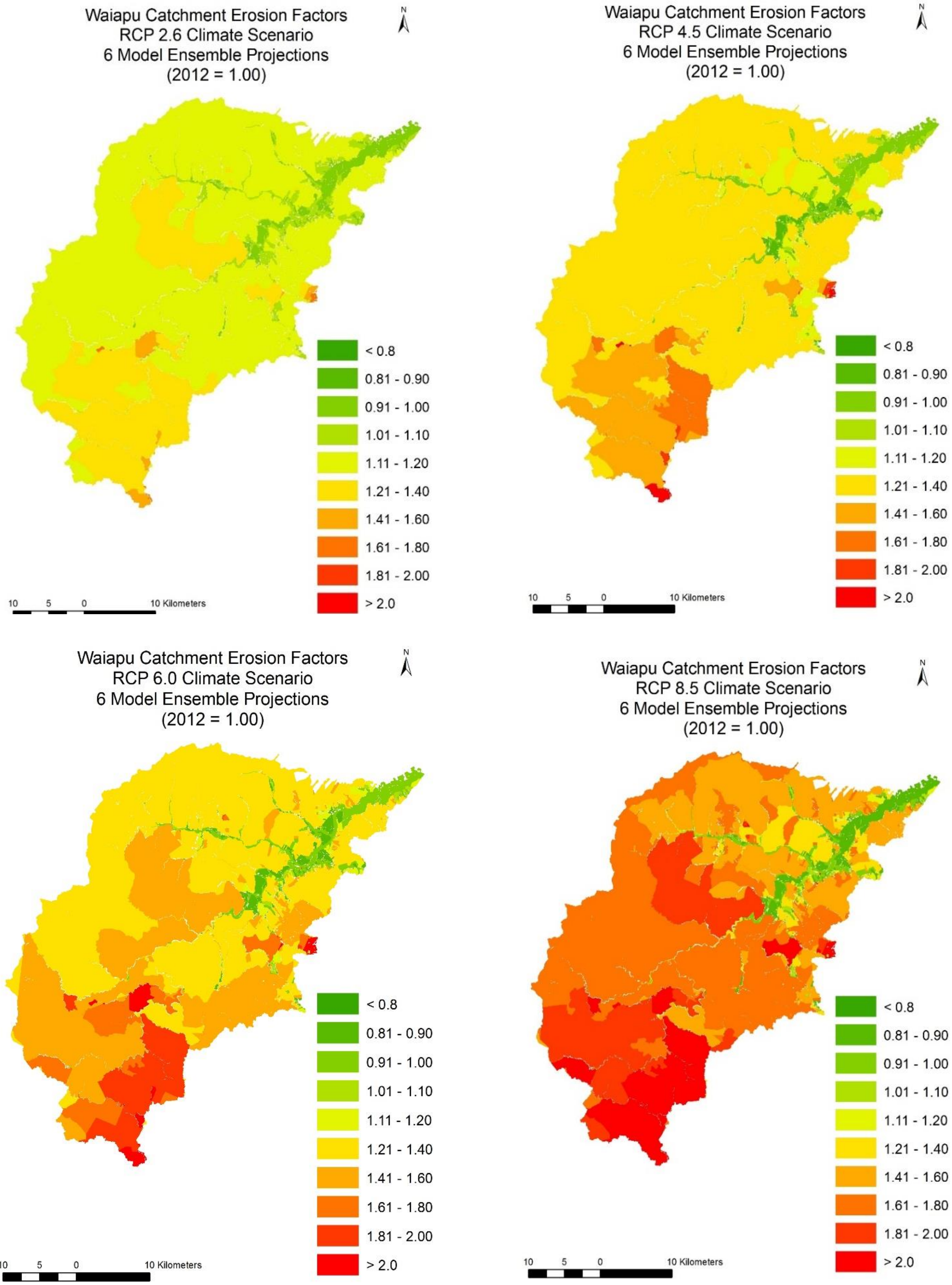

Figure 10: Total soil erosion from baseline by land use (model ensemble estimates) – spatial.

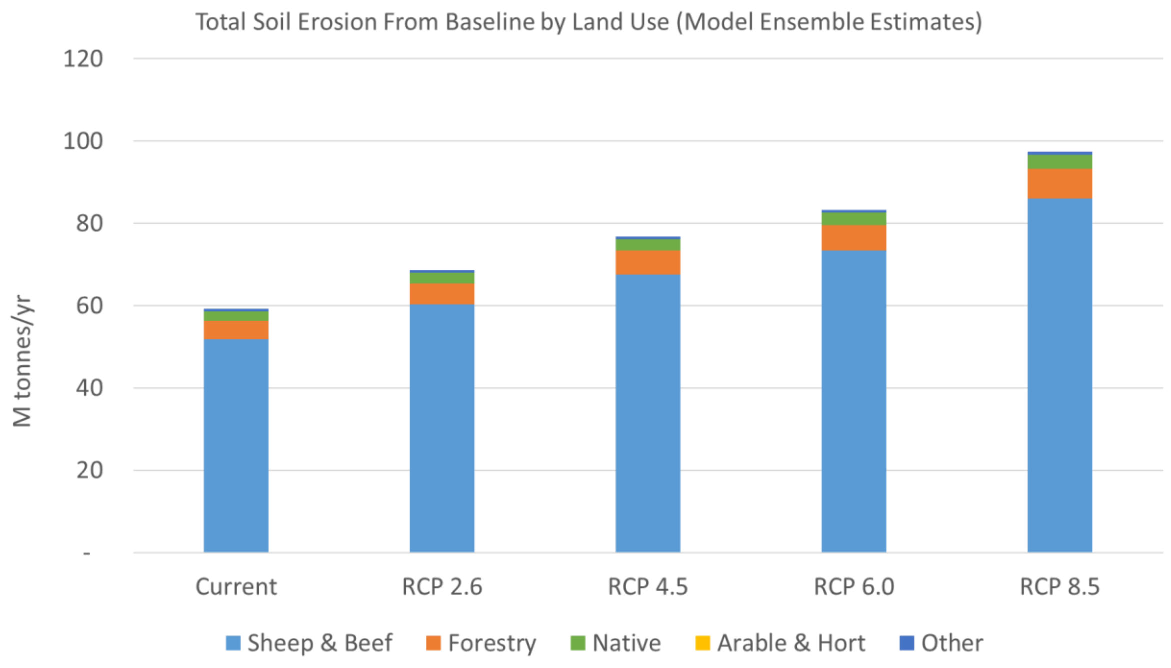

Figure 11: Total soil erosion from baseline by land use (model ensemble estimates) – tabular.

Climate change could potentially increase the erosion risk for the Waiapu catchment. Forestry would help mitigate the risk from erosion. The Waiapu catchment is approx. 158,000 ha and the area suitable for forestry (Landuse Classes 3–8) is 145,365 ha or 92% of the catchment. Figure 12 below identifies the areas where forestry is the most suitable option The Erosion Susceptibility Classification (ESC) system divides the New Zealand landscape into 4 erosion categories that are colour-coded according to risk (MPI, 2017c).

- **Green (low) and yellow (moderate)** — land less likely to erode. Plantation forestry activities are permitted.
- **Orange (high risk) or red (very high risk)** — land more likely to erode. Most forestry activities can't be carried out on red-zoned land without resource consent. Some activities, such as earthworks also require consent on orange-zoned land with steeper slopes.

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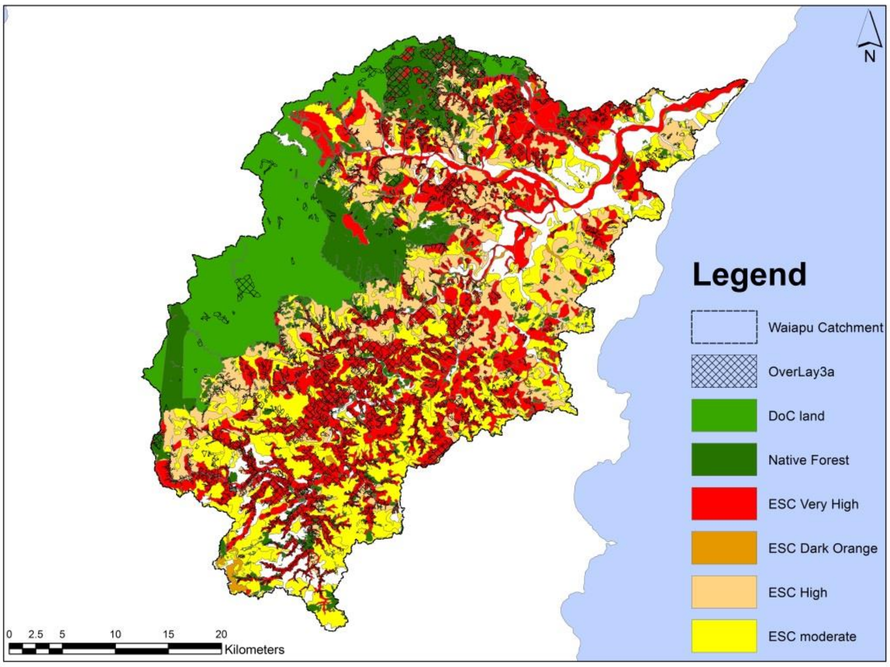
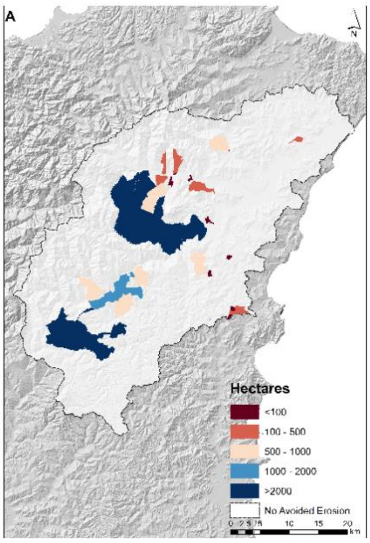
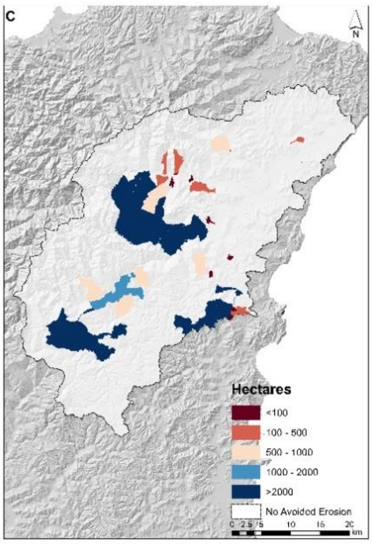
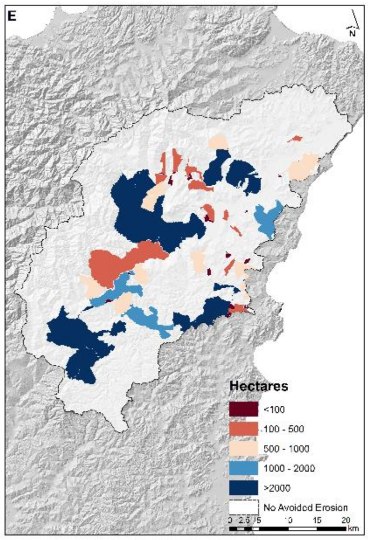


Figure 12: Areas suitable for forestry in the Waiapu catchment.

Forecasted erosion and avoided erosion for each erosion reduction target are listed in Table 12. Notice that avoided erosion for the catchment only happens in sheep-beef farms due to afforestation. The total afforested areas in sheep-beef farms are listed in the last column of Table 12 (see p. 27). Notice that the afforested area increases as the reduction target increases. The spatial location of such afforested areas is shown in Figure 13.



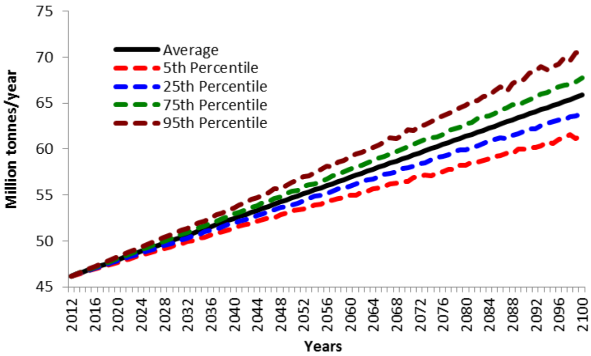




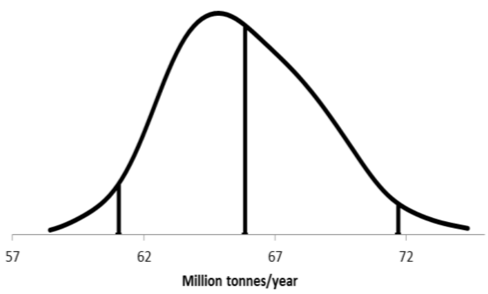
(A) **(B)** **(C)**

Figure 13: Afforested areas of each parcel needed to reach various erosion-reduction targets identified with NZFARM: (A) low, (B) medium, and (C) high.

As previously mentioned, to model uncertainty about the deterministic erosion forecasts listed in Table 12 we assumed a linear increment in mean forecasted erosion and an expanding uncertainty across time for the 286 sheep-beef farms (refer to Appendix 2 for a more detailed formula on how the linear increment was estimated). The summation of such forecast with its respective uncertainty is shown in Figure 14(A). The expanding uncertainty was based on an empirical distribution fitted with erosion forecasts for all 286 sheep-beef farms for year 2100. Figure 14(B) shows a graphical approximation of the empirical distribution of total forecasted erosion in year 2100 generated by summing the 21 forecasts for all sheep-beef farms.



(A)



(B)

Figure 14: Uncertainty about forecasted total erosion in sheep-beef farms in the Waiapu catchment under climate change: (A) through time and (B) in year 2100.

4.2.2 Stochastic dominance analysis

Table 13 lists the average NPVs and respective standard deviations for the three afforestation scenarios. The highest expected NPV is for mānuka-only (MO), due to the early revenues from honey sales, followed by mānuka-tōtara (MT) and mānuka-tōtara-kawakawa (MTK). The most uncertain alternative is MTK followed by MT and MO (last column of Table 13). The standard deviations have been generated under various sources of uncertainty to identify the most relevant source for each scenario. Market uncertainty (i.e. product prices) is the most prevalent one for MTK whereas policy uncertainty (i.e. NZU price through NZ ETS) is the most relevant one for MO and MT.

Table 13: Average NPVs and standard deviations for the three afforestation scenarios ($/ha)

Afforestation scenarios	Average	Std dev. under various uncertainty sources (uncertain parameter)			
		Market (product prices)	Policy (carbon price)	Ecosys. service (carbon seq.)	All combined
MO	11,521	103	430	22	445
MT	–15,076	139	430	22	461
MTK	–120,844	11,304	429	35	11,276

Figure 15 shows the Cumulative Distribution Functions (CDFs) of the afforestation scenarios under various discount rates. There are three important aspects to note about the CDFs from the graphs: (1) the width (i.e. uncertainty); (2) the position relative to the vertical axis cutting the horizontal one through 0; and (3) the position relative to the other CDFs. For example, the MTK scenario is the most uncertain one followed by MT and MO as previously identified. The uncertainty of the various scenarios also increases as the discount rate decreases, which is expected since one of the sources of uncertainty are product prices, which in some cases would be received far in the future, being discounted less. Such discounted uncertainty effect is more evident in Figure 15D for MTK.

The position relative to the vertical axis reflects profitability as the vertical axis represents an NPV=0. Hence, the MO scenario is always to the right of the vertical axis meaning that its NPV is greater than 0 in all three scenarios. The MT and MTK scenarios become profitable under a discount rate of 1%. The probabilities of an NPV lower than 0 can also be identified by looking at the level at which the CDF cuts the vertical axis. Hence, the probabilities of an NPV lower than 0 for MTK and MT are quite low under a 1% discount rate.

Regarding the relative position of each CDF, the MO scenario is the preferred one by FDD since it is the one positioned farthest to the right in the first two cases – 5% and 3% discount rates in Figure 15A and B, respectively. The CDFs under a 1% discount rate cannot be ranked by FDD nor by SDD since they cross each other, and they are not mean-preserving spreads of one another, respectively. Hence, SDRF and SERF were used to rank them.

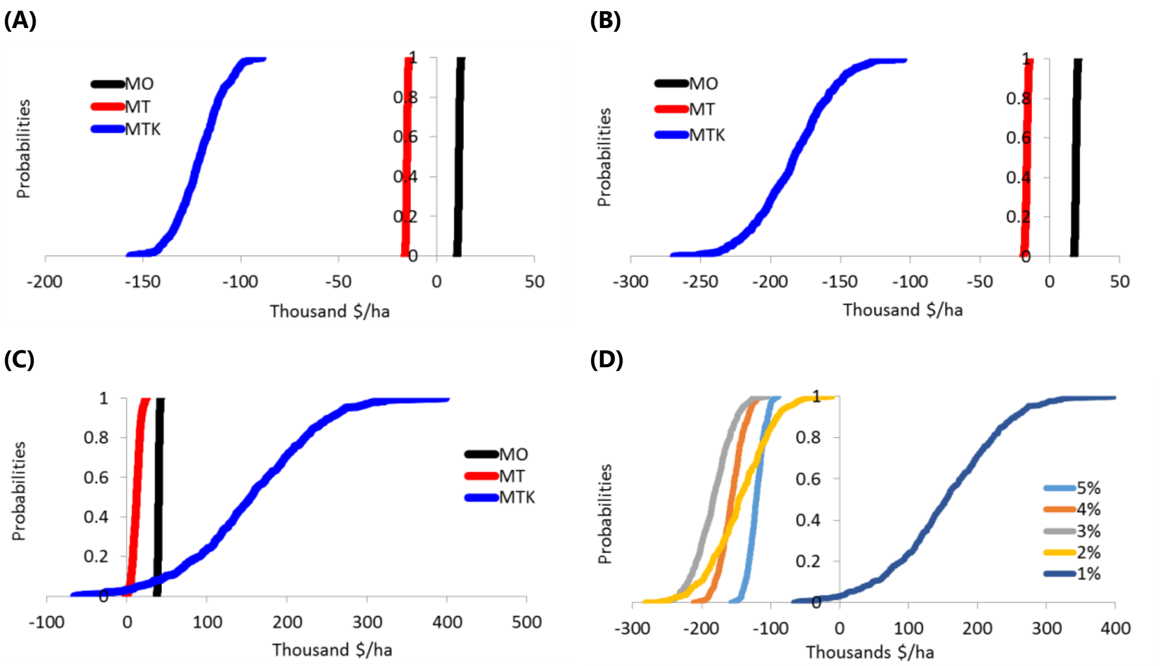


Figure 15: Cumulative distributions functions of the net present values of the following afforestation scenarios: (A) all under a 5% discount rate, (B) all under a 3% discount rate, (C) all under a 1% discount rate, and (D) the mtk scenario under various discount rates.

The rankings change when using SERF and two extreme risk aversion coefficients representing a risk-neutral landowner (r_1=0) and an extremely risk-averse landowner (r_2). The rankings are the following ones under the two extremes:

- Risk-neutral landowner: MTK > MO > MT;
- Extremely risk-averse landowner: MO ~ MT ~ MTK or indifferent among the three scenarios.

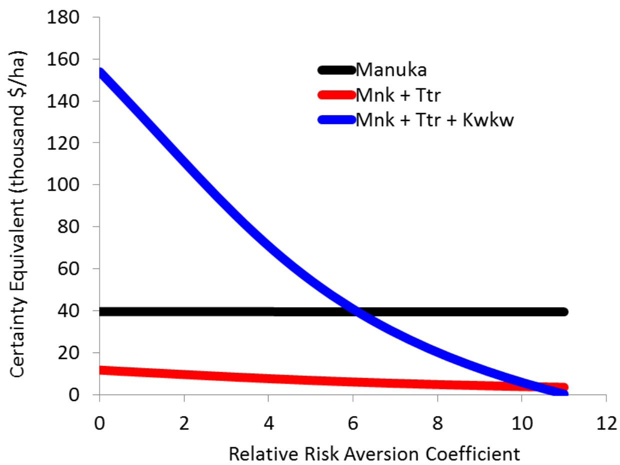


Figure 16: Stochastic efficiency with respect to a function under a negative exponential function for the net present value of three different afforestation scenarios and a 1% discount rate.

SERF was used to graphically identify the risk-aversion coefficient at which the rankings change. Assuming a negative exponential function, the landowner would have to be exaggeratedly risk averse to prefer the MO and MT scenarios over the MTK one as shown in Figure 16.[13] According to the risk-aversion range developed by Anderson et al. (1992), an individual with a relative risk-aversion coefficient of 4 is considered highly risk averse. As depicted in Figure 16, the landowner would have to be extremely risk averse (i.e. relative risk-aversion coefficient of 6) to prefer MO over MTK. The certainty equivalent of the MTK scenario drops quite drastically across the risk-aversion range considered due to its high uncertainty. At relative risk-aversion coefficients lower than 6, the risk premium that would have to be paid to the landowner to choose the MO over the MTK scenario would be the vertical difference between the MO's and the MTK's certainty equivalent lines. Hence, as the landowner type leans more towards risk neutrality (i.e. towards the left of the horizontal axis), the higher such risk premium must be (~ $110 thousand/ha).

4.2.3 Probabilistic cost-benefit analysis

Table 14 shows the total afforested areas by scenario with respective total ECFP payments. The discounted ECFP payment was approximately $1,463 per hectare. Figure 17 shows the CDF of the stochastic benefits under the low erosion-reduction scenario contrasted with the total ECFP payments paid to the approximately ~17,000 afforested hectares in the catchment. It is important to notice the area under the CDF and to the left of the ECFP reference is almost half of the area under the CDF, meaning there is a ~50% chance that the ECFP will not reach the benefits desired due to climate change uncertainty, i.e. the benefit-cost ratio will be lower than 1.

Table 14: Total afforested areas and ECFP payments by erosion reduction scenario

Reduction scenarios	ECFP payments ($/ha)		Afforested area (ha)	Total ECFP payments ($)
	Undiscounted	Discounted*		
2100–Baseline	1,500	1,463	0	0
2100–Low	1,500	1,463	16,704	24,436,176
2100–Medium	1,500	1,463	27,699	40,520,779
2100–High	1,500	1,463	41,875	61,259,442

*Discounted at a public discount rate of 2%

[13] According to Hardaker BJ 2006. Farm risk management: past, present and prospects. Journal of Farm Management 12: 593–612, a utility function assuming constant relative risk aversion (e.g. power function) is more appropriate when wealth accumulation across time is a critical factor. However, wealth accumulation is not critical in this study since the cash flow approach used only considers annual surpluses (or losses). Hence, the negative exponential utility function assuming constant absolute risk aversion is good enough for the objectives sought.

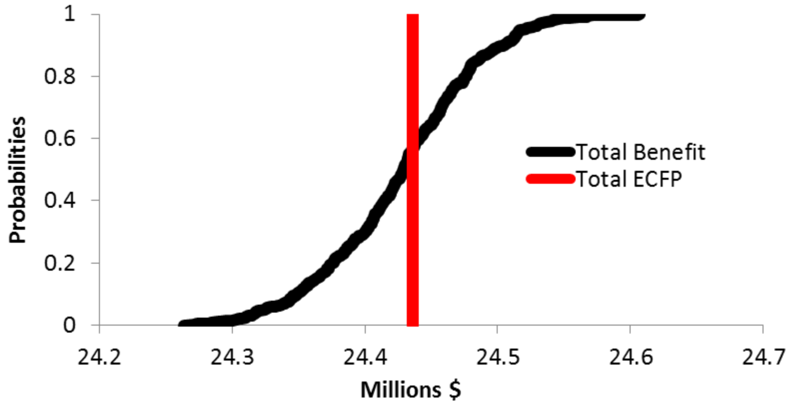


Figure 17: Cumulative distribution function of the discounted public benefits obtained from a low erosion-reduction scenario and respective ECFP investment (i.e. cost).

Hence, to increase the chances (i.e. probabilities) of obtaining a benefit-cost ratio greater or equal to 1, the total benefits would need to be much greater than the benefits ECFP is paying. A key question is what would be the benefits that achieve greater odds (i.e. higher certainty) when the benefit-cost ratio is greater or equal to 1?

Figure 18 shows the average discounted benefits (unitary and total) necessary to obtain a benefit-cost ratio greater or equal to 1 with various certainty levels for the different reduction scenarios. From a deterministic perspective, Figure 18(D) shows that average unitary benefits would need to be approximately $1.14, $1.37, and $1.60/tonne of erosion to compensate ECFP investment half of the time (i.e. 50% certainty) for the low, medium and high reduction scenarios, respectively. However, to be almost 100% certain that the benefits would compensate the ECFP investment, such unitary benefits would need to increase to $1.15, $1.38, and $1.61/tonne for the low, medium and high reduction scenarios, respectively. This implies that total benefits would need to increase by approximately $0.2, $0.3, and $0.4 million, to almost certainly compensate total ECFP investment for the low, medium and high reduction scenarios, respectively.[14]

[14] Estimated with the difference between total ECFP payments and the value that achieves 100% certainty on the second vertical axis in the various graphs.

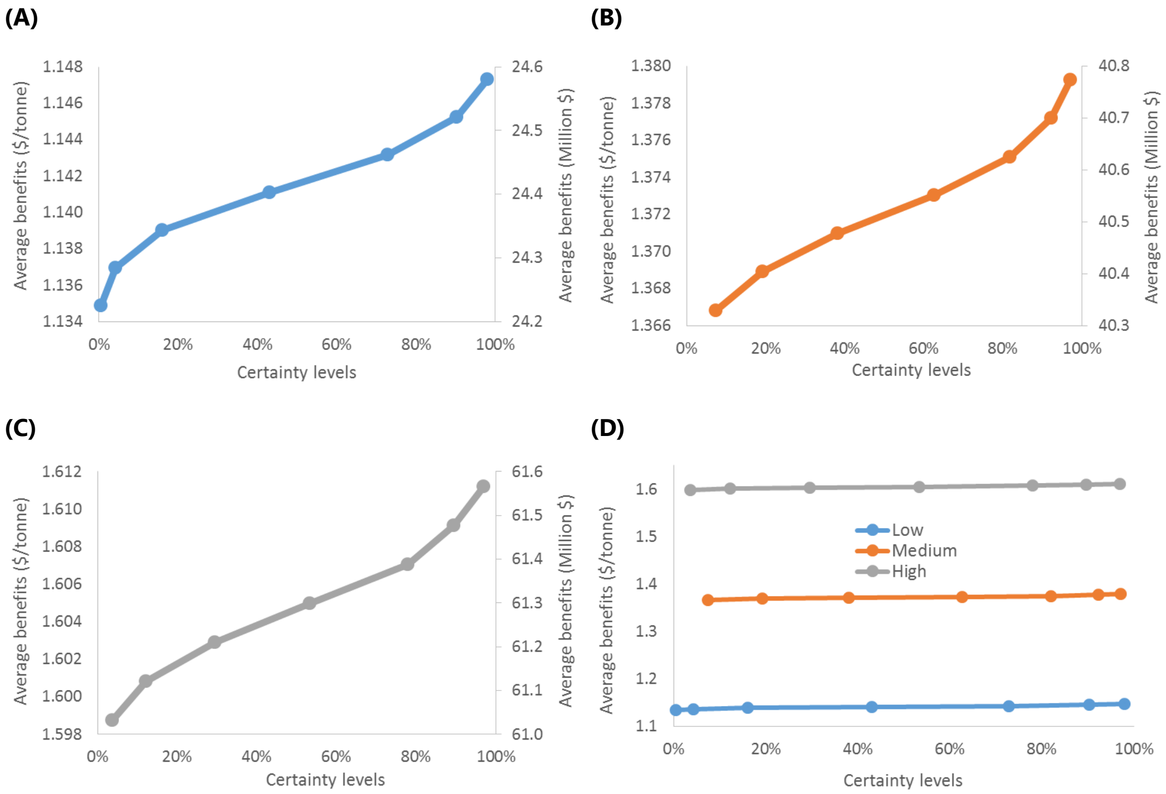


Figure 18: The expected benefits from avoided erosion necessary to compensate ECFP investment with various certainty levels under climate change uncertainty for the following scenarios: (A) low, (B) medium, (C) high, (D) all.

The estimation of benefits from avoided erosion can be performed in multiple ways, from non-market valuation approaches to estimating the avoided investment in expensive technologies (e.g. water treatment). An example of the former is the study by Rivas Palma (2008), who estimated the benefit of avoiding erosion by forests at $105/ha/yr for the Hawke's Bay region in New Zealand; however, this is not directly comparable with the results obtained in this study. An example of the estimation of benefits from avoided costs is provided in Dymond et al. (2012), who performed a national assessment using both the total cost estimated in Krausse et al. (2001) and the annual estimate of eroded soil by Dymond et al. (2010) to arrive at a cost of $1/tonne, which is more in line with the results obtained in this study.

4.2.4 Key findings

We used NZFARM as a deterministic economic optimisation model to estimate the potential impact of climate change on erosion and to spatially identify the optimal areas to be afforested to achieve various erosion-reduction goals. Using 24 climate projections that vary by GCM and RCP, we estimated that if current land use practices continue, mean aggregate erosion could increase by 41% by the end of the century. These potential impacts, coupled with an already extremely high erosion rate, have driven national and local agencies to consider policy options and incentives to reduce erosion and their impacts to the economy and ecosystem, namely afforestation programmes. As a result, we estimated the area of existing sheep-beef pasture land that would have to be afforested to achieve various erosion-reduction levels in the catchment. Our analysis found that between 16,700 and 41,900 hectares of pasture would have to be afforested to achieve various erosion reduction targets, i.e. equivalent to 19–48% of the current area of sheep-beef farms in the catchment.

Due to the deterministic nature of NZFARM, we used Monte Carlo procedures as a complement to simulate the uncertainty stemming from various sources, namely market, policy, ecosystem service generation and climate change. Due to the lack of detailed historical or forecasted time-series data, we used simple and practical functions (i.e. triangular and empirical) that can be implemented in various software packages or programming languages. The triangular distribution was used to simulate the uncertainty around the profitability of various afforestation scenarios based on native tree species. The empirical distribution was used to add uncertainty around the expected erosion projections developed by NZEEM and NZFARM using the 24 climate projections for 286 sheep-beef farms in the catchment.

We used simple and widely accepted stochastic dominance tests to help landowners assess the implications of uncertainty on the profitability of afforestation scenarios under various plausible discount rates. The mānuka-only scenario provided the highest return under high discount rates due to the early revenues from honey sales and was particularly appealing for risk-averse landowners. The mānuka-tōtara-kawakawa scenario, having the most uncertain profitability, became the preferred alternative only under a very low discount rate of 1%. The relatively high revenues obtained far in the future are disadvantaged with higher discount rates. The uncertainty from such scenarios also increased as the discount rate decreased, reflecting the trade-off between profitability and uncertainty. Such a scenario could be plausible on the East Coast due to the predominant Māori presence, iwi/hapū values like kaitiakitanga, manaakitanga, and whakatipu rawa reflect intergenerational aspirations and collective business structures based on family or tribal kinship.

The simple probabilistic cost-benefit analysis was developed by combining the optimal afforestation areas identified by NZFARM with the probabilistic erosion forecasts. We initially identified that the expected benefits from avoided erosion would need to increase as the erosion-reduction levels increased. We also identified that for each reduction level the benefits would have to increase even further to lower the chances of underinvesting in ECFP (i.e. increase the chances of a benefit-cost ratio greater or equal to 1). ECFP is unlikely to achieve the expected benefits as climatic uncertainty negatively impacts the flow of benefits. This may incentivise the Ministry for Primary Industries (MPI) and the Gisborne District Council (GDC) to re-evaluate the benefits (e.g. economic, social, environmental, etc.) from the programme in light of our estimated effects of climate change.

5 Limitations of the study

The limitations of our assessment of investment opportunities for the Waiapu catchment under climate change are:

- *Erosion rates*: Results from the climate change modelling require expert assessment and validation in terms of the practical application of the modelling results.
- *Land use*: Land use data, while generally accurate at the catchment level, was not sufficiently refined for smaller scales. For instance, exotic forest was sometimes classified as indigenous forest, and vice versa. Therefore, the land use data for farm and block scale has to be refined with input from landowners and stakeholders.
- *Lack of productivity data*: The economic modelling was unable to incorporate any productivity effects of climate change on the tree/crop species included in the modelling. The assessment initially considered using radiata pine data as a surrogate for indigenous forest species but, due to the high variability in indigenous tree species and their responses to climate change compared to pine, we decided the pine results are not likely to be representative for indigenous forest. Future research ought to investigate the impacts of climate change on the productivity of indigenous tree species, particularly those species with economic and kaupapa Māori potential.
- *Mean annualised returns*: While the NPVs for the land use options on the flatter areas suggest that the crops are profitable, there is an establishment period for some crops, like apples and olives. This means, in the short term, there will be an initial financial burden for investors.

6 Recommendations

Some governance recommendations for the Waiapu catchment are:

6.1 Governance implications

- The current project has identified the potential options for mitigating erosion susceptibility due to climate change that can be implemented by Waiapu Kōkā Huhua – Waiapu Catchment Restoration Programme (WCRP). Furthermore, the findings of the current study support the approach of Waiapu Kōkā Huhua. Waiapu Kōkā Huhua's approach considers the socio-economic benefits, particularly improvement in the health of the awa (river), which will lead to improvements in the health of the whenua and its people. Additionally, the findings from the study were received by the governance group for Waiapu Kōkā Huhua – Waiapu Catchment Restoration Programme (WCRP) in October 2017. We are confident the outcomes from the Climate Resilient Māori Land project will be considered in future decision-making in the catchment.
- The wānanga with Māori landowners raised the issue of continuity in support for mitigation strategies that control erosion within the Waiapu catchment. Greater benefits for the Waiapu catchment could be achieved through greater coordination in the implementation of erosion management and mitigation actions, for example, between ECFP and Waiapu Kōkā Huhua.

6.2 Policy implications

- For all future climate change scenarios, investing in afforestation results in a significant reduction in soil erosion for the Waiapu catchment. Therefore, we recommend that policies and processes are developed by governance and policy institutions in Te Tairāwhiti to support further afforestation in the Waiapu catchment.
- The simple, probabilistic cost-benefit analysis was developed by combining the optimal afforestation areas identified by NZFARM with the probabilistic erosion forecasts. We identified, first, that the expected benefits from avoided erosion would need to increase as the erosion-reduction levels increase. We also identified that for each reduction level, the benefits would have to increase even further to lower the chances of underinvesting in ECFP (i.e. increase the chances of a benefit-cost ratio greater or equal to 1). We recommend the Ministry for Primary Industries and the Gisborne District Council, re-evaluate the likely benefits for the Waiapu catchment of the ECFP (as it is currently designed) so that it incorporates the impacts of climate change.
- Long-term support for climate mitigation approaches by the government is required for long-term investment in carbon sequestration by land owners. Waiapu Kōkā Huhua provides the basis for negotiating a long-term solution for carbon sequestration investment in the Waiapu catchment. It is possible that the current government's initiative for planting 1 billion trees in 10 years could be aligned with the outcomes for Waiapu Kōkā Huhua. MPI is providing incentives for planting, for

example, through their grant programmes. With the end of the Erosion Control Funding Programme, we recommend that a successive programme is implemented to ensure Crown accountability to the vision of the Waiapu Accord.

- The results from the study were well-received, with participants confirming that the proposed mitigation approaches to climate change (afforestation scenarios) are consistent with their aspirations for long-term investment in afforestation. Continued support by local and central government on several issues (e.g. governance training for Māori Land institutions, capability development for local entrepreneurs/Māori landowners, and entrepreneurial efficacy for local entrepreneurs/Māori landowners) is required for successful implementation of climate mitigation approaches through afforestation.

6.3 Implications for Māori landowners

- There are significant governance issues for Māori land in the catchment that provide barriers to the implementation of the afforestation scenarios for climate change mitigation. We recommend further investment in the implementation of government policy that supports capability development of Māori institutions governing Māori land, for example, governance training.
- To realise investment opportunities, people require essential skills in forestry, governance, entrepreneurship, finance, and leadership; e.g. there is a need for indigenous tree-planting specialists, i.e. beyond willow and poplars. We recommend further investment to develop the capability of whanau/hapū/iwi as local champions, providing them with the necessary policy and enterprise assistance to invest in opportunities such as afforestation to help mitigate and adapt to climate change.
- There are challenges in getting all owners and trustees from a Māori land institution present to discuss options for the improvement of Māori land development; therefore, projects and programmes supporting land development rely on local champions to develop capability. We recommend identifying local champions and providing them with necessary policy and enterprise assistance to realise investment opportunities for mitigating climate change.

6.4 Methodological implications

Some recommendations on approaches for working with Māori to address climate issues include:

- Economic assessments like NPVs provide useful information for identifying land use options. However, we recommend that Kaupapa Māori assessments ought to run alongside economic modelling to provide a fuller representation of aspirations and values from a Kaupapa Māori position. NPVs for most afforestation scenarios, excluding mānuka only, are negative, which highlights the potential long-term and inter-generational benefits from indigenous afforestation. This raises issues for inter-generational equity and requires socialisation with land-owners. Furthermore, the case for payments for ecosystem services such as erosion control and carbon sequestration is likely to increase the cash flow.

- No assessments were carried out for wāhi tapu/taonga (significant sites) due to a lack of data. Future Kaupapa Māori assessments ought to include an assessment of wāhi tapu/taonga; however, this requires knowledge of wāhi tapu/taonga by local people. We recommend that when there are knowledge gaps, wānanga are required to rediscover and share this knowledge.
- Ecosystem-based catchment restoration activities are required for the prosperity of the catchment and will not only increase the resilience of the catchment to climate change but enhance Māori values in the catchment. For instance, in areas prone to erosion the restoration of indigenous forest may reduce erosion risk and mitigate coastal sediment deposition as well as enhance other values important to Māori such as mahinga kai, taonga species, site access, water quality and quantity, metaphysical values and the connection between mana whenua and their natural environments. We recommend that assessments of the benefits from erosion control practices (e.g. afforestation) ought to consider both an ecosystem services evaluation and a Kaupapa Māori assessment to provide a more holistic and robust assessment of potential benefits.
- Previous studies have estimated that the national toll from erosion and sedimentation is approximately $1/tonne (Dymond et al. 2012). According to our results, if the government relied on such national estimates as the unitary benefits from avoiding further erosion, the ECFP investment would not be worthwhile in the Waiapu catchment – not even under our low reduction scenario. However, due to the unique characteristics of the catchment, a study should be performed to properly measure the benefits expected from avoiding erosion. We recommend that such a study should include climate change projections to account for the possibility of public underinvestment. The study should not only consider the proximate benefits such as avoiding investments in expensive technologies, among others, but also the social impacts both on the community and on the various ecosystems that are affected by erosion and sedimentation (e.g. freshwater and marine ecosystems). Estimating the benefits in the catchment under climate change uncertainty not only supports investments to achieve specific erosion reduction targets but also supports identifying more beneficial investments.
- Landscape data are generally reliable at providing a landscape-level analysis but need to be refined by input from landowners and stakeholders when assessing afforestation scenarios at a farm or block scale.
- The economic modelling for climate change investment focuses on mitigating the impact from erosion and does not include the impact from climate change on the productivity of indigenous tree/crop species. Future research is required to explore the impact on tree/crop species due to temperature changes.

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Appendix 1 – SWOT Analysis

The following tables provide a SWOT analysis for a mix of afforestation and horticulture scenarios including: mānuka, lemons, blueberries, macadamias, hemp, olives and avocado. Each SWOT analysis considers: the market conditions, establishment and operating costs, mean annual profits (over a 25-year rotation), internal rate of return, time between establishment and returns, bio-physical constraints, strengths, weaknesses, opportunities and threats.

Summary of Te Tairāwhiti Mānuka honey land opportunity

Market Conditions	International demand is strong for mānuka honey. There has been significant export growth over the past decade Prices are expected to remain high in the near future Supply in New Zealand cannot currently meet the expected growth in demand
Costs	Land conversion per hectare approximately $2,500 Hive establishment per hectare approximately $500, $0 if stand is established and bees are managed by an independent beekeeper Annual hive maintenance per hectare approximately $300, $0 if stand is established and bees are managed by an independent beekeeper
Mean annual profits (over 25-year rotation)	Honey revenue can potentially start when mānuka is 4 years old with 10kg of honey produced per hectare, increasing to full productivity at 30kg per hectare by year 6. The value per kilogram is approximately $35 per kg
Time between establishment and returns	5 or more years
Potential Area	Entire catchment: 162,502 ha Māori land blocks: 59,845 ha
Physical constraints:	LUC: 6–8 Could be difficult to establish and manage in very high erosion susceptibility land
Strengths	Strong market demand Can be profitable, even when grown on marginal land Low maintenance costs Low environmental footprint compared with most other productive land uses as it supports erosion control, habitat and carbon sequestration Could be implemented as part of the wider farm operation Can be planted on small blocks
Weaknesses	High establishment costs Price subject to international market conditions There is a significant lag between investment are reaching full production (6–7 years) Requires a large area of plantation to be economically viable Requires significant amount of expertise Bees require year-round pollen Competing plant species need to be removed
Opportunities	Rapidly growing market for mānuka products Source of income on steep and marginal land Possibility for reduced erosion and sedimentation if planted on heavily sloping marginal pasture Creates 3 jobs per 1,000 ha through planting, clearing, and beekeeping
Threats	Significant production variability from season to season Production is vulnerable to weather fluctuations Hives vulnerable to disease and collapse if not managed correctly Liability associated with high establishment costs The rapid growth in the market is being driven by exports, so is vulnerable to global economic fluctuations

Summary of Te Tairāwhiti lemon growing opportunity

Market Conditions	There is growing demand for exports to Asia. The local market is lucrative in summer; however, there is domestic oversupply in winter
Costs	The cost of plants for establishing an orchard is estimated to be between $7,000 and $15,500 per hectare. Costs could be higher if higher density planting is chosen. Pruning, thinning, and fertilization are required during orchard establishment. An irrigation system is likely to be required Annual operating costs are around $19,200/ha/yr
Mean annual profits	Varies by market, climate conditions and orchard size, but could be up to $22,000/ha Profits are subject to seasonal fluctuations
Time between establishment and returns	7–8 years for trees to establish. Begin harvesting fruit after 3–4 years. Full yields after 8 years.
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints	LUC 1–4 Soil drainage must be sufficient to avoid wet soil problems, poorly drained soils will not produce profitable crops All New Zealand soils require correcting for mineral content and acidity A Mediterranean climate with a long hot dry summer and significantly cooler winter with most rainfall during winter is suitable for lemon growing
Strengths	High profit potential Increasing export market demand Gisborne has very good summer temperatures for lemon growing The lemon industry is already established in Gisborne Lemons have several crops of different ages on the tree at one time and are harvested several times a year Short transit times to market for exports relative to competitors gives New Zealand a comparative advantage
Weaknesses	High capital cost to establish Requires high level of expertise Domestic oversupply in winter Citrus trees are susceptible to wind and poorly drained soils All New Zealand soils require correcting for mineral content and acidity before planting citrus Alternative bearing can lead to variable harvests Lack of southbound freight leads to containers returning empty from export destinations and increases export costs
Opportunities	Growing export market is Asia Potential for new seasonal employment over winter months from May to August Could be carried out on multiple blocks if close together, although a good rootstock is required for high quality fruit Lucrative local market in summer Excess winter crop can be exported to South East Asia
Threats	Growth in the market is being driven by exports, so is vulnerable to global economic fluctuations Environmental regulations could constrain intensification and land management Citrus is affected by many viruses and virus-like diseases Micro-climates within a district will influence viability and can be more important than regional guidelines New Zealand's wet humid conditions raises the threat of fungus and bacterial diseases to citrus Citrus has a wide spectrum of pests compared with most crops

Summary of Te Tairāwhiti blueberry growing opportunity

Market Conditions	Strong domestic demand; and exports in 2016 were up 50% compared with the previous 3 years' average Australia is the major export market
Costs	Cost of plants when establishing will be approximately $20,000 per hectare if harvesting manually and $30,000 per hectare if harvesting mechanically (differences due to difference in planting density) Operating costs per hectare for frozen blueberries were $8,305 and $45,520 for fresh blueberries in 2008/2009
Mean annual profits	Varies by market and climatic conditions and orchard size, but could be $13,000/ha or more (average reached $21,000 in 06/07) for frozen and $22,000/ha or more (average reached $30,470 in 06/07) for fresh
Dried blueberries	The dried blueberry market in New Zealand is still developing and is currently fills niche organic and health food markets There is potential to develop a small enterprise in one of these niches Market penetration could be difficult and purchasing drying equipment is expensive and risky ENZA offer contract drying services as an alternative to purchasing drying equipment. Contract drying could be used indefinitely or in the short term to minimise risks while establishing
Time between establishment and returns	Two-year old plants should be planted. The third season after planting the orchard will produce a small crop with full production at 10–12 years
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints	LUC 1–4 Require well-drained soils with high organic matter content Will not tolerate prolonged exposure to wet soils Requires a warm growing season with adequate chilling out of growing season (at least 500 hours below 7 degrees)
Strengths	High profit potential Strong and increasing market demand Established plants are hardy to low temperatures Planting a range of blueberry varieties allows for a staggered harvest
Weaknesses	High capital cost to establish Lag of several years between orchard establishment and achieving returns Requires high level of expertise Blueberry growers rely heavily on seasonal labour to harvest, grade and pack their fruit. Limited availability of quality seasonal labour and the increased costs of employing labour are increasing harvesting and packing costs, particularly for fresh blueberry growers
Opportunities	Rapidly growing market Potential for new employment from upskilling Could be carried out on multiple blocks if close together Local development and processing of niche products for domestic and international markets Dried or frozen fruit could reach overseas market with limited risk of product loss or damage
Threats	The rapid growth in the market is being driven by exports, so is vulnerable to global economic fluctuations Processors may be selective about suppliers Environmental regulations could constrain intensification and land management

Summary of Te Tairāwhiti macadamia land opportunity

Market Conditions	In 2016 domestic consumption exceeded domestic production by more than a factor of three
Costs	Cost of trees for orchard establishment is estimated to range from $6,000 to $40,000 depending on planting density (ranging between 200 and 1000 trees per hectare) Annual operating costs are approximately $6,400 per hectare
Mean annual profits	Net income is approximately $6,110 per hectare (gross of tax and debt repayments, values are from New South Wales and converted to NZD); however, well-performing orchards have the potential for higher production and higher profits
Time between establishment and returns	Full production reached once orchard is 15 years old
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints:	LUC 1–4 Best suited to organic soils but will grow in a wide range of soils Susceptible to frosts, particularly before maturity Vulnerable to wind and shelter is required Vulnerable to pooling water and flooded soils
Strengths	Market growth is not reliant on the export market Can be implemented on small blocks as part of a cooperative Macadamias are hardy aside from frosts and flooded soils There are commercial dryers available for on orchard drying Orchards already exist in the Gisborne region Existing Gisborne orchardists have stated intentions to form a macadamia growers' cooperative Irrigation is typically not necessary in New Zealand Macadamia orchards are relatively low maintenance
Weaknesses	Require a frost-free or low frost risk climate Nuts must be husked soon after picking so access to facilities is necessary
Opportunities	There is potential for orchards to sequester carbon In 2016 domestic consumption exceeded domestic production by more than a factor of three Potential for small scale production of niche products to diversify income stream from the crop There exists at least one small de-husking plant in the Gisborne region
Threats	Macadamia trees are slow growing so full production will not be reached for 10–15 years Rats are major pests, and fungus and insect control is also required

Summary of Te Tairāwhiti hemp land opportunity

Market Conditions	The market is small but beginning to grow in NZ A growing market in China could present an export opportunity
Costs	Input costs per hectare (excl. harvesting costs) are $700 An annual general licence costs $511.11 from the Ministry of Health Irrigation is likely to be required
Mean annual profits	Revenue per hectare (from seed) is around $3,000 giving a net return of input costs of $2,300 Returns have been estimated as high as $7,000 to $8,000/ha
Time between establishment and returns	Full production reached once orchard is X years old
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints:	LUC 1–4 Requires well-drained soils and is sensitive to water logging Needs daylight hours to be sufficiently short to flower
Strengths	Can be used as either an annual or rotation crop Multiple products can be produced from the same plant (fibre and seeds) Hemp is relatively easy to grow
Weaknesses	The industry is not yet well established A licence is required for commercial production of hemp It is illegal to sell hemp foods other than oil for human consumption in New Zealand Requires a large amount of water but is sensitive to water logging Requires moderate to high fertiliser levels
Opportunities	Hemp seed oil has desirable characteristics for health products Some plant varieties can be used to produce fibre for fabric or construction Potential demand from China for bulk industrial hemp fibre Construction with hemp products can provide permanent net carbon removal from the atmosphere Most pests and diseases do not cause economic damage
Threats	Production of hemp is subject to various controls Environmental regulations could constrain intensification and land management Birds are a significant pest for hemp seed Hemp is difficult to harvest. Fibre strength means converting harvesters from other uses is not practical Processing of fibre can be difficult

Summary of Te Tairāwhiti olives land opportunity

Market Conditions	Strong domestic demand, in 2012 New Zealand imported almost 6,000 tonnes of olive oil, annual domestic production is estimated to be 400 tonnes The olive oil market in New Zealand was estimated to be $35million in 2011
Costs	Costs per hectare are around $4,000 including annual operating costs and annualised capital costs
Mean annual profits	$3,000 per hectare
Time between establishment and returns	Full production reached once the orchard is 9-10 years old
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints	LUC 2–4 Free draining soil with reasonable moisture content, soil with high retention of trace elements In New Zealand, most olives are grown at altitudes up to 200 m on flat or hilly land which receives over 2,000 hours of sunshine per year and between 700 and 1,350 mm of annual rainfall
Strengths	High source of income Can be implemented on small blocks Could be carried as part of the wider farm operation Existing growers association
Weaknesses	Significant capital investment required to establish orchard and install irrigation if required 9–10-year period between planting orchard and full production Olives are vulnerable to birds Need access to processing facilities May be difficult to acquire market access May require irrigation
Opportunities	High returns and stable yields can be expected once trees reach maturity Job creation for planting, harvesting, and processing Potential to diversify agricultural production in region
Threats	Environmental regulations could constrain intensification and land management Pests, disease (particularly peacock sport), and climate change could affect crop yields particularly when establishing an orchard

Summary of Te Tairāwhiti avocado land opportunity

Market Conditions	Exports of avocados are relatively large ($82.6 million in 2016) but fluctuate with harvest Strong domestic demand served entirely by domestic production
Costs	Costs per hectare are around $16,000 including annual operating costs and annualised capital costs. Annual operating costs make up the majority of costs ($14,000)
Mean annual profits	$4,500 per hectare
Time between establishment and returns	Full production reached once orchard is 9 years old
Potential area	Entire catchment: 14,965 ha Māori land blocks: 7,917 ha
Physical constraints:	LUC 2–4 Climate is unsuitable for avocado growing in areas where: there are occasional winter frosts colder than –4 degrees, day temperatures consistently under 20 degrees, night temperatures consistently under 10 degrees, and occasional lights frosts after 1 October Moderately fertile, non-compacted, free draining soil
Strengths	High source of income Can be implemented on small blocks Could be carried as part of the wider farm operation Existing growers association
Weaknesses	Significant capital investment required to establish orchard High annual operating costs 9-year period between planting orchard and full production Seasonal fluctuation in yield and income Climatic requirements limit the locations where avocado can be grown Need to acquire market access to export markets AvoGreen compliance is required to export avocado
Opportunities	High returns can be expected once trees reach maturity Job creation for planting, and harvesting
Threats	Environmental regulations could constrain intensification and land management High annual operating costs and variable income leave growers financially vulnerable Pests, disease, and climate change could affect crop yields particularly when establishing an orchard

Appendix 2 – Supplementary material

Erosion under uncertain climate change

Climate change uncertainty was modelled with empirical distributions using baseline erosion rates developed with the New Zealand Empirical Erosion Model (NZEEM) developed by Dymond et al. (2010). In this study, we estimated annual erosion for all 286 sheep-beef land parcels in the catchment and a combination of 6 GCMs for the 4 Representative Concentration Pathways (RCP) scenarios for year 2100.[15] Refer to Appendix 2 for more information. The entire dataset included a total of 6,864 baseline erosion forecasts (6 GCMs x 4 RCPs x 286 parcels) represented by erosion coefficients (taking 2012 as the base or equal to 1) for year 2100. Figure 6 shows catchment maps of the baseline annual erosion rates per parcel for 2015 and 2100. Using 286 sets of 24 forecasted erosion coefficients, 286 non-parametric empirical distributions were developed for each sheep-beef parcel in the catchment following the procedure developed in Richardson et al. (2000) and used in Monge et al. (2016) in the following manner:[16,17,18]

The means ($\bar{x}$) were first estimated using the 24 NZEEM erosion coefficients (ec) for the various land parcels:

$$\bar{x}_{l,t} = \frac{\sum_{c}^{24} ec_{c,l}}{N} \quad \text{for t = 89 or year 2100}$$

where c represents the set of 24 observations obtained from 6 GCMs and 4 RCPs for year 2100, *t* time, *l* the 286 sheep-beef parcels in the catchment, and *N* is the total number of observations (i.e. 24).

1 Percent deviates (dev) from the mean were then estimated using:

$$dev_{c,l,t} = \frac{ec_{c,l,t} - \bar{x}_{l,t}}{\bar{x}_{l,t}}, \forall c, l \text{ and } t = 89$$

2 Sorted the percent deviates from minimum to maximum using a sorting function (sort):

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[15] The 6 best-performing GCMs for the New Zealand region were selected, based on comparisons with observations over the historical data period of the models, namely the HadGEM2-ES (UK), CESM1-CAM5 (USA), NorESM1-M (Norway), GFDL-CM3 (USA), GISS-E2-R (USA) and BCC-CSM1.1 (China), (Tait et al. 2016a)

[16] The main benefit of using an empirical distribution function is that it relies on as few assumptions as possible about the data. Contrary to parametric distributions where a large number of observations are necessary to identify optimal parameters through maximum likelihood or method of moment approaches, an empirical distribution function can be generated with a small dataset.

[17] Similar to Scholze M, Knorr W, Arnell NW, Prentice IC 2006. A climate-change risk analysis for world ecosystems. Proceedings of the National Academy of Sciences 103: 13116–13120, our analysis did not assign probabilities to scenarios or weights to models but, instead, we created an empirical distribution using the outcomes (i.e. erosion baselines).

[18] Most software packages or programming languages used to model stochastic processes offer functions to develop empirical distribution functions such as *ecdf* in R and Matlab among others.

$$sortdev_{c,l,t} = sort(dev_{c,l,t}), \forall l \text{ and } t = 89$$

3 Developed probabilities for the sorted deviates (sortdev):

$$P(Pmin) = 0.0, \text{where } Pmin = Min\left(sortdev_{c,l,t}\right) * 1.0001$$

$$P\left(sortdev_{1,l,t}\right) = (1/N) \cdot 0.5$$

$$P\left(sortdev_{2,l,t}\right) = (1/\mathrm{N}) + P\left(sortdev_{1,l,t}\right)$$

$$\vdots$$

$$P\left(sortdev_{N,l,t}\right) = (1/\mathrm{N}) + P\left(sortdev_{N-1,l,t}\right)$$

$$P(Pmax) = 1.0, \text{where } Pmax = Max\left(sortdev_{c,l,t}\right) * 1.0001$$

Uncertainty through time was modelled through a combination of: (1) an empirical function using the sorted deviates and probabilities developed in the previous steps, (2) a linear trend as the mean between the base erosion differential in 2012 (=1) and the 2100 mean developed in the first step, and (3) an increasing expansion factor to model increasing uncertainty in the following manner:

$$\widetilde{ec}_{l,t} = \bar{x}_{l,t} * \left[1 + \left(\widetilde{dev}_{c,l,t} * exp_t\right)\right]$$

$$\widetilde{dev}_{c,l,t} = EMP(sortdev_{c,l,t}, P\left(sortdev_{c,l,t}, Pmin, Pmax\right), \widetilde{usd}_t)$$

where exp_t is an uncertainty expansion factor that increases linearly from 0 in 2012 to 1 in 2100, *usd* is a uniform standard deviate generated for each time period, and *EMP* represents the empirical distribution function. When *exp* = 1, we would obtain the same coefficient of variation estimated from the original 24 climate-change erosion estimates for 2100. When *exp* = 0, we would obtain the mean. Notice that *usd* is the same across *l* or, in other words, there is a perfect stochastic spatial correlation. The latter assumption implies that the direction and, to a certain extent, the magnitude of the erosion effects will be the same across parcels in a specific year. However, the magnitude will still change per parcel as each parcel contains its respective deviations from its respective mean.

4 Finally, the stochastic erosion estimates ($\widetilde{erosion}_{l,t}^{s\&b}$) were estimated based on the baseline erosion estimates in 2012 ($erosion_{l,t=1}^{s\&b}$) as follows:

$$\widetilde{erosion}_{l,t}^{s\&b} = erosion_{l,t=1}^{s\&b} * \widetilde{ec}_{l,t}$$

Details of assumptions of afforestation scenarios

Scenarios of multiple forest management systems were developed using forest tree species chosen by the community. Scenarios used continuous cover forest management with different combinations of Mānuka (*Leptospermum scoparium*), Tōtara (*Podocarpus tōtara*), and Kawakawa (*Piper excelsum*). Due to limited information available for these species, best estimates were used to construct expected cash flows for land use modelling. Costs, revenues, and growth assumptions were estimated using comparisons with other similar forest operations and species where documented, as well as growth studies where available. The resulting assumptions are described in the following sections.

General costs

Operational costs were calculated in line with the methodology for calculating costs in planted radiata pine (*Pinus radiata*) forestry using a spreadsheet calculator developed for the New Zealand plantation forest industry. Estimations were calibrated to the scenarios for this study by assuming hindrance was equivalent to land on slopes of 25 degrees or greater. The results of this calibration are outlined below in the following table.

Costs included in calculating value of forest system scenarios

Planting (all species)	\$3.95 per seedling
Annual management	\$65/ha/yr, except for the Mānuka only scenario after year 10 where they dropped to \$30/ha/yr
Pest control	\$35/ha
Inter planting (under canopy)	\$9.5 per seedling initially, increasing to \$18 for 100 stems/ha under dense canopy cover after year 28
Clearing light wells	\$2.48 per sapling for Tōtara
Form pruning low	\$1.70 per sapling for Tōtara
Form pruning high	\$2.30 per sapling for Tōtara
Roading	\$4,000/ha
Harvest	\$210/m^3 for mixed species. \$100/m^3 for pure stands
Log transport	\$33.25/m^3
Log value	\$350/m^3

It was assumed that mixed stand scenarios were less likely to be suitable for more efficient ground-based harvest operations due to the more complex forest layout and differing tree species growth rates. For this reason, a harvest rate of \$210/m^3 was used for the mixed species scenarios representing helicopter logging, and a rate of \$100 was assumed for pure stands to account for a mix of flat ground based harvesting and steep ground cable based harvesting. In many cases, multiple operations occurred in a single simulated year, particularly in scenarios with multiple tree species. An adjustment was used to avoid double counting time required for accessing trees representing the gained operational efficiency when conducting multiple operations at the same time. The adjustment was a reduction of costs by 35% of the difference between the sum of operations and the most expensive operational in that year.

Additional growth and operational assumptions were made specific to tree species. These assumptions and the background to why they were used are outlined under the following headings:

Mānuka

Mānuka grows well on the East Cape of New Zealand. Mānuka provides revenue from the sale of honey and additionally, where the plants are accessible potentially the sale of mānuka oil and firewood. However, in this study only revenue from honey were considered. The mānuka honey industry is well established with large overseas markets, but is still variable compared with more traditional farming products in part due to the younger market. Mānuka can remain as the main forest crop, but may require maintenance in the form of rejuvenation plantings as the stand ages to maintain maximum production. Without young plants the mānuka crop will age, creating uncertain honey production. Generally, the accepted productive life span is 25 years.

In this study, costs were included for an initial weed spray and planting at 1,300 stems/ha. Mānuka was assumed to be planted from high quality plant stock at a high stocking to control weed competition and comply with local regulations for erosion control requirements. Costs were included for weed control for 2 years after planting with release spraying. For all but one scenario the forest canopy was transitioned to another dominant canopy species before the mānuka honey production reduced from aging. During the transition mānuka was shaded out by the subsequent tree species.

We have assumed mānuka was planted on steep slopes in a challenging environment for growth, and so have used an estimate in between unimproved and top-producing mānuka. It was assumed honey revenue started from age 4 with 10 kg of honey produced per hectare, increasing to full productivity at 30 kg per hectare by year 6. It was assumed that there was one hive per hectare at a cost of $450 per hive per year. In the pure stand mānuka scenario with no subsequent tree crop, productivity was assumed to drop from 30 to 20 kg per hectare from year 26–27 and remain at 20 kg per hectare from year 28 onwards. For scenarios with a subsequent tree crop during the transition to the subsequent tree crop honey production was assumed to fall to 10 kg per hectare over 3 years before the mānuka is shaded out completely. Also, the quality of the honey was assumed to drop. The value per kilogram was assumed to drop from $35 to $25 per kilo from year 28 onwards.

Tōtara

Tōtara grows well on the East Cape and can produce high value timber. If left to grow long enough it will produce naturally durable heart wood in the centre of the logs, which would achieve a higher price with the right buyer. The additional value of heartwood timber was not included in this study. To produce quality logs for sawmilling tōtara needs to be grown either at a high stocking (over 2,000 stems/ha) or in competition with neighbouring plants while it is young. Competition keeps the trees growing straight with small branches. Without competition, weeds will become established and compete with tōtara, reducing its growth. Also, where tōtara has a lot of space it will produce large branches, unsuitable for sawmilling. There is local demand for tōtara logs, but supply has been limited so there is not an established market to allow for easy sale. Selling tōtara logs will require some work finding harvesting contractors and log buyers.

In these scenarios, tōtara was used as a secondary dominant canopy species to take over from mānuka. Initially, the mānuka was used as a nurse crop, to shelter the tōtara and keep it growing straight. As the mānuka aged, the tōtara seedlings were assumed to become established and taller, eventually overshadowing the mānuka crop. By age 30, the mānuka was assumed to have died out from shading, and the resulting forest canopy was predominantly tōtara. The alternative approach would have been to assume planting tōtara directly without a nurse crop, at a higher stocking. This scenario is not considered here as the early cash flow from the honey of the mānuka nurse crop made the nurse crop more financially appealing.

Tōtara will not regenerate naturally in large numbers without large clear areas, and so planting and management was included to maintain timber production in the long term. It was assumed tōtara would be planted initially in year 8 under established mānuka at 900 plants per hectare for the pure stand and 500 plants per hectare for mixed stands, with additional plantings of 100 plants per hectare year 28 and every 20 years from there for the pure stands, and every 40 years for mixed stands. This intermittent planting allows for steady future harvests and allows for recovery from potential poor survival due to pests, diseases or weather. To get good growth the seedlings will need light. In the earlier years, while mānuka was the dominant canopy, species light wells were assumed to be cut into the mānuka for every seedling, every year until 10 years after planting, or for later plantings until year 21 when the mānuka was assumed to have been shaded out. To maintain good tree form pruning was assumed to be used to keep the tōtara growing straight and removing branches below 6m. Form pruning was estimated to be needed from 3 years after planting until 12 years after planting.

Tōtara volume productivity in pure stands was assumed be 800 m^3/ha. Total Standing Volume (TSV) at 800 stems/ha in year 80, and for mixed stands 400 m^3/ha TSV at 400 stems/ha. Recovery timber volume productivity for the pure tōtara scenario following selective harvest was assumed to be 14 m^3/ha/yr. This productivity is based on the stand being managed to produce timber which is justified by the costs included for planting at even spacing and cutting light wells. Where pūriri and mātai are included, the volumes assumed to drop to 7 m^3/ha/yr, because the stocking is almost halved, and competition will be increased. Bergin and Kimberley (2003) found a growth rate of 14.2 m^3/ha/yr for planted managed Tōtara stands at 1,000 stems/ha, which was compared with a rate of 5.6 m^3/ha/yr for unmanaged stands at year 60 and 1,000 stems/ha in the same study.

Kawakawa

Kawakawa is of high cultural value, and in addition provides the opportunity to produce a specialised product for a niche market. Kawakawa is an understory crop that is sensitive to frost and poor drainage.

The active constituents in kawakawa that give it its medicinal properties include the *volatile oil* (45–70% in essential oils and 1.6–2.5% in the dry herb (mostly myristicin)) and mixed *cadinenes* (12.2 % essential oils – 0.43% in dry herb).[19] Both these can be extracted when kawakawa is dried. A number of factors need to be considered when growing kawakawa. The plant is rich in moisture; therefore, fresh leaves of 7 kg would be reduced to 1 kg when dried – a fact that discourages some interested growers. However, the calculation of economic returns below may be useful.

It is assumed that 11 alleys per hectare are available for planting in mature forest, with one plant of kawakawa per square metre. As a hectare of forest would have about 3,300 square metres of alleys, the same number of kawakawa plants could be planted. Treeline Native Nursery (2013) indicates that kawakawa costs $3 per seedling. Assuming $1,000 cost for transport of seedlings to the planting site, the total cost of seedlings and transport would be $10,130.

Costs for site preparation, weed control, and crop protection (e.g. installation of hail net fences) are approximately $8,600; planting costs would be $1,200; harvesting costs are estimated at $350,300, which accounts for about 90% of the overall costs.

Kawakawa leaves and fruits can be harvested a year after planting. Based on personal conversation with a nursery expert, we could harvest every fortnight and 10–20 leaves could be harvested from each plant for the first few years. This harvest will increase over the years. Assuming that 95% of kawakawa seedlings survive and that 10 mature leaves per plant could be handpicked in 1 minute allows calculation of harvest costs. Assuming also that drying tea leaves is similar as drying kawakawa, an expert in kawakawa indicated that 100 kg of newly plucked fresh leaves would yield 14kg of dried leaves. In consultation with buyers of dried kawakawa, prices range between $75 and $300 per kg. Calculations suggest that the amount of dried kawakawa materials that can be harvested from the 11 alleys over the 6-year period would be around 4,490 kg. This implies that a kawakawa plant would provide 1.4 kg of dried materials that could be sold. Assuming that market price of dried kawakawa is $110 per kg, an NPV of $8,800 per ha is achieved, which indicates that kawakawa would be a profitable understorey crop. An assumed market price of $75 per kg returns a negative NPV of –$104,400 per ha.

In the simulations for this study it was assumed that after the forest canopy was established kawakawa planting was included over three planting operations, each of which was 2 years apart, starting from year 25. The kawakawa crop was planted in multiple operations to allow for blanking and to hedge against risk of poor establishment from adverse seasonal weather, poor plant placement or pests. Each planting operation was costed for a rate of 300 plants per hectare, assuming planting under the existing canopy.

Additional costs were included for two years for kawakawa specific pest and weed control after each planting. Harvesting started 1 year after the first planting. Yields for the first year were estimated at 100kg dried Kawakawa per hectare. Over the next 4 years the

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[19] http://www.earthenergiesnz.com/kawakawa-profile

remaining plants were planted which brought the total planted stocking up to 900 stems/ha. By year 32 the last lot of planting had been growing for 3 years and the full harvest potential was reached at 900kg/ha/yr dried kawakawa. In each subsequent year costs for harvesting, transporting and drying kawakawa were included at $70,000/ha/yr, which is in line with the experience of those growing kawakawa in other parts of the North Island. Revenues were included as $110/kg of dried leaves. However, due to the small market size this value is highly variable, and is reported to commonly dip below the breakeven point. At $75/kg of dried leaves Kawakawa harvesting is unprofitable.

Details of NZFARM

The objective function estimates the level of agriculture production (i.e. commodities) that maximize the net revenue (π) from production across a given geographical area subject to feasible land-use and land-management options for each farm parcel, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs. The objective function is mathematically specified as:

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

where P is the product output price, A is the agricultural product output quantity, Y is other gross income earned by landowners (e.g. grazing fees), X is the area of specific farm-activity, ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs, τ is an environmental tax (if applicable), γ^{env} is an environmental output coefficient, ω^{land} is a land-use conversion cost, and Z is the area of land-use change from the baseline allocation. Summing the revenue and costs of production across the total catchment region (r), which consists of several soil types (s), land covers (l), enterprises (e), and land management options (m), yields the total net revenue for the geographical area of concern. Net revenue is limited not only by the output prices and costs of production but also by a number of production, land, technology and environmental constraints.

Production is constrained by the product-balance equation using a processing coefficient (α^{proc}) that specifies what agricultural commodities can be produced by a given activity in the catchment:

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

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

$$\textstyle\sum_{s,l,e,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq \ W_r$$

Land use is constrained by the amount of land available (**L**) on a particular soil type in a given catchment:

$$\sum_{e,m} X_{r,s,l,e,m} \leq \ L_{r,s,l}$$

and landowners are constrained by their initial land-use allocation ($\mathbf{L}^{init}$) and the area of land that they can feasibly manage or change:

$$L_{r,s,l} \leq L_{r,s,l}^{init} + Z_{r,s,l}$$

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

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

and we assume that it is feasible for all managed land uses to change with the exception of protected native forest and tussock grassland on conservation land:

$$L_{r,s,native} = L_{r,s,native}^{init}$$

In addition to estimating economic output from the agriculture and forest sectors, the model also tracks a series of environmental factors including soil loss. Should central government or a regional council in New Zealand regulate farm-based environmental outputs or emissions (γ^{env}) by placing a cap on a given environmental output from land-based activities ($\mathbf{E}$), landowners could also face an environmental constraint:

$$\sum_{s,l,e,m} \gamma_{r,s,l,e,m}^{env} X_{r,s,l,e,m} \leq E_r$$

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

$$Y, X, L \geq 0$$

The 'optimal' distribution of soil type $s_{1\ldots i}$, land cover $l_{1\ldots j}$, enterprise area $e_{1\ldots k}$, land management $m_{1\ldots l}$, and agricultural output $a_{1\ldots m}$ are simultaneously determined in a nested framework that is calibrated based on the shares of initial enterprise areas for each of the specified geographical areas, in this case farm boundary.

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

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

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

The CET functions are calibrated using the share of total baseline area for each element of the nest and a CET elasticity parameter, σ_i, where $i \in \{s, l, e, m, a\}$ for the respective soil type, land use, enterprise, land management, and agricultural output. These CET elasticity parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes.

The CET function is nonlinear, where the marginal rate of transformation between land used in one enterprise activity under a certain management system and land used for another enterprise system under an alternative management system is declining. The parameters for these equations are derived from the area of each farm level activity in the baseline ($X_{r,s,l,e,m}$), the net return for each enterprise activity ($\pi_{r,s,l,e,m}$), and an elasticity of transformation (σ_e). Net returns for each enterprise activity are obtained from shadow prices on calibration constraints that are placed on the objective function (equation 1).

The enterprise-level CET function is mathematically represented as:

$$RAC_{r,s,e} = \alpha_{r,s,e} * \left[\sum_{r,s,l,e,m}\left(\delta_{r,s,e} * X_{r,s,l,e,m}\right)^{-\rho_e}\right]^{-\left(\frac{1}{\rho_e}\right)}$$

In this equation, $RAC_{r,s,e}$ is the area of enterprise *e*, and $\delta_{r,s,e}$ is the CET allocation parameter for enterprise area *e* on land use *l* and soil type *s* in catchment *r*, specified as:

$$\delta_{r,s,e} = \frac{\pi_{r,s,l,e,m} * X_{r,s,l,e,m}{}^{1+\rho_{r,s,e}}}{\sum_{r,s,l,e,m}\left(\pi_{r,s,l,e,m} * X_{r,s,l,e,m}\right)^{1+\rho_{r,s,e}}}$$

where $\pi_{r,s,l,e,m}$ equals the net return per hectare for each enterprise and is derived from the shadow value of constraints placed on the allocation of enterprise activities in each catchment, ρ_e is the CET substitution parameter estimated using the CET elasticity parameter σ_e:

$$\rho_e = \frac{1 - \sigma_e}{\sigma_e}$$

and $\alpha_{r,s,e}$ is the enterprise CET scale parameter based on the share of one unit of that enterprise activity *e* on soil type *s* in catchment *r*:

$$\alpha_{r,s,e} = \frac{RAC_{r,s,e}}{\left[\sum_{r,s,l,e,m}\left(\delta_{r,s,e} * X_{r,s,l,e,m}\right)^{-\rho_e}\right]^{-\left(\frac{1}{\rho_e}\right)}}$$

The mathematical formulations for the land use and land management-level CET functions are similar to the enterprise-level CET function.

The economic model is solved using the General Algebraic Modelling System, and the baseline calibration and scenario analysis are derived using the non-linear programming version of the CONOPT solver (GAMS 2015).

The CET functions are parameterized based on estimates from the literature on other regional economic land-use models (Adams et al. 1996; Hendy & Kerr 2006; Johansson et al. 2007), and econometric estimates of New Zealand land use change (Dake 2011; Adams & Turner 2012; Kerr & Olssen 2012). The CET elasticity parameter values increase with each level of the nest between land use, enterprise, and land management, such that the values are land cover (σL) = –2, enterprise (σE) = –4, and land management (σM) = –8). A larger CET elasticity was used in the land-management nest to simulate that over the long term most landowners are likely to employ new management technologies on their existing enterprise to meet environmental constraints rather than change land use, which is consistent with the literature. A lower elasticity value (in absolute terms) would indicate that landowners are less likely to implement a management change and are more willing to change their land use to meet the environmental constraint, all other things held equal. The CET elasticity parameter for soil (σS) is set to be 0 as the area containing a particular soil type in a region is fixed. In addition, the parameter for agricultural production (σP) is also assumed to be 0, implying that a given activity produces a fixed set of outputs.

The model is calibrated such that optimality conditions are satisfied at observed levels of decision variables (e.g. baseline land-use and production matches input data). This is achieved through the Positive Mathematical Programming (PMP) methodology that has been proven to generate solutions with realistic diversification of production activities and smooth supply responses without adding weakly justified constraints to the model formulation (Howitt 1995), such as placing ad hoc restrictions on how much land-use can deviate from the baseline area. PMP has been used extensively for the calibration of agri-environmental programming models (Cortignani & Severini 2009; Merel & Bucaram 2010). The model extends the general PMP formulation by nesting sets of nonlinear transformation functions that represent constraints imposed by our assumptions on production technologies. We use a CET function that incorporates prices, quantities, average costs and a substitution elasticity. Shadow prices from calibration constraints are used to obtain the difference between average and marginal returns to specify the transformation function parameters.

Erosion modelling under climate change

As climate changes, it is anticipated that temperature will generally increase and precipitation will either increase or decrease, depending on the location within New Zealand (MfE 2008). As temperature increases, the warmer air can hold more moisture and thus storms will be more intense. With an increased storminess, is anticipated that mass movement erosion in the form of landslide events will increase as more rainfall will be associated with storms. Additionally, with increased rainfall, it is anticipated that lowland environments will see an increase in surface erosion.

We use two different models to simulate impact of climate change on hillslope area (dominated by landsliding erosion) and on lowland area (dominated by surficial erosion).

To separate lowland from hillslope, we used a hill country map derived from LENZ (Leathwick et al. 2003).

For hillslope erosion, previous research has shown that storminess was a better predictor of potential change in sediment yield in the future (Schierlitz 2008). Historical rainfall daily data from meteorological sites from around New Zealand were obtained from the CliFlo database (NIWA, 2013) and analysed for continuity and completeness.We assumed that for an average storm duration of 3 hours, the increase in storm rainfall is 7.8% for every increase of 1°C (MfE 2008). We then used the estimated increase in storm rain due to change in temperature and a relationship between landslide density and storm magnitude to develop linear relationships between change in temperature and change in landslide density. These relationships were developed for a range of climates across New Zealand, using the Land Environments of New Zealand (LENZ) (Leathwick et al. 2003) as a proxy for climate and soil variability across New Zealand. Relationships between landslide density and storm rainfall were developed per LENZ level one class (20 classes for New Zealand), giving an extreme event factor that could be applied to the current erosion rates, provided by the NZEEM model (Dymond et al. 2010).

For lowland environments, we assume that sediment yield is strongly correlated with annual runoff. Since rainfall and runoff are highly inter-correlated, we use the NZEEM relationship that assumes a power law relationship with rainfall: $\bar{e}(x, y) \propto R^2(x, y)$. A change of 10% in rainfall would result in a 20% change in sediment loss.

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