Steering land use change to meet water quality targets

The Catchment Synthesis Scenarios Project

Prepared for

Our Land and Water National Science Challenge

Report prepared by

Perrin Ag Consultants Ltd
in collaboration with
Manaaki Whenua Landcare Research

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Executive Summary

The Catchment Synthesis Scenarios project, funded by the Our Land and Water – Toitū te Whenua, Toiora te Wai (OLW) National Science Challenge, seeks to estimate the scope of land practice and land use change over a 20-year time horizon that might be required by regional councils to achieve the agreed water quality outcomes for degraded catchments. The project seeks to then validate if such changes are achievable at an individual farm business level (through individual business cases).

Three catchments were investigated in the research - Tukituki (Hawke's Bay), Te Hoiere (Marlborough) and South Coastal Canterbury [Waihao] (Canterbury). These catchments have pre-existing community-defined water quality objectives that are unlikely to be achieved through reasonable mitigation efforts alone. Agricultural land use is the dominant cause of poor water quality in these catchments.

To evaluate how a water quality target can be met through mitigating and changing land use, a catchment modelling approach was used.

The catchments of interest were delineated into polygons of discrete land use typologies. Specific economic and environmental outputs were then created for and assigned to each typology, including outputs associated with potential future land uses. The range of water quality mitigations applicable to each typology were then identified from an overarching mitigation library, with their impacts on economic and environmental outputs estimated from literature and peer reviewed software models. A total of 71 farmers across the three catchments were then surveyed about their preferences for the adoption of land management practices or land use changes. Catchment-specific mitigation cost curves were then developed based on applicable mitigations, but primarily informed by the adoption preferences of the surveyed farmers. These curves and their outputs were then adapted for use within the catchment models.

To identify land-use management change options for achieving water quality targets, a spatially explicit optimisation-based approach was used, utilising the Land Use Management Support System (LUMASS[1]) (Herzig et al. 2013, Herzig et al. 2018). Specific geospatial catchment models were then used to solve for scenarios of land management and land use change that would see national water quality targets achieved in both the catchments as a whole and in each specific sub-catchment. This was undertaken for Tukituki and Te Hoiere, with four scenarios (each with an irrigation water variant) completed for the Tukituki and two for the Te Hoiere.

Following the scenario runs, a high-level feasibility analysis was then conducted on the transition of five actual properties within the Tukituki catchment from their current state to potential futures with lower contaminant loads. The feasibility of any required land use and practice change was assessed against three key measures over time, being interest cover, annual cash surplus and total debt. The transition to the new practice and land use mix was considered fully feasible if interest cover remained at a ratio of 1 or higher for the entire twenty-year period, annual cash surpluses were achieved for a minimum of fifteen of the twenty years; and total debt was lower at the end of the twenty years than at the start.

The interview responses from farmers in three catchments with water quality that is below nationally mandated bottom lines indicated they had a willingness to continue to adopt and implement a wide range of mitigations. Based on the evaluation of mitigation efficacy on land uses within the specific

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

catchments, these included mitigations that invariably reduced productivity or took land away from productive use, including land retirement. In general terms, farmer preference aligned with the order of adoption that conventional assessment of mitigation cost would determine, but the sequential adoption of mitigations is ultimately expected reduce farm profitability. Where required contaminant load reductions are high, moving away from mitigation activity to land use change will ultimately be needed to deliver desired water quality outcomes for a reduced economic cost.

Regarding the Tukituki catchment, two scenario runs (the CNmax and CNmax-*iex* scenarios) were closest to achieving NPS-FM nitrogen water quality targets, with 80 of 82 (98%) and 75 out of 82 (98%) of the critical sub-catchments predicted to achieve N targets, respectively. The CNmax scenarios resulted in a significantly more profitable outcome for the catchment than the earlier scenarios (or the status quo), which the addition of water (the -*iex* variant) accelerated further. Reductions in phosphorus, sediment and *E coli* losses were also achieved in all these scenarios, although not all at levels required by the NPS-FM. These scenarios also estimated there would be an aggregate reduction in methane emissions. The scale and nature of the predicted land use change under either of these scenarios is likely to be confronting. In a catchment of approximately 221,000 hectares, the CNmax scenarios suggests that around 78% of the catchment area may require land use change, including the complete loss of the sheep, beef and deer sectors, primarily replaced with exotic production forestry. An initial scenario, N30, aligning most closely with a farmer-determined approach to practice and land use change and provides an outcome resembling the often discussed "mosaic of land uses", but this only saw N targets achieved in 5% of critical catchments and indicated profit erosion in the order of 17% from current levels. Interestingly, the transition to the predicted combination of mitigation and land use for the five case study farms was considered unfeasible for most of them under both then N30 and CNmax scenarios, despite the latter estimated to be significantly more profitable than the status quo. Pre-existing level of debt, cadence of revenues from new land uses as the required speed of transition were all identified as significant factors in the feasibility of transition.

For the Te Hoiere, each of two scenarios targeted different contaminants. One (allCons) achieved 100% of N and P loss NPS-FM targets but only had 53% and 56% of critical catchments meeting *E. coli* targets and sediment respectively. The second scenario (minEC) increased the number of critical catchments meeting the primary *E. coli* targets to 81%, and while still meeting N and P targets. Sediment target achievement increased slightly to 56% of critical sub-catchments. As in the Tukituki, methane emissions from land use were reduced in both analysed scenarios. The greater extent of reduction in the allCons scenario was due to a greater reduction in pastoral farming area. Both scenarios failed to improve water quality without a predicted erosion in aggregate catchment profitability. As a result of the climate (high rainfall) and landscape (prone to flooding) there is an assumed lack of higher value, lower impact alternate land uses available for adoption in the Te Hoiere catchment. Given this assumption and the dominance of dairy as the predominant pastoral land use, it is hypothesised that additional scenarios with fewer constraints to land use change may not have been able to determine a more profitable pathway.

While not providing a definitive solution to addressing this wicked challenge, the Catchment Synthesis Scenarios project does indicate that potential pathways to profitable water quality outcomes might exist. However, when interrogated through even a single perspective (like financial capacity), the feasibility of the change required is potentially uncertain and, even if change is desired, it might not always be possible to achieve. This should not be interpreted as grounds to dismiss action or targets as meaningless or misguided, but rather as an opportunity to continue to explore the pathways towards the better future our communities both desire and require.

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1 Introduction

1.1 Project context

The Our Land and Water – Toitū te Whenua, Toiora te Wai (OLW) National Science Challenge seeks a future where catchments contain mosaics of land uses that are more resilient, healthy, and prosperous than today. To achieve this future, land use change and changes in land management will be required.

1.2 Project objectives

The Catchment Synthesis Scenarios project seeks to estimate the scope of land practice and land use change over a 20-year time horizon that might be required by regional councils to achieve the agreed water quality outcomes for those catchments. The project seeks to then validate if such changes are achievable at an individual farm business level (through individual business cases). It is funded by the OLW National Science Challenge and led by Perrin Ag.

The specific objectives of this research are:

(i) To show how a water quality target can be met through mitigating and changing land use in three high profile catchments, without (hopefully) compromising profitability or GHG emissions requirements; and

(ii) To provide examples that demonstrate that the mission of the OLW Challenge can be achieved, using the type of research which OLW has supported.

The catchments of interest were all identified by Snelder et al. (2023) as having a significant number critical catchments in relation to their exceedance of national bottom lines for water quality as established by the National Policy Statement for Freshwater Management (NPS-FM).

1.3 Project scope considerations

Specific considerations regarding the scope of the work were:

- The creation of land use change scenarios for these catchments (based on OLW-research) then the use of catchment modelling to assess achievable improvements in water.
- The business case for the land use change/mitigation should ideally be feasible.
- The proposed land use change/mitigation scenario(s) must not result in other environmental impacts (other water attributes degrading or GHG emissions increasing etc.).
- This modelling exercise had to be completed within 11 months of project initiation.

2 Background

In response to an ongoing decline in the quality of water in rivers, lakes and estuaries across New Zealand, the National Policy Statement for Freshwater Management 2020 (NPS-FM; NZ Government, 2023) established national bottom lines for the water quality attributes of these waterbodies. These attributes related to four primary contaminants - nitrogen, phosphorus, Escherichia coli (*E. coli*) and sediment.

While various regional governments had, under the provisions of the Resource Management Act 1991, been independently regulating water quality (and subsequently land use) for many years prior to 2020, there had been no overarching minimum standards in place across New Zealand. While these approaches tended to address the specific needs and requirements of the relevant communities, these regulations weren't necessarily designed to achieve similar standards of water quality for a given contaminant or necessarily address more than one contaminant.

While most of the rivers in catchments in the urban land-cover class are also polluted with nutrients and suspended sediment (MfE 2020), the ongoing and well reported decline rural water quality has tended to remain elevated in the New Zealand public's consciousness and is a key focus for regional authorities. However, with the food and fibre sector still responsible for 81.9% of New Zealand's merchandise exports in the year to June 2023 (MPI, 2023), the tension between economic prosperity and the state of our environment is apparent.

It is this context, that the OLW National Science Challenge was established in 2016 with a primary objective to enhance the production and productivity of New Zealand's primary sector, while maintaining and improving the quality of the country's land and water for future generations.

One of the Challenge's three research themes is Pathways to Transition, with a focus on halving the time to adoption of tools, technology and innovation needed for New Zealand to achieve its environmental goals through farmers and growers transitioning to the most sustainable land use and management practices (OLW, 2024).

The Catchment Synthesis scenario project was intended to undertake scenario modelling to determine how a water quality target could be met in up to three catchments by changing land use. These scenarios would ideally not compromise profitability, increase GHG emissions, or result in other environmental impacts.

The three catchments being investigated are Tukituki (Hawke's Bay), Te Hoiere (Marlborough) and South Coastal Canterbury [Waihao] (Canterbury). These catchments have pre-existing community-defined water quality objectives that are unlikely to be achieved through reasonable mitigation efforts alone. Water quality in these catchments is responding directly to current agricultural land use, and this is the dominant cause of poor water quality.

All three catchments are briefly described below.

2.1 Tukituki catchment

(Source: Hawkes Bay Regional Council)

The Tukituki catchment in Hawkes Bay is approximately 221,000 hectares in area and generally encapsulates the land surrounding the Tukituki and Waipawa Rivers. The footprint extends west to the

Ruahine Ranges and east to the southern coastal hills of Hawke's Bay. This area is dominated by the Ruataniwha Plains, the Ruataniwha Aquifer beneath, and the Papanui Aquifer near Ōtāne. Soils on the plains range from free-draining gravels to water-logged clays. A series of fault lines align with the ranges, namely the Mohaka and Ruahine faults. The climate is variable with higher rainfall in the mountains and a rain shadow across the plains. Temperatures are moderate-to-hot in summer with frosts in winter. The area is also prone to droughts and flooding.

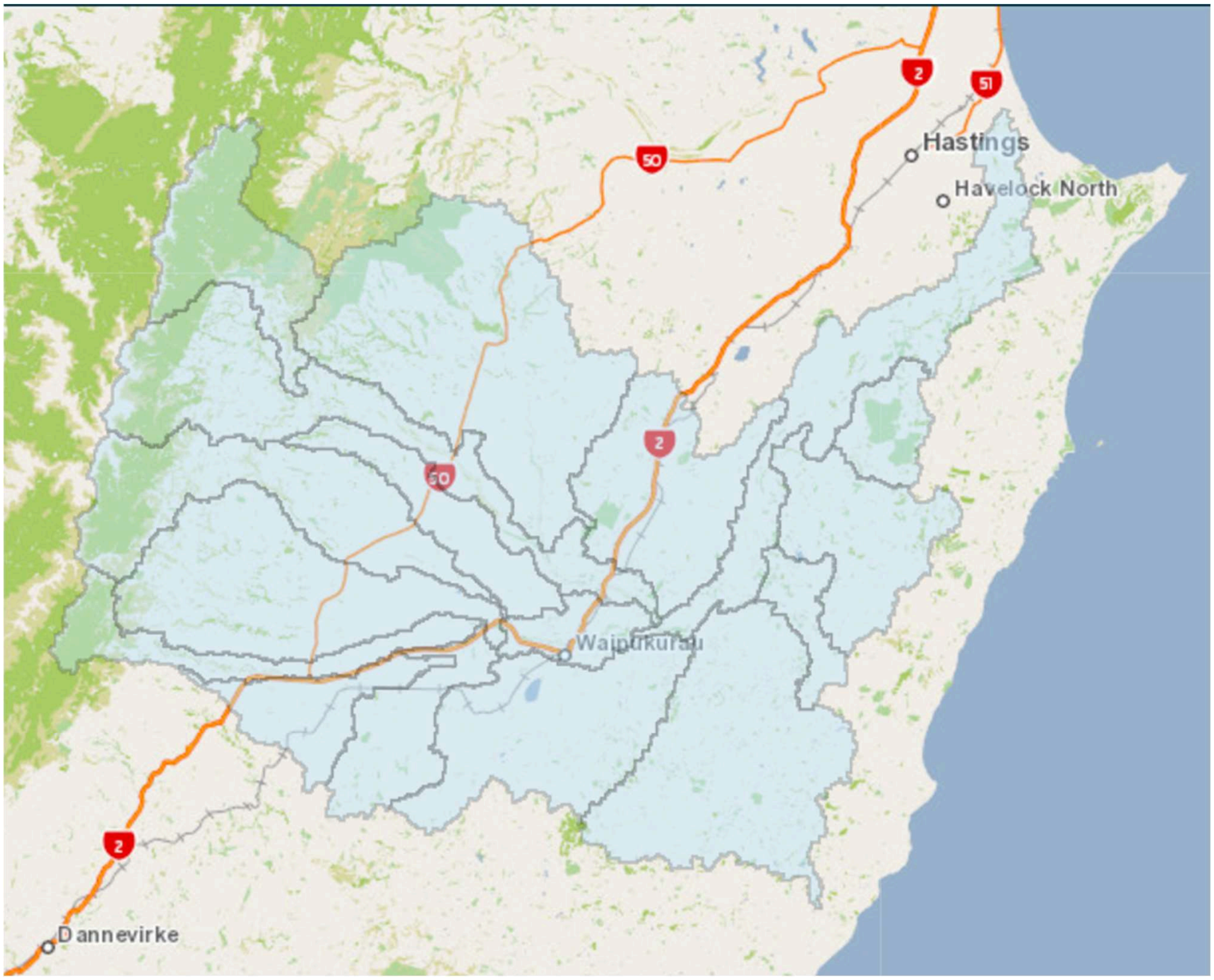


Figure 1: Map of the Tukituki catchment

Land use in the catchment is currently dominated by pastoral agriculture, with 75% of the catchment's land area in sheep and beef farming. Dairying accounts for approximately 5% of land use, on par with exotic production forestry.

Land use in the catchment is governed by the Tukituki Plan Change (2015). Under these rules, farmers and growers must now prepare farm environment management plans ("FEMPs"). Those farming in priority catchments – where nitrogen limits are exceeded – must also get a resource consent to manage the adverse effects of their farming activities on the environment. Although most applications are currently on hold. Ground and surface water for irrigation is essentially fully allocated, although an additional groundwater allocation, known as Tranche 2, is currently part of a current resource consent application and due to be heard in the Environment Court before the end of 2024.

The nitrogen limits at all monitoring sites on the Ruataniwha Plains are exceeded. Nitrogen concentrations reduce naturally in the river's main stem downstream, due to assimilation. Instream assimilation is driven by rapid and excessive algal (periphyton) growth in the river between Waipawa and the coast. A nutrient issue beginning in the Ruataniwha Plains becomes a periphyton problem in the Tukituki downstream of the Plains.

Phosphorus follows a similar pattern to nitrogen. There are high concentrations in the Plains – the main stem concentrations are highest around Central Hawke's Bay. DRP (Dissolved Reactive Phosphorus) concentrations are particularly high in the Mangatarata and Papanui tributaries of Tukituki River. These two rivers also score lowest for bug and insect counts (macroinvertebrates), which is a measure of stream health. Based on *E. coli* levels, these two rivers and the Tukituki River at Red Bridge do not meet national bottom-lines for swimming. Water clarity is neither especially good nor bad, and generally does meet guidelines for contact recreation. There is extremely elevated turbidity in the main stem during high flow events, reflecting the large distribution of sediment being carried down the Tukituki River during floods. Some wells on the Ruataniwha Plains and around the Papanui catchment have not met the drinking water standards for E. coli at least once over the five-year period 2013-2018, albeit not unexpected where there are shallow bores.

Nitrogen is considered the primary contaminant of concern for the Tukituki, followed by phosphorus.

2.2 Te Hoiere catchment

(Source: Henkel, 2021)

The area of the "Te Hoiere" catchment contains the catchments of several rivers, including the Te Hoiere/Pelorus River, Kaituna River and Cullen Creek. All catchments drain into the lower part of the Pelorus Sound/Te Hoiere. The area receives between 1,500 and 2,650 mm of rain annually, which represents some of the highest rainfall in the Marlborough region.

The soils across Te Hoiere are highly erodible, with clay content reaching up to 60%. The underlying geology in the valleys is mostly alluvial sediments and greywacke rock, with greywacke and schist in the mountains (Davidson & Wilson, 2011, Boffa Miskell & Marlborough District Council, 2015).

The catchment area of approximately 107,000 hectares is dominated by both indigenous vegetation (47%) and exotic forestry (27%). Pastoral land use makes up a comparatively small area of the catchment, with dairying comprising only 14.4% of land use (over half of which is irrigated) and sheep and beef farming at 7.7%.

Given a large component of the wider Te Hoiere catchment remains in native vegetation, water quality is generally considered good. Yet, State of the Environment monitoring has shown, that anthropogenic activities, such as pastoral land use and production forestry have caused water quality in some catchments to degrade. Subsequently, the Te Hoiere area was included in the "At Risk Catchment" programme of the Ministry of the Environment (MfE) and due to high biodiversity values, was designated as one of the 14 Ngā Awa rivers by the Department of Conservation (DoC).

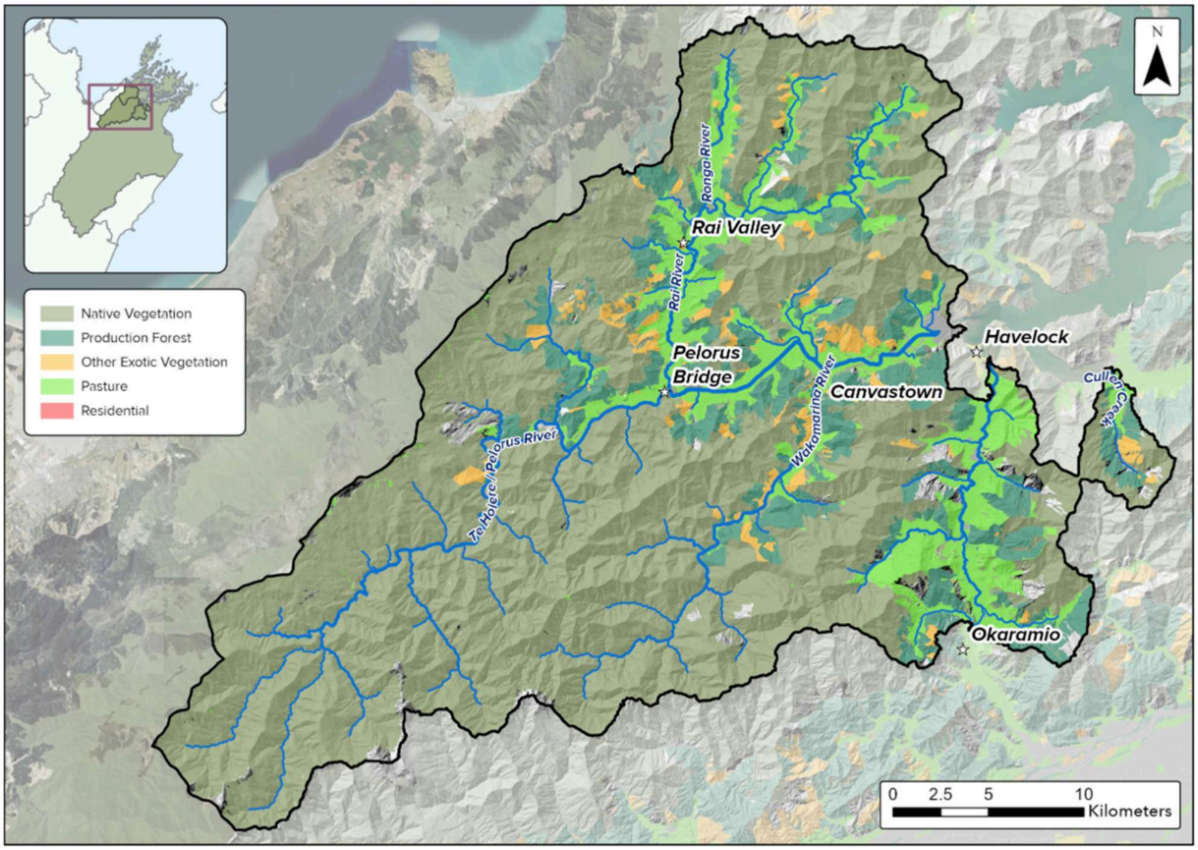


Figure 2: Map of the Te Hoiere catchment

In the most recent monitoring period, among the sub-catchments in the Te Hoiere catchment, Linkwater had the poorest water quality, showing the highest Ammoniacal Nitrogen, DRP and *E. coli* concentrations. Water quality in the Rai catchment was also comparatively poor. The catchments with the highest water quality were the Tunakino and Wakamarina. Apart from elevated DRP concentrations, waterways in catchments dominated by native vegetation maintained good water quality, with streambeds relatively clear of fine sediment and nuisance algae. It is likely that a large part of DRP in the Te Hoiere waterways originates from natural sources. Waterways flowing through pasture in the Te Hoiere/Pelorus had the poorest water quality, with the highest concentrations of Ammoniacal and Nitrate Nitrogen as well as *E. coli* and turbidity. Deposited fine sediment cover was also high. However, stream bed cover with filamentous and thick algae mats was comparatively low.

Streams flowing through catchments dominated by production forestry had elevated concentrations for all parameters monitored. In all land cover classes, rainfall caused an increase in the concentrations for most contaminants. Smaller streams generally had poorer water quality, with higher Ammoniacal Nitrogen and *E. coli* concentrations and higher turbidity compared to larger waterways. The difference was particularly noticeable in Te Hoiere/Pelorus pasture, for which animal access to the waterways was hypothesised as the likely reason.

E.coli is considered the primary contaminant of concern for the Te Hoiere, followed by sediment.

2.3 South Coastal Canterbury catchment

(Source: Canterbury Land and Water Regional Plan, ECan)

The South Coastal Canterbury catchment, the specific catchment area comprises the area between the Otaio River in the north and Morven Drain in the south, extending inland to the Hunter Hills. The area includes hill-fed intermittent flowing rivers and lowland springs with the major feature of the area being Wainono Lagoon. The area is within the takiwā of Te Rūnanga o Waihao and Te Rūnanga o Arowhenua.

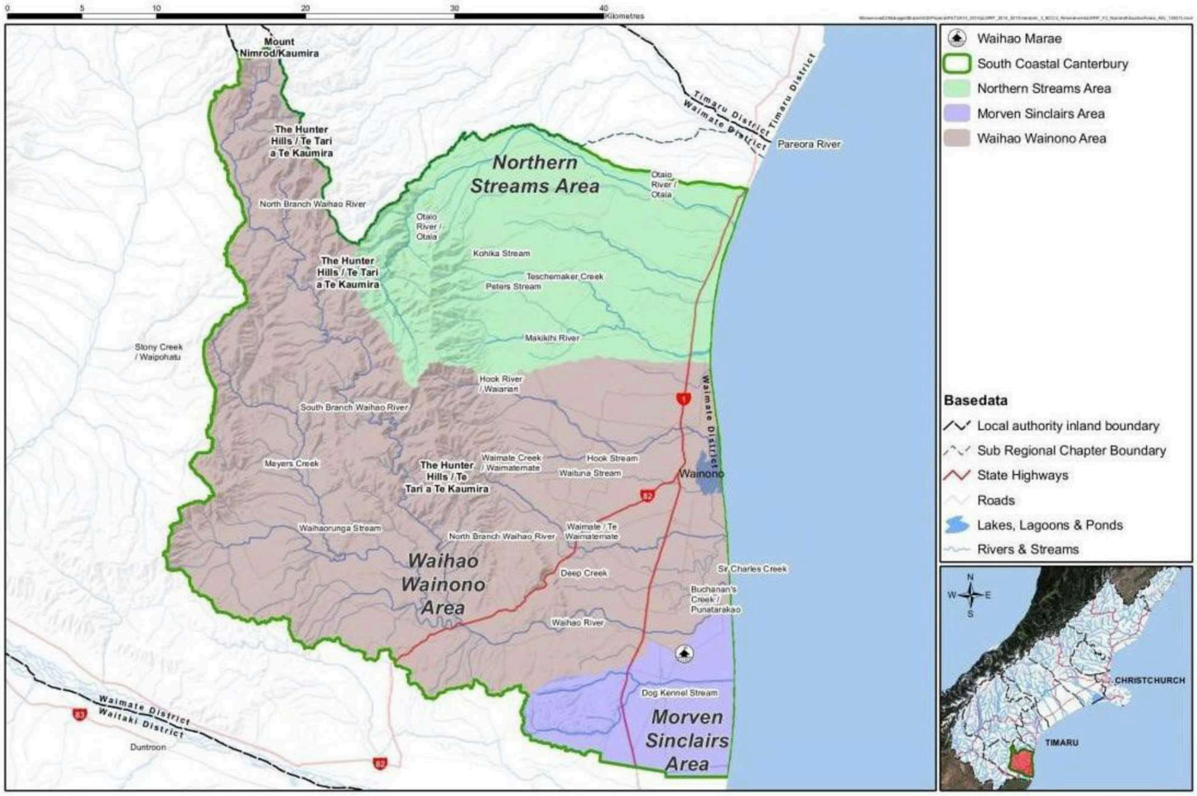


Figure 3: Map of the South Coastal Canterbury catchment

As a result of the geography and distinguishing features of the area, South Coastal Canterbury has been divided into three areas to manage freshwater quality:

(i) Northern Streams Area includes the Otaio River and the Makikihi River catchments and is characterised by the rivers and streams flowing directly to the Pacific Ocean.

(ii) Waihao-Wainono Area includes all the waterbodies from the Hook Beach drain catchment to the Waihao River which flow to, or have a flow connection with, Wainono Lagoon. Wainono Lagoon is the distinguishing feature of this area; it holds important ecological values and is a taonga for tangata whenua.

(iii) The Morven-Sinclairs Area includes Morven Drain and Sinclairs Creek catchments. The streams in this area flow directly to the Pacific Ocean. Most landowners are shareholders in the Morven Glenavy Irrigation Scheme which has been running since the 1970s.

Soils range from Recent soils on the plains to Yellow-Grey Earths on the downlands to Yellow-Brown Earths in the high country. Annual rainfall varies from 500 to 600 mm on the coast and drier downlands to 750 to 850 mm on the wetter downlands. The inland high country can receive as little as 300 mm on the plains to as much as 1500 mm on the higher country (Parker, 1985).

Most of the 110,000 hectare catchment is used for productive agriculture, dominated by sheep, beef and deer farming (50%), irrigated dairying (18%) and mixed arable systems (9%). Approximately 10% of the catchment area is in exotic production forestry.

In the last 30 years water use, irrigation and intensive land use have increased substantially in South Coastal Canterbury. In general, in-catchment water use is at or beyond sustainable limits for both surface and groundwater, and water quality has declined. Wainono Lagoon has seen the greatest effects on water quality with a continual decline since the first land clearance in the 1860s and 1870s. The area is now dependent on sourcing additional water for irrigation for further economic development to occur. South Coastal Canterbury lies to the north of the Waitaki River, and out-of-catchment water is accessible to irrigation schemes in the area.

The Lower Waitaki South Coastal Canterbury Zone Implementation Programme Addendum 2014 to the Regional Plan records the full package of actions to be implemented and includes both regulatory and nonregulatory recommendations. The key actions include the use of Farm Environment Plans throughout South Coastal Canterbury, specifically to help reduce the loss of sediment, phosphorus and nitrogen.

Nitrogen is considered the primary contaminant of concern for the South Coastal Canterbury catchment, followed by phosphorus.

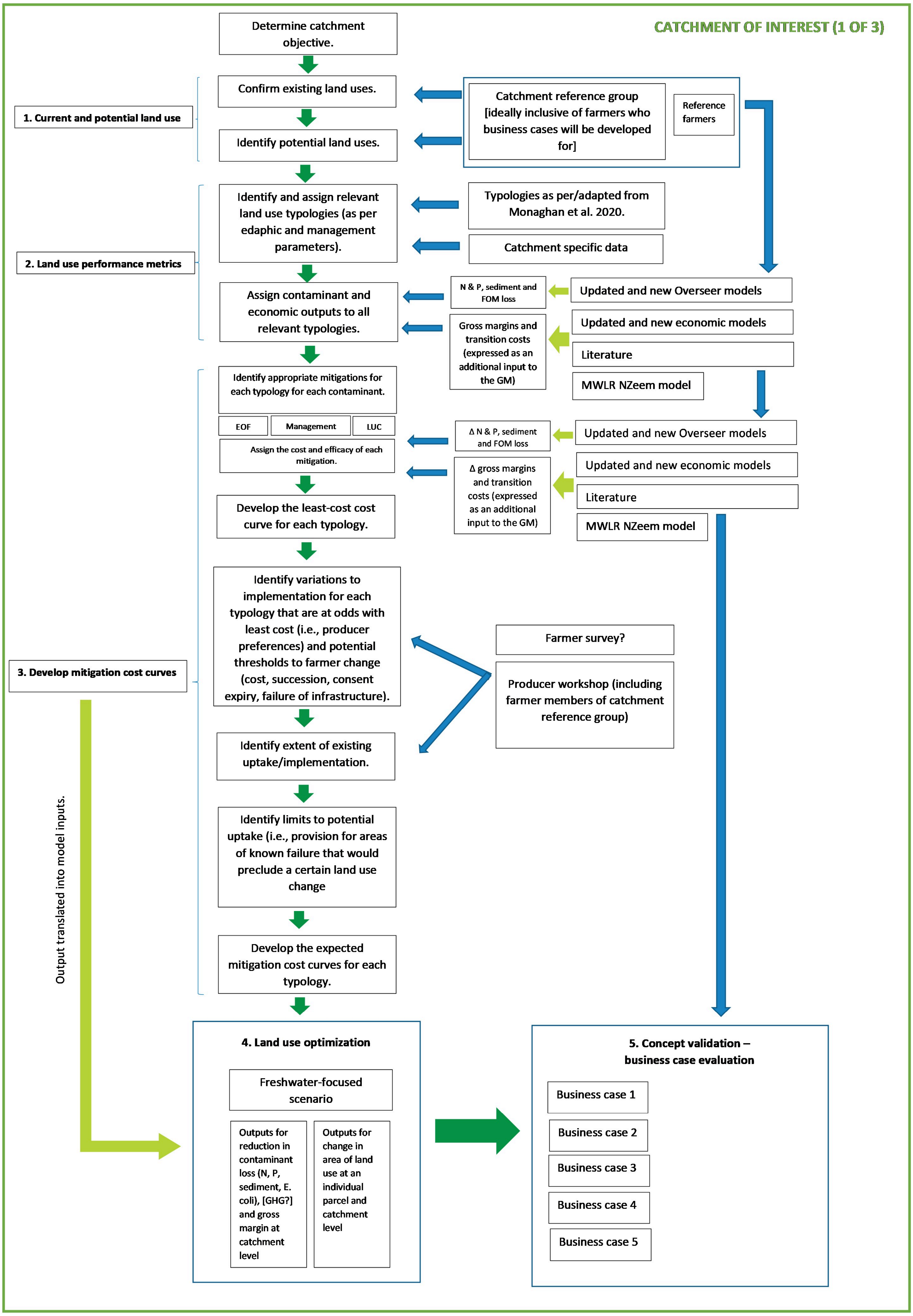


Figure 4: Original method concept for the Catchment Synthesis Scenarios project

3 Method

The method used for this research was derived from an original concept developed in the early stages of the project (Figure 4). This evolved over the course of the project, largely due to time pressures, varying levels of farmer engagement and the limitations of the various approaches used to deliver the research components.

The method used ultimately comprised seven key components. These were as follows:

(i) The delineation of the catchments of interest into polygons of discrete land use typologies.

(ii) The assignment of specific economic and environmental outputs to each typology, including potential future land uses.

(iii) Identifying the range of water quality mitigations applicable to each typology and calculating its estimated impact on its economic and environmental outputs.

(iv) Surveying farmers in the catchments about their preferences for the adoption of land management practices or land use changes.

(v) The development of catchment-specific mitigation cost curves based on applicable mitigations, but primarily informed by the adoption preferences of the surveyed farmers. These then needed to be adapted for use within the catchment models.

(vi) Creating specific geospatial catchment models and then using these to solve for scenarios of land management and land use change that would see national water quality targets achieved in both the catchments as a whole and in each specific sub-catchment.

(vii) Testing the feasibility of the property-level changes required to achieve catchment outcomes with real farms within the catchment.

3.1 Typology delineation

Each land use typology was defined by a discrete combination of geospatial layers. In forming the geospatial land use typology definitions, a combination of both publicly available and proprietary data layers were used.

Geospatial land use information from AgriBase (AsureQuality, 2024) for the most recent period of reporting (between 2001-2023) was collated, which was subsequently overlayed with additional geospatial information. These data sets were merged to create a master layer set. This layer contained polygons defined by the attributes from each data set. Table 1 presents the layer information for each of those used throughout this process.

Table 1: Layer information for each attribute used in geospatially defining typologies.

Data (attribute used)	Link to data source
Land cover data from MfE (Name_2018)	https://doi.org/10.26060/W5B4-WK93
NZLRI data (slope)	https://lris.scinfo.org.nz/layer/48076-nzlri-land-use-capability-2021/
Irrigated land area - 2020 - Aqualinc Research Limited (type)	https://data.mfe.govt.nz/layer/105407-irrigated-land-area-raw-2020-update/
Average annual rainfall (1972-2016) MfE (DN)	https://data.mfe.govt.nz/layer/89421-average-annual-rainfall-19722016/
Stream lengths (order 1,2 only clipped to each typology, shape length)	https://niwa.co.nz/freshwater/management-tools/environmental-flow-tools/river-environment-classification#:~:text=REC2%20provides%20a%20recut%20framework,and%20a%20better%20coastline%20contour.
FSL - Soil drainage class (Drain_Class)	https://lris.scinfo.org.nz/layer/112061-fsl-north-island-v11-all-attributes/

These layers and respective attributes were then utilised to form categories. Each polygon was allocated slope, irrigation, rainfall and drainage categories based on the geospatial layer attributes. Table 2 outlines how each of these categories were formed and what data from each layer was used.

Table 2: Data used to form slope, irrigation, rainfall and drainage categories of each polygon

Additional categories		Data criteria
OvrSlope	Flat	NZLRI slope - A/B
	Rolling	NZLRI slope - C
	Easy hill	NZLRI slope - D/E
	Steep	NZLRI slope - F/G/H
Irrigated	Non-irrigated	Irrigation data (Aqualink) - type = unknown and blank
	Irrigated	Irrigation data (Aqualink) - Type = Drip, Gun, K-line, Lateral, Pivot, Rotorainer
Rainfall	Very low	Rainfall data (MfE) - DN = <900mm
	Low	Rainfall data (MfE) - DN = 900-1200mm
	High	Rainfall data (MfE) - DN = >1200mm
Poorly drained		FSL = Drain class 1,2

Each land use typology is defined by geospatial layers and described by land use, wetness category (if applicable) and slope category (if applicable). Each typology was further delineated by slope at the polygon level. As a result, each catchment is ultimately comprised of polygons comprising a specific land use typology and slope class.

Once the master layer and corresponding attributes, which were restricted by the catchment boundaries were overlayed, individual attributes for each typology were defined. The attributes identified as the defining factors for typology parcels for all three catchments of interest are outlined in Appendix 1 to Appendix 14.

The process of typology definition drew heavily on the methods used in Monaghan et al. (2021).

The specific farm and horticultural systems that each typology represents were derived from both publicly available industry sources and published literature and then validated with external industry professionals and our own professional judgement.

Manual analysis of the catchment through aerial imagery was also used to validate catchment land use at a high level. This process included analyzing final typology areas, and working back to ensure each typology was truly present or obsolete. This process also involved merging or separating out typologies based on their degree of presence and likely management aspects. It should be noted that the assignation of typologies did not involve in-depth validation at a property level or of their individual land parcels and respected typology designation.

Typology definition parameters were adjusted for each catchment. This allowed for a closer alignment of what was occurring in practice and the model data.

The typologies have been described in terms of the characteristics also used in Monaghan et al. (2021). The below diagram (Figure 5) demonstrates how the nomenclature of each typology should be interpreted.

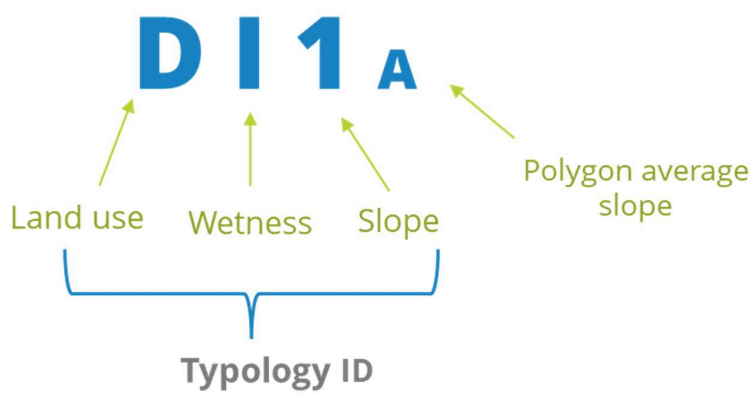


Figure 5: Nomenclature format of typologies

Based on the interpretation in the table below, DI1, for example, is irrigated dairy land use with an average slope for the typology of <15 degrees.

Table 3: Categories used to determine nomenclature for land use typologies

Land use	Wetness	Average slope	Polygon slope
Dairy (D)	Irrigated (I)	<15 degrees (1)	0-3 degrees (A)
Sheep + beef (SB)	Irrigated wet (IW)	>15 degrees (2)	4-7 degrees (B)
Deer (DE)	>1200 mm yr-1 (H)		8-15 degrees (C)
Arable (A)	1200-900 mm yr-1 (L)		16-20 degrees (D)
Vegetable (VE)	<900 mm yr-1 (VL)		21-25 degrees (E)
Viticulture (VT)			26-35 degrees (F)
Fruit (FR)			36-42 degrees (G)
Exotic forestry (EF)			≥ 42 degrees (H)
Indigenous forestry (IF)			
Gorse/broom (GB)			
Matagouri/grey scrub (MS)			
Lifestyle (L)			

A property can be made up of polygons of multiple typologies i.e., a breeding-finishing sheep and beef farm will likely be made up of SB1, SB2, IF and EF typologies.

3.2 Economic and environmental outputs

Baseline ("unmitigated") economic and environmental outputs were then determined for each land use typology in each catchment. Farm and orchard systems were modelled using conventional software where possible, namely FARMAX Red Meat or FARMAX Dairy and OverseerSci, the latter utilising the Overseer Best Practice Data Entry Standards. Geophysical inputs (climate data and soil type) were generated based on GPS coordinates for each farm systems, utilising the inbuilt climate station tool in OverseerSci and S-map soil data. Additional financial modelling was undertaken using proprietary models built in Microsoft Excel.

Both the input parameters and the subsequent outputs were validated with regional professionals and some farmers within each of the catchments to ensure they were a reasonable representation of medium-term expectations. The prices used for revenues and expenses attempted to look through the current volatility and cost-price inflation being experienced within the sectors. In this sense they could be considered as being representative of medium-term pricing expectations.

The profitability measures also accounted for the amortized cost of capital of marginal assets involved in the farm system (i.e., livestock, supplier shares etc.) over a 20-year time frame and a 5% discount rate. The base profitability measures determined for typologies following land use change include the net amortized cost of capital of all deployed assets other than land (i.e., cost of conversion[2], capital released from the sale of livestock assets because of changing land use, supplier shares etc.). In these

[2] For permanent horticulture systems, this would include on-farm Irrigation, all rootstock, trees & structures, working capital, frost protection, plant & equipment and ancillary buildings. It was assumed unlicensed varieties of pipfruit would be established.

instances, a positive profit measure implies that the land use change has a payback period within 20 years.

3.2.1 Farm, orchard, and forest system modelling

An agronomically feasible farm model was constructed in FARMAX for all pastoral land use typologies in each catchment. These utilised publicly available data sources (as well as the authors' proprietary knowledge) to derive the key production parameters for the farms system appropriate to the region in which the catchment was located. These sources included:

- New Zealand Dairy Statistics 2022-23 (LIC & DairyNZ, 2023)
- 2021-22 DairyNZ Economic Survey (DairyNZ, 2023)
- Beef+Lamb NZ Sheep & beef farm surveys (B+LNZ, 2023)

The economic outputs for typologies designated as "lifestyle", all flat/rolling contour, were set as the equivalent of their (lower productivity) hill country equivalents for the same wetness categories (in line with the approach in Parsons et al. (2015)) and adjusted for a lower level of capital deployed. It is accepted that these smaller properties might not be commercially, and their economic output estimates are potentially overstated. They do, typically, have a high level of intrinsic value to their owners that well exceeds any commercial return, so assigning a positive economic yield to these properties makes sense.

Arable and horticultural systems were modelled in Microsoft Excel, using relevant production and performance metrics from available sources, including:

- MPI Pipfruit and Viticulture monitoring reports (MPI, 2017)
- Archer and Brookes (2018).
- Norris et al. (2018).

Estimates of exotic forestry profitability were derived from a discounted cashflow methodology over two rotations (54 years), incorporating carbon revenue in the first rotation under the averaging regime at a price of $70/NZU (claimed every five years) and a discount rate of 5%. Rates of carbon sequestration appropriate for the catchments were obtained from published MPI carbon look-up tables[3]. An annuity that generated an identical net present value to the stream of cashflows under these assumptions was then used as a proxy for the annual enterprise margin. It is acknowledged that the relative profitability of forestry is highly sensitive to carbon revenues in the first 15-17 years.

Outputs were all expressed on a per hectare basis. These along with their primary sources are described in Table 4 below.

[3] https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns-and-carbon-units-nzus-for-forestry/calculating-the-amount-of-carbon-in-your-forest-land/carbon-tables-for-calculating-carbon/

Table 4: Description of economic and environmental outputs

Output	Metric	Source	Comment
Enterprise margin	$ ha^{-1}	Modelled in Farmax software or calculated from MS Excel models	This is essentially operating profit, or EBITRm – earnings before interest, tax, rental and wages of management – but also includes the amortized cost of capital of marginal assets (i.e., livestock, supplier shares etc.) over a 20-year time frame and a 5% cost of capital. Base enterprise margins determined for typologies following land use change include the net amortized cost of capital of all deployed assets other than land (i.e., cost of conversion, Δ livestock, supplier shares etc.).
N loss	kg N ha^{-1} yr^{-1}	Modelled in OverseerSci or derived from literature	Estimates for gorse derived from Magesan and Wang (2008). A direct allowance for septic tank losses was applied to lifestyle properties.
P loss	kg P ha^{-1} yr^{-1}	Modelled in OverseerSci or derived from literature	
Sediment loss	t km^{-2} yr^{-1}	GIS layer from OLW data supermarket	Median suspended sediment yields under climate change – Manaaki Whenua Landcare Research https://landuseopportunities.nz/dataset/climate-change-impacts-on-suspended-sediment-loads-in-new-zealand
Pathogens	*E. coli* ha^{-1} yr^{-1}	Derived from literature	CLUES outputs [Daigenault and Elliott, 2017.]
CH_4	kg CH_4 yr^{-1}	Modelled in OverseerSci and MFE emissions calculator	OverseerSci https://environment.govt.nz/what-you-can-do/agricultural-emissions-calculator/
N_2O	kg CO_2e yr^{-1}	Modelled in OverseerSci, HortNZ emissions calculator and derived from literature	OverseerSci https://www.hortnz.co.nz/environment/national-policy/climate/he-waka-eke-noa/know-your-number-emissions-calculator/
CO_2	kg CO_2 yr^{-1}	Modelled in OverseerSci, HortNZ emissions calculator and derived from literature. Sequestration rates for forest species derived	Biogenic CO_2 only OverseerSci https://www.hortnz.co.nz/environment/national-policy/climate/he-waka-eke-noa/know-your-number-emissions-calculator/

		from MPI and literature.	Carswell et al. (2013) provided sequestration estimates for gorse.
Total GHG	kg CO_2e yr^{-1}	Calculated from above using a GWP_{100} of 28 kg CO_2e for CH_4 and 298 kg CO_2e for N_2O	Biogenic sources only

The summarised physical, financial and environmental performance of all the typologies for each of the catchments are summarised in Table 5 through to Table 10 below.

Table 5: Physical and financial parameters of the land use typologies for the Tukituki catchment

Typology	Description	Slope	Wetness	Rainfall	Area	Milk production	Annual stocking rate		Forage crop area	Enterprise margin
				mm yr^{-1}	ha	kg MS ha^{-1} yr^{-1}	Cows ha^{-1}	RSU ha^{-1}	%	\$ ha^{-1} yr^{-1}
DI1	Dairy irrigated	Flat (2.4°)	Irrigated	966	3,011	1,685	3.3	-	0%	$4,550
DH1	Dairy wet dryland	Rolling (8.3°)	Moist	1,344	3,535	958	2.5	-	0%	$2,964
DL1	Dairy dryland (low/very low)	Flat (5.5°)	Dry	1,034	4,032	796	2.1	-	0%	$2,053
SBI1	SB finishing (irrigated)	Flat (2°)	Irrigated	914	6,026	-		11.3	22%	$1,792
SBH1	SB finishing (high rainfall)	Undulating (4.2°)	Moist	1,464	9,942	-		12.8	2%	$461
SBL1	SB finishing (low rainfall)	Flat (3.2°)	Dry	1,046	22,292	-		9.4	2%	$543
SBVL1	SB finishing (very low rainfall)	Undulating (5.2°)	Very dry	830	25,092	-		7.1	7%	$253
SBVL2	SB breeding (very low rainfall)	Moderately steep (22°)	Very dry	832	33,166	-		7.5	0%	$369
SBH2	SB breeding (high rainfall)	Moderately steep (25°)	Moist	1,531	26,116	-		9.8	0%	$292
SBL2	SB breeding (low rainfall)	Moderately steep (23°)	Dry	1,054	42,285	-		10.0	0%	$500
DEH1	Deer finishing (high rainfall)	Strongly rolling (19.1°)	Moist	1,326	1,478	-		12.3	3%	$226
DEL1	Deer finishing (low/very low rainfall)	Undulating (6.7°)	Dry	980	1,492	-		10.7	3%	$53
AI1	Arable (irrigated)	Flat (1.8°)	Irrigated	814	578	-		-	-	$2,637
AL1	Arable dryland (low rainfall)	Flat (2.2°)	Dry	1,047	900	-		-	-	$1,434
VEI1	Vegetable (irrigated)	Flat (1.5°)	Irrigated	812	203	-		-	-	$11,906
FRI1	Fruit (irrigated)	Flat (1.5°)	Irrigated	849	805	-		-	-	$26,420
VTI1	Viticulture (irrigated)	Flat (1.5°)	Irrigated	750	102	-		-	-	$9,082
EF1	Exotic forestry (gentle)	Undulating (4.2°)	Moist	1,201	2,322	-		-	-	$525
EF2	Exotic forestry (steep)	Moderately steep (24°)	Moist	1,255	9,087	-		-	-	$525
IF1	Indigenous forestry (gentle)	Undulating (5°)	Moist	1,463	1,325	-		-	-	-$264
IF2	Indigenous forestry (steep)	Steep (34°)	Moist	1,785	25,540	-		-	-	-$264
LH1	Lifestyle (high rainfall)	Strongly rolling (17°)	Moist	1,355	104	-		-	-	$367
LL1	Lifestyle (low rainfall)	Undulating (7.3°)	Dry	1,042	683	-		-	-	$527
LVL1	Lifestyle (very low rainfall)	Rolling (10°)	Very dry	807	1,516	-		-	-	$396

Table 6: Environmental parameters of the land use typologies for the Tukituki catchment

Typology	Description	N loss	P loss	Sediment yield	E. coli	CH_4	N_2O	CO_2	Total GHG
		kg N ha^{-1} yr^{-1}	kg P ha^{-1} yr^{-1}	t km^{-2} yr^{-1}	'000 E. coli ha^{-1} yr^{-1}	kg CH_4 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}	kg CO_2 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}
DI1	Dairy irrigated	60	0.8	894	4,100,000	435	3,032	290	15,393
DH1	Dairy wet dryland	42	1.0	1,891	4,100,000	307	2,167	182	10,866
DL1	Dairy dryland (low/very low)	29	0.6	1,104	4,100,000	256	1,841	178	9,112
SBI1	SB finishing (irrigated)	32	0.9	1,187	4,000,000	112	1,353	146	4,594
SBH1	SB finishing (high rainfall)	22	1.0	5,940	4,000,000	144	1,069	16	5,081
SBL1	SB finishing (low rainfall)	12	0.4	2,102	4,000,000	98	757	16	3,483
SBVL1	SB finishing (very low rainfall)	14	0.3	1,657	4,000,000	78	829	35	3,038
SBVL2	SB breeding (very low rainfall)	7	0.5	3,203	4,000,000	86	537	0	2,929
SBH2	SB breeding (high rainfall)	15	1.1	8,791	4,000,000	101	622	0	3,423
SBL2	SB breeding (low rainfall)	9	1.0	6,171	4,000,000	111	715	0	3,806
DEH1	Deer finishing (high rainfall)	23	0.6	2,127	600,000	118	818	8	4,112
DEL1	Deer finishing (low/very low rainfall)	16	0.7	2,221	600,000	104	786	28	3,711
AI1	Arable (irrigated)	23	0.8	771	200,000	116	800	200	4,219
AL1	Arable dryland (low rainfall)	17	0.8	1,235	200,000	140	500	100	4,485
VEI1	Vegetable (irrigated)	27	1.7	450	1,600,000	-	1,664	78	1,742
FRI1	Fruit (irrigated)	15	0.2	380	1,600,000	-	-	0	526
VTI1	Viticulture (irrigated)	9	0.6	240	1,600,000	-	-	0	526
EF1	Exotic forestry (gentle)	3	0.2	2,612	400,000	-	-	(27,350)	(27,350)
EF2	Exotic forestry (steep)	3	0.2	3,562	400,000	-	-	(27,350)	(27,350)
IF1	Indigenous forestry (gentle)	3	0.2	5,909	400,000	-	-	(7,935)	(7,935)
IF2	Indigenous forestry (steep)	3	0.2	4,063	400,000	-	-	(7,935)	(7,935)
LH1	Lifestyle (high rainfall)	19	1.1	3,461	4,000,000	101	622	0	3,423
LL1	Lifestyle (low rainfall)	13	1.0	1,821	4,000,000	111	715	0	3,806
LVL1	Lifestyle (very low rainfall)	11	0.5	1,167	4,000,000	86	537	0	2,929

Table 7: Physical and financial parameters of the land use typologies for the Te Hoiere catchment

Typology	Description	Slope	Wetness	Rainfall	Area	Milk production	Annual stocking rate		Forage crop area	Enterprise margin
				mm yr^{-1}	ha	kg MS ha^{-1} yr^{-1}	Cows ha^{-1}	RSU ha^{-1}	%	\$ ha^{-1} yr^{-1}
DI1	Dairy irrigated	Undulating (5.7°)	Irrigated	1627	632	1,497	3.3		-	$4,794
DH1	Dairy wet dryland	Undulating (5.2°)	Moist	1,623	4,256	1,198	2.8		8%	$3,920
DH2	Dairy wet dryland (steep)	Steep (28.4°)	Moist	1,635	1,595	787	2.1		8%	$2,373
SBH1	SB finishing (high rainfall)	Undulating (4.9°)	Moist	1,602	3,361			11.5	0%	$444
SBH2	SB breeding (high rainfall)	Steep (29.5°)	Moist	1,590	2,916			12.7	0%	$314
EF1	Exotic forestry (gentle)	Undulating (7.2°)	Moist	1,630	1,243					$378
EF2	Exotic forestry (steep)	Steep (29.3°)	Moist	1,619	14,255					$208
IF1	Indigenous forestry (gentle)	Undulating (6.8°)	Moist	1,677	1,512					-$70
IF2	Indigenous forestry (steep)	Steep (31.1°)	Moist	1,877	76,537					-$103
GB2	Gorse/broom (steep)	Steep (27.5°)	Moist	1,645	935					$0
LH1	Lifestyle (high rainfall)	Rolling (9.6°)	Moist	1,612	369					$295

Table 8: Environmental parameters of the land use typologies for the Te Hoiere catchment

Typology	Description	N loss	P loss	Sediment yield	E. coli	CH_4	N_2O	CO_2	Total GHG
		kg N ha^{-1} yr^{-1}	kg P ha^{-1} yr^{-1}	t km^{-2} yr^{-1}	'000 E. coli ha^{-1} yr^{-1}	kg CH_4 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}	kg CO_2 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}
DI1	Dairy irrigated	128	2.8	3,048	4,100,000	427	3,655	263	15,772
DH1	Dairy wet dryland	60	1.5	2,579	4,100,000	343	2,743	212	12,471
DH2	Dairy wet dryland (steep)	30	4.4	3,177	4,100,000	251	1,499	142	8,604
SBH1	SB finishing (high rainfall)	17	0.5	2,709	4,000,000	125	920	-	4,399
SBH2	SB breeding (high rainfall)	20	3.9	2,835	4,000,000	139	698	-	4,559
EF1	Exotic forestry (gentle)	3	0.2	1,247	400,000	-	-	(19,300)	(19,300)
EF2	Exotic forestry (steep)	3	0.2	1,233	400,000	-	-	(19,300)	(19,300)
IF1	Indigenous forestry (gentle)	3	0.2	1,139	400,000	-	-	(7,935)	(7,935)
IF2	Indigenous forestry (steep)	3	0.2	1,364	400,000	-	-	(7,935)	(7,935)
GB2	Gorse/broom (steep)	38	0.2	1,326	400,000	-	-	(15,300)	(15,300)
LH1	Lifestyle (high rainfall)	24	2.1	2,255	4,000,000	-	-	-	4,559

Table 9: Physical and financial parameters of the land use typologies for the South Coastal Canterbury catchment

Typology	Description	Slope	Wetness	Rainfall	Area	Milk production	Annual stocking rate		Forage crop area	Enterprise margin
				mm yr^{-1}	ha	kg MS ha^{-1} yr^{-1}	Cows ha^{-1}	RSU ha^{-1}	%	\$ ha^{-1} yr^{-1}
DI1	Dairy irrigated (flat/rolling)	Undulating (3.9)	Irrigated	591	19,411	1,455	3.4			$4,586
DI2	Dairy irrigated (easy hill/steep)	Moderately steep (21.5)	Irrigated	598	379	1,120	2.7			$3,649
DVL2	Dairy dryland extensive (very low rainfall; rolling/easy/steep)	Strongly rolling (17.9)	Very dry	660	3,802	721	1.9		8%	$1,761
SBI1	SB finishing (irrigated)	Undulating (6.2)	Irrigated	590	6,184			-	4%	$1,134
SBVL1	SB finishing (very low rainfall)	Rolling (7.5)	Very dry	648	26,071			13	14%	$356
SBVL2	SB breeding (very low rainfall)	Moderately steep (23.3)	Very dry	718	15,012			5		$136
SBVL3	SB breeding (high country, very low rainfall)	Steep (26.5)	Very dry	786	6,746			1		$71
DEVL1	Deer finishing (very low rainfall)	Undulating (6)	Very dry	617	902			-	7%	$1,049
DEVL2	Deer breeding (very low rainfall)	Moderately steep (21.4)	Very dry	650	345			-	10%	-$16
AI1	Arable (irrigated)	Flat (2.3)	Irrigated	567	2,238					$3,091
AVL1	Arable dryland (very low rainfall)	Undulating (4.0)	Very dry	585	7,760					$1,914
FRI1	Fruit (irrigated)	Flat (1.5)	Irrigated	576	20					$21,928
EF1	Exotic forestry (gentle)	Rolling (8.2)	Very dry	685	4,401					$188
EF2	Exotic forestry (steep)	Moderately steep (25.2)	Very dry	706	6,323					$4
IF1	Indigenous forestry (gentle)	Undulating (7.4)	Very dry	667	405					-$70
IF2	Indigenous forestry (steep)	Moderately steep (25)	Very dry	707	3,872					-$103
GB1	Gorse/broom (gentle)	Undulating (5.8)	Very dry	653	916					$0
GB2	Gorse/broom (steep)	Moderately steep (25.5)	Very dry	679	1,900					$0
MS2	Matagouri/grey scrub (steep)	Moderately steep (24.2)	Very dry	785	2,645					$0
LVL1	Lifestyle (very low rainfall)	Undulating (3.5)	Very dry	596	1,250					$172

Table 10: Environmental parameters of the land use typologies for the South Coastal Canterbury catchment

Typology	Description	N loss	P loss	Sediment yield	E. coli	CH_4	N_2O	CO_2	Total GHG
		kg N ha^{-1} yr^{-1}	kg P ha^{-1} yr^{-1}	t km^{-2} yr^{-1}	'000 E. coli ha^{-1} yr^{-1}	kg CH_4 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}	kg CO_2 ha^{-1} yr^{-1}	kg CO_2e ha^{-1} yr^{-1}
DI1	Dairy irrigated (flat/rolling)	49	2.4	402	4,100,000	385	3,193	294	14,184
DI2	Dairy irrigated (easy hill/steep)	18	1.8	1,108	4,100,000	315	2,524	294	11,558
DVL2	Dairy dryland extensive (very low rainfall; rolling/easy/steep)	11	0.5	1,962	4,100,000	194	1,419	192	7,000
SBI1	SB finishing (irrigated)	13	0.4	782	4,000,000	125	1,073	120	4,671
SBVL1	SB finishing (very low rainfall)	4	0.1	703	4,000,000	125	905	11	4,385
SBVL2	SB breeding (very low rainfall)	4	0.1	1,231	4,000,000	59	340	-	1,966
SBVL3	SB breeding (high country, very low rainfall)	4	0.2	758	4,000,000	15	89	-	506
DEVL1	Deer finishing (very low rainfall)	4	0.4	362	600,000	139	865	5	4,722
DEVL2	Deer breeding (very low rainfall)	5	0.2	600	600,000	165	986	7	5,584
AI1	Arable (irrigated)	20	0.3	323	200,000	27	711	81	1,550
AVL1	Arable dryland (very low rainfall)	16	0.1	330	200,000	19	521	81	1,138
FRI1	Fruit (irrigated)	7	0.1	314	1,600,000	-	733	76	809
EF1	Exotic forestry (gentle)	3	0.2	303	400,000	-	-	(15,000)	(15,000)
EF2	Exotic forestry (steep)	3	0.2	193	400,000	-	-	(15,000)	(15,000)
IF1	Indigenous forestry (gentle)	3	0.2	380	400,000	-	-	(7,935)	(7,935)
IF2	Indigenous forestry (steep)	3	0.2	304	400,000	-	-	(7,935)	(7,935)
GB1	Gorse/broom (gentle)	38	0.2	390	400,000	-	-	(15,300)	(15,300)
GB2	Gorse/broom (steep)	38	0.2	382	400,000	-	-	(15,300)	(15,300)
MS2	Matagouri/grey scrub (steep)	3	0.2	375	400,000	-	-	(5,280)	(5,280)
LVL1	Lifestyle (very low rainfall)	7	0.1	389	4,000,000	59	340	-	1,966

3.3 Mitigations

A master water quality mitigation library was compiled from literature. The impact of the discrete adoption of each mitigation on the four main water quality contaminants, biogenic greenhouse gas (GHG) emissions and economic output was calculated on a per hectare basis using a standardised method for each mitigation. Modelling, as per the baseline outputs, was utilised where possible, otherwise impacts were manually estimated from the empirical observations in published research.

A total of 33 possible mitigations were considered, noting not all were applicable to every typology across all three catchments. These comprised five farm system ("FS") mitigations, nineteen general ("G") mitigations, seven edge of field mitigation ("EOF") and two [partial] land use change ("LUC") mitigations. These are summarised in Table 11 below.

Table 11: Summary of the mitigation library used for the Catchment Synthesis Scenarios project

Mitigation	Description	Type	Primary modelling assumption	Sources of mitigation efficacy
1	Reduced stocking rates	FS	Lower SR by 0.3 cows/ha [dairy only]	OverseerSci
2	Increased sheep : cattle ratio	FS	Increase sheep ratio by up to 10% if possible to a max of 80% sheep : 20 % cattle.	OverseerSci
3	Reduced forage cropping	FS	Eliminate summer cropping (if any): for dairy, replace feed with up to 3kg PKE/cow, then lower production. For drystock, reduce feed demand (i.e., sell lambs store). Reduce winter cropping (if any) by 50%.	OverseerSci
4	Reduce N fertiliser use	G	For pastoral farms, annual N fertiliser usage is reduced to no more than 100 kg N/ha. For vegetable and arable activities, one scheduled N application was eliminated.	OverseerSci
5	Lined effluent ponds	EOF	Installation of dairy effluent storage with an impermeable liner.	Longhurst et al. (2013)
6	Variable rate irrigation	G	Moving from a uniform return interval to based on soil moisture levels.	Hedley et al. (2009)
7	Off-paddock structures - with roof	G	Construction of a barn and integration into pastoral	Journeaux and Newman (2015)

			dairying system based on range of case studies.	
8	Stand-off pads - no roof	G	Construction of an uncovered stand-off area and integration into pastoral dairying system.	Smith & Muirhead (2019) [Cardenas et al. (2011); Christensen et al. (2012); de Klein et al. (2006); Ledgard et al. (2006)]
9	Retention dams, bunds or sediment traps	EOF	Installation of a bund for every 50 ha of catchment.	Monaghan 2021, Daigneault & Elloitt 2017, Barber et al. 2019, Levine 2020
10	Facilitated wetlands	EOF	Enhancement of a wetland equivalent to 2% of treatment area.	Tanner et al. (2022), Sukias & Tanner (2023), Daigneault & Elliott (2017)
11	Constructed wetlands	EOF	Construction of a wetland equivalent to 4% of treatment area.	Tanner et al. (2022), Sukias & Tanner (2023), Daigneault & Elliott (2017)
12	Stream fencing	EOF	The fencing of both sides of REC 1 & 2 waterways with a 1 m buffer.	Doole 2015, Daigneault & Elliott 2017
13	Riparian planting (incl. forestry)	EOF	The increase in buffer of 2.5 m for all fenced REC 1 & 2 waterways and subsequent riparian planting.	Muller et al 2022, NIWA 2010
14	Vegetated buffer strips (for arable cropping)	EOF	Creating and maintaining a 5 m buffer from all arable activity.	Barber & Stenning 2021
15	Space planted trees	EOF	Planting poles at 40 SPH on 10% of all land >16 degree slope.	Daigneault & Elliott (2017)
16	Increased effluent area	FS	Increase effluent area such that N/ha in effluent reduces to 100 kg N/ha.	Matheson et al. 2018, OverseerSci
17	Reduced N to effluent area	FS	All fertiliser N to effluent areas eliminated. Up to 3 kg/cow/day of PKE fed to replace feed deficit,	OverseerSci

			otherwise reduce production	
18	Minimum tillage	G	Use of minimum (shallow) tillage practices in lieu of full cultivation.	Daigneault & Elliott 2017 Matheson et al 2018
19	Zero tillage	G	Use of zero tillage practices (direct drilling) in lieu of full cultivation.	Daigneault & Elliott 2017
20	Variable rate fertiliser	G	Applying variable rates of maintenance fertiliser across the landscape based on pre-determined spatial and fertility characteristics.	McDowell et al. 2021.
21	Cover crops	G	A cover crop at the end of autumn to ensure there is no winter fallow.	Daigneault & Elliott (2017), Matheson et al. 2018 [Low et al. 2017]
22	Catch crops for forage cropping	G	Sowing of a crop at the end of a winter forage crop ahead of establishing new pasture.	OverseerSci
23	Diverse pastures (i.e., plantain)	G	20% of farm area qualifies as having a sward content as 30% plantain/"diverse pasture"	OverseerSci
24	Irrigating based on soil moisture	G	Moving from FF to a uniform return interval (URI) with trigger and targets based on soil moisture in core blocks of farm.	Bright et al. 2018
25	Reduce soil P test to optimum	G	Applying P fertiliser sufficient to maintain soil Olsen P test levels at the agronomic optimum for soil type and land use activity.	McDowell et al 2013.
26	Use of low water-soluble P fertiliser	G	Replacement of superphosphate with dicalcic for all fertiliser P applications.	Smith & Muirhead (2019) [McDowell & Catto (2005), McDowell et al. (2010), McDowell & Smith (2012), Sharpley & Syers (1979)]

27	Deferred and low-rate effluent application	G	Application of farm dairy effluent to a depth of <12 mm	Smith & Muirhead (2019) [Houlbrooke et al. (2006); Monaghan et al. (2010); Muirhead et al. (2011); Muirhead (2013)]
28	Applying alum to pasture and crops 100%	G	Applying a single annual application of 20 kg Al as alum to all pasture and crops.	Smith & Muirhead (2019) [McDowell (2010; 2015); McDowell & Norris (2014)]
29	Applying alum to pasture and crops just to critical source areas (CSAs).	G	Applying a single annual application of 20 kg Al as alum to all pastoral and crop critical source areas.	Monaghan et al. 2021.
30	Fence-line pacing prevention	G	Installation of buffer fence and vegetated screen.	Smith & Muirhead (2019) [McDowell et al. (2004, 2006)]
31	Alternative wallowing	G	Creation of new wallows away from flow paths and remediation of existing wallows.	Smith & Muirhead (2019) [McDowell (2008,2009)]
32	Land retirement (permanent native forestry)	LUC	Establishment of indigenous forest on polygons with a slope of >25 degrees. Sediment load estimated to reduce by 90% following land use change.	OverseerSci Dymond et al. (2010); Dymond et al. (2016).
33	Plantation forestry	LUC	Establishment of P. radiata forest on polygons with a slope of 16-25 degrees. Sediment load estimated to reduce by 80% following land use change.	OverseerSci Vale et al. (2021).

It is recognised that the mitigation library is not exhaustive, and there are actions not included which farmers may have already adopted or are considering, that they believe help mitigate water quality contaminants. Exclusion from the mitigation library was primarily due to insufficient literature on the efficacy in the New Zealand environment, lack of alignment with other analyses, or an inability to model such actions within the tools used, either at farm or catchment level.

The changes to unmitigated outputs from a discrete application of each mitigation was typically reported in modelling or literature as an absolute change in output. Changes in environmental outputs were then converted to a percentage change basis for utilisation in the mitigation cost curves (see 3.5.1 below).

The change to underlying enterprise margins from mitigation adoption were calculated to include both changes to operating margins and the impact of any required capital investment, which was amortized over a twenty-year period at a discount rate of 5%.

3.3.1 Spatially applicable mitigations

General and farm system mitigations were deemed applicable to every polygon of an appropriate typology. Edge of field mitigations and partial land use change were intended to be restricted to specific polygons of appropriate typologies, depending on the nature of the mitigation proposed.

Table 12. Spatial mitigation and partial land use change applicability parameters

Mitigation	Selection criteria	Data and source	Assumptions
Stream fencing	All polygons with streams (order 1,2) running through it	Data from NIWA - GIS layer (REC2 version 5)	Assume stream order 3 and higher are already fenced
Riparian planting	All polygons with streams (order 1,2) running through it	Data from NIWA - GIS layer (REC2 version 5)	Assume stream order 3 and higher are already fenced
Land retirement - native	SnB/Deer - slopes (F/G/H), Dairy/Arable(E/F/G/H)	NZLRI data (slope) - GIS layer	
Plantation forestry	SnB/Deer - slopes (D/E), Dairy/Arable (D)	NZLRI data (slope) - GIS layer	
Irrigated land use change	Slopes (A/B)	NZLRI data (slope) - GIS layer	Total area of irrigation constrained to existing total
Non-irrigated land use change	Identical wetness and slope category, suitability (pipfruit, viticulture)	Rainfall (Mfe), assigned slope category, OLW data supermarket	
Facilitated wetlands	800mm and above rainfall	Average annual rainfall (1972-2016) MfE (DN)	Only built on slopes (ABC) <16 degrees - Mitigation Library V3.
	Only built on slopes (C) and poorly drained soils (drain class 1/2)	Drain class 1/2 included as poorly drained - FSL GIS layer	In Waihao - Rainfall parameter was removed.
	1% of area		
Constructed wetlands	800mm and above rainfall	Average annual rainfall (1972-2016) MfE - GIS Layer	Only built on slopes (ABC) <16 degrees - Mitigation Library V3.
	Only built on slopes (AB) and poorly drained soils (drain class 1/2)	Drain class 1/2 included as poorly drained - FSL GIS layer	In Waihao - Rainfall parameter was removed.
	4% of area		
Space planting	>16 degrees (D/E/F/G/H)	NZLRI data (slope) - GIS layer	Mit library 16 degrees
Sediment traps/ Detainment bunds	Flat and rolling land only (A/B/C)	NZLRI data (slope) - GIS layer	1 every 50 ha

While the adoption of partial land use change to forestry could be managed geospatially in the catchment model, there is considerable complexity involved with both representing and calculating the economic and environmental impact of edge of field mitigations at the polygon level within each typology. This is particularly the case where an attribute other than slope (i.e., soil type, proximity to a waterway) is required to determine applicability and impact.

To simplify the modelling, the average impact per hectare across any given typology was calculated and applied within the mitigation cost curves. By way of example:

- For the riparian planting and stream fencing mitigations the average stream length per unit area of each typology (across all polygons) was calculated, along with the average costs and impact length of stream fencing. From this an average cost and effect per hectare for the typology was derived and applied to all polygons of that typology, irrespective of whether an individual polygon was adjacent to a stream or not.

- If GIS analysis determined that based on the proportion of applicable polygons that 0.5% of a typology by area would be eligible for a constructed wetland, the average estimated impact across the typology is 0.5% of what it would be a hectare of that typology was fully mitigated by a wetland.

3.4 Farmer preference survey

To identify the preference of farmers in the target catchments to adopt water quality mitigations for use in the development of catchment specific mitigation cost curves and their preference for alternative land uses, farmers within the catchments were invited to participate in both a phone interview and an online survey. A sound ethics process was developed by the research team prior to the project initiation, which was followed meticulously to ensure integrity of the results.

The identification of and contact with suitable participants occurred through several channels, including catchment groups, irrigation zone committees and regional council networks. Interested interviewees across the three catchments received an initial email with an information sheet and farmer consent form. A unique identifier and a range of interview time options were provided to the farmer to confirm a time for interviewing. All phone participants were also invited to take part in the online survey, the second step of the research process. All participants received a koha (donation) of $150 for participating in the phone interview. Participants willing to partake in the follow up online survey received an additional $100 koha on receipt of the submitted survey.

If a potential participant decided to participate in the interview during the initial phone call, the interviewer was required to gain verbal consent and follow up with written consent. A consent form was provided via email with the initial project information and was requested to be returned to Perrin Ag.

In total there were 47 respondents from the Tukituki, 15 from Te Hoiere and 9 from South Coastal Canterbury. Two additional farmers from Tukituki indicated a willingness to participate, but one withdrew their consent before the interview and the second afterwards, with the latter's responses excluded from the analysis.

All the data from survey participants was anonymous and only used to draw catchment-level conclusions from the research. To maintain anonymity, each farmer was allocated a specific code. This code with their contact details was only accessible to the immediate interviewing team. Any sharing of the raw interview and survey data to the wider Perrin Ag team was only provided from the anonymised dataset. The raw dataset will not be published. The identity of the researcher(s) was not concealed from participants at any time during the research.

Prior to undertaking the farmer interviews, a meeting was held with the interviewers to outline the process. A pilot phone interview was undertaken to ensure the questions will extract the appropriate data and identify and improvements to be made.

Both the phone interview and online survey sought to gain insights into farmer preferences towards adopting specific actions or altering land use practices on their farms, all with the aim of advancing water quality outcomes within their catchment.

Participants were presented with a series of questions relating to current actions, their willingness to adopt future actions that affect water quality and their willingness to adopt or expand alternative land uses to current farming operations in future. Farmers were asked whether there are perceived or known barriers and/or challenges with land use change for farmers in their catchment, and what they consider the biggest drivers of land use change in the catchment will be in future. The phone survey questions are provided in Appendix 10.2.

The data was recorded in a Microsoft Excel spreadsheet that detail the following:

- Farmer anonymised identification code.
- Date and time of interview.
- Catchment and size of farm.

Quantitative and qualitative data was also captured from survey answers and any additional commentary provided by the farmers.

The online survey was conducted via SurveyMonkey® (see Appendix 10.3) and the data extracted into a Microsoft Excel format to be compatible with the phone interview data recorded from each respondent. The survey data sought to complement and expand on the data collected from the phone interview. Raw data from the mixed-methods research was analysed through the process of triangulation to integrative the quantitative and qualitative data (Olsen et al., 2004; Webb, 2009). Key themes were identified and ranked based on occurrence.

The data collected in the farmer survey was then used to inform a preference to the application of mitigations as an alternative to what a least-cost or cost-efficacy ordering approach might suggest.

NB. Specific analysis of the responses from farmers in the Tukituki were presented at the 2024 Farm Landscapes Research Centre conference and published in the proceedings as Stone et al. (2024).

3.5 Development of mitigation cost curves for use in the catchment model

3.5.1 Mitigation cost curves

A specific water quality mitigation cost curve was created for each land use typology in each catchment.

Determining the order of adoption for mitigations in each cost curve utilised a six-stage process:

(i) The primary and secondary contaminant of interest for each catchment were identified.

(ii) Mitigations applicable for each typology were identified. This included discarding any mitigations that were assessed as increasing primary contaminant load or those that were assessed as having no discernable water quality impact.

(iii) Applicable mitigations then ranked from lowest to highest in terms of $ cost/unit of primary contaminant (of interest to the catchment) reduction. If there was no impact on primary contaminant yield, the remaining applicable mitigations were then ranked lowest to highest in terms of $ cost/unit of secondary contaminant reduced and tertiary contaminant of interest (if required).

(iv) Mitigations were then ranked lowest to highest in terms of their impact on enterprise margin per hectare.

(v) An interim order for mitigation adoption was then determined based on the average ranking score from steps (iii) and (iv) above.

(vi) Applicable mitigations were then ranked from highest preference for adoption to lowest preference based on the landowner surveys completed in each catchment. A score between 0 and 4 was assigned to each landowner response, with existing adoption assigned a score of 4, and no knowledge of the mitigation assigned a score of 0. Where possible, the specific responses from farmers aligned with specific typologies are reflected in those curves i.e., only the mitigation adoption preferences of irrigated dairy farmers are reflected in the mitigation order for irrigated dairy land. Where a mitigation had received the same preference score, its final order in the abatement curve was determined by its interim order in (v) above.

In this way, each mitigation cost curve reflects the current approach to water quality improvement of the farmers and growers who are in each respective catchment.

Once the order of mitigation adoption was confirmed, the aggregate impact from the sequential adoption of individual mitigations on all outputs for application within the catchment model was determined. Mitigations are applied at polygon level.

There is an inability to consistently estimate the impact of mitigation practices on losses for individual contaminants within the same modelling software. Due to both this and the large number of typologies with any given catchment, an arithmetic approach to calculating the cumulative impact of mitigation implementation was chosen.

It is acknowledged that such an approach may not always accurately capture the true system response to mitigation adoption due to the complexity of interrelationships within a farm or orchard system and the use of dynamic systems model (like FARMAX) to interrogate each step would be preferable. However, at the scale of the ultimate analysis and its inherent lack of granularity, the use of an arithmetic method to estimate cumulative impact is considered appropriate.

The approach is as follows:

(i) Changes in economic outputs are calculated by adding to the base gross margin the absolute change in gross margin associated with each discrete mitigation. Where mitigations need to be applied to a polygon that has undergone land use change, the base gross margin will reflect the cost of conversion from the original land use.

(ii) The change to water contaminants and individual GHG outputs[4] will be calculated by applying to the base yield the sequentially multiplied percentage reductions (or increases) in yield associated with each mitigation. However, the EOF mitigations requires different treatment. Once in place, EOF mitigations are considered to apply to all the aggregate contaminant losses

[4] Total GHG output (in CO_2e) will need to be calculated from the absolute gas yields after the application of each mitigation.

generated from a farm or orchard system. As such, the calculation of aggregate reductions from EOF mitigations must always be applied to a polygon after the impact of all other applicable system mitigations have been derived.

(iii) Where partial land use change is a mitigation, the appropriate polygons are deemed to change land use and inherit the economic and environmental outputs associated with their new land use. No further mitigations from the original land use mitigation cost curve are to be applied.

(iv) Where farmers have indicated existing adoption of EOF and general mitigations (of which none are reflected in the average system parameters used), these are reflected in both the current economic and environmental outputs [being a step up from the unmitigated or baseline outputs] and the potential extent of opportunity for future adoption and its associated economic impact.

There is, however, no data to quantify the extent of mitigation adoption by those indicating implementation, other than mitigations that are simply binary decisions (i.e., the adoption of a lined effluent pond). In these instances, we have assumed that 50% of the potential opportunity has been implemented for the applicable cohort.

In general, the formulas for calculating both current yield ($yield_c$) and abated yields ($yield_n$) of environmental outputs are as below.

$$yield_c = [yield_0 * (1+M_x*c_x) * (1+M_y*c_y) * \ldots * (1+M_z*c_z)] * [(1+EOF_x*c_x) * (1+EOF_y*c_y) * \ldots * EOF_z*c_z)]$$

where the unmitigated yield is $yield_0$, M_x is the percentage change in contaminant yield for system mitigation *x*, c_x is the current percentage extent of implementation of system mitigation *x*, EOF_y is the percentage change in contaminant yield edge of field mitigation *y* and c_y is the current percentage extent of implementation of edge of field mitigation *y*.

and

$$yield_n = [yield_c * (1+M_1*r_1) * (1+M_2*r_2) * \ldots * (1+M_n*r_n)] * [(1+EOF_1*r_1) * (1+EOF_2*r_2) * \ldots * EOF_n*r_n)]$$

where the current yield is $yield_c$, yield at step *n* on the abatement curve is $yield_n$, M_x is the percentage change in contaminant yield for system mitigation *x*, r_x is the residual opportunity for the implementation of system mitigation *x* [$r_x = 1/(1+M_x*c_x)$], EOF_y is the percentage change in contaminant yield for edge of field mitigation *y* and r_y is the residual opportunity for implementation of EOF mitigation *y* [$r_y = 1/(1+EOF_y*c_y)$.]

With respect to the economic impact of mitigations that have already been partially or fully adopted, the “cost” per hectare is assumed to already be either partially or fully incorporated into the current gross margin, with the residual “cost” of mitigation included in the mitigation cost curve.

It is important to note that in some cases, the assumed rate of existing adoption (as indicated by farmers) does not reconcile with the geospatial assumptions for the mitigations. For example, in the Tukituki catchment 37% of the surveyed sheep & beef farmers indicated they were already utilising a constructed wetland. At the scale utilised, however, only four of the seven “SB” typologies contain polygons that were considered suitable for a constructed wetland mitigation.

The assumptions for the extent of the potential opportunity for mitigations may well exceed their practical ability to be implemented. Mitigations that rely on specific placement within a landscape, primarily in relation to hydrology, may not be able to be maximised as assumed here. For example, in applicable polygons, it is assumed that detention bunds (if adopted) can treat 100% of the area over which they are implemented, but this seems unlikely to be the case in practice.

3.5.2 Land use change preference

For each typology, the preference of farmers for significant land use change was also determined from survey data. Applicable land uses that farmers within a typology are prepared to adopt were identified and ranked in order of preference. Baseline enterprise margins were subsequently determined for each land use that accounts for the recouping the cost of conversion over a 20-year period. These enterprise margins also assumed a level of practice change, on the basis that in an environment where achieving water quality outcomes is imperative, current practice will be insufficient. The level of practice change assumed to be appropriate was M3 (see 3.5.3 below).

Itis theorised that at a certain point, the cost of mitigation may result in a farmer deciding to change land use (or even exit farming) to preserve their financial position. It is assumed, however, that farmers and growers have an inherent desire to maintain their current land use, even if alternatives may be more profitable. This is borne out in the frequent observation of the continuance of sheep & beef farming in marginal environments where conventional economic analysis would suggest production forestry is a more profitable land use. Other themes that act as a barrier to [profitable] land use change were also highlighted through commentary recorded throughout the farmer survey analysis as reported in Stone et al. (2024). In the Tukituki, these included compliance (32% respondents), water availability (28% respondents) and cost (23% respondents). On this basis, the subsequent catchment modelling assigned, ceteris paribus, a higher weighting to the continuation of current land use (and practice) compared to the adoption of new land uses.

3.5.3 Combining mitigation output for the catchment model

To simplify the modelling process and reduce the number of points along the mitigation cost curves, the mitigations for each land use typology were combined or “bundled”. The bundling of mitigations is a common practice when modelling land management changes to understand the economic and environmental outcomes from adoption. These bundles tend to be defined within the context or framework of social and economic factors (i.e. complexity, ease of implementation, cost, risk). This approach has been used by Everest (2013), Vibart et al (2015), Parsons et al (2015), Daigneault & Elliot (2017) and Matheson et al. (2018), amongst others. For this analysis, mitigations were bundled based on the assessed farmer preference for implementation from the farmer and grower surveys, which is a novel approach. The bundling logic is as follows:

(i) M0 – current state

(ii) M1 – mitigations that had a farmer preference score of greater than 3 (implemented or planning to implement).

(iii) M2 – all mitigations that had a farmer preference score of between 2.9 and 2 (willing to implement) or up to the point of a partial land use change decision (either indigenous or exotic forestry).

(iv) M3 – all mitigations from M2 up to a [second] partial land use change decision (either indigenous or exotic forestry) or where preference score <2.

(v) M4 – all other mitigations, primarily through to those that had a farmer preference score of < 2 (obstacles to implement/not familiar).

Because of the need to have partial land use change decisions occur along the mitigation cost curve (but not strictly be part of it) it made sense to allow partial land use change (which means a full polygon land use change) occur at break points in the curve.

3.6 Catchment modelling

3.6.1 Land use options

To identify land-use management change options for achieving water quality targets, a spatially explicit optimisation-based approach was used. Each scenario (s. below) optimises the allocation of mitigation bundles and/or land-use change options to the set of typologies defined for a given catchment, such that a specified objective, e.g. minimise nitrogen loss, is optimised while meeting a set of spatial and performance constraints, e.g. only allocate irrigated land-use options to flat land and specific typologies and maintain a farm-based gross margin of at least 70%.

The Land Use Management Support System (LUMASS[5]) (Herzig et al. 2013, Herzig et al. 2018) was used for modelling the optimization scenarios. LUMASS is a free and open-source spatial modelling and optimisation framework and employs the mixed-integer linear programming system 'lp solve' (Berkelaar 2007) to solve multi-objective spatial optimisation problems. It has been utilised in various spatial optimisation case studies in New Zealand (Herzig et al. 2016; Thomas et al. 2020; Herzig et al. 2024) and abroad (Herzig et al. 2018).

To run the scenarios, the information on mitigation bundles, land-use change options and critical catchments (Snelder et al. 2023) was integrated into the geospatial typology layer. This enabled the definition of catchment and farm-specific constraints, e.g. contaminant reduction and gross margin targets, and the summary of relevant performance metrics for the business-cases and the NPS-FM compliance assessment. For the latter, we created an additional geospatial layer that integrates River Environment Classification (REC v2) (Snelder et al. 2010) data and information on critical catchments.

3.6.2 NPS-FM compliance

The identification of critical catchments and the assessment of NPS-FM compliance is based on a national-scale analysis of contaminant loads in New Zealand rivers and their comparison to national bottom lines by Snelder et al. (2023). The authors define, for each contaminant, critical points (Snelder et al. 2020) along the river network that identify receiving environments not achieving NPS-FM bottom-line limits. At a critical point, the current contaminant load delivered to that point from the upstream catchment, exceeds the maximum allowable load (MAL) for maintaining a bottom-line state of ecological health (Snelder et al. 2020). For each point Snelder et al. (2023) estimate the excess load by which the current contaminant load needs to be reduced to achieve the national bottom-line standard for the given contaminant.

The information provided on critical catchments and their excess load, expressed as proportion of the current load (Snelder et al. 2023), was integrated together with information on the REC (Snelder et al. 2010) into a geospatial layer. Based on the contaminant load calculated for our baseline land-use

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

scenario, i.e. the typology loads for the 'M0' state, and the relative excess load for each critical point, a MAL was calculated related to the baseline loads for each critical point.

For each land-use scenario the scenario load delivered to a critical point was then compared to the corresponding MAL to determine whether the given scenario achieved the NPS-FM bottom line for the given contaminant and critical-point catchment. Overall NPS-FM compliance for each modelled region, i.e. Tukituki and Te Hoiere, was then expressed by the number (percentage) of critical catchments that achieve the NPS-FM bottom line for a given contaminant.

The lag time between mitigation implementation or land use change and water quality improvement is considered negligible owing to 20-year period for adoption. As such, static coefficients developed for the CLUES model (Semadeni-Davies et al., 2020) were applied to account for contaminant attenuation effects in the soil and in the waterways.

Due to a combination of time pressures and a relatively low response rate from farmers and growers in the South Coastal Canterbury catchment, catchment modelling was only completed for the Tukituki and Te Hoiere catchments.

3.6.3 Scenarios

A series of scenarios were modelled for each catchment in a stepwise procedure. The first step identified the contaminant reduction potential focusing on farmers' preferences and overall estimated economic feasibility for farms. If NPS-FM targets were not met, achieving them was the focus of the second step. In one or more scenarios, we spatial allocation constraints were successively relaxed for indigenous and exotic forest, complete land-use change enables, and contaminant reduction targets increased.

The first step scenarios, focusing on the least amount of change from the status quo, were characterized by the following constraints:

- No increase in the amount of irrigable land (based on the assumption that existing surface or groundwater takes were fully allocated6).
- Profitability at the aggregate property level was 70% of the baseline or greater.
- Any land use change had a maximum potential area of 20% of the original farm property.
- Land use change to forestry can only occur on polygons as per Table 12 above.
- Dairy farms had a minimum viable size of 100 ha or their existing size, whatever was the smaller.
- Land use change to pipfruit or viticulture was restricted to climatic zones where the suitability of these crops (as available from https://ourlandandwater.nz/outputs/data-supermarket/) was expected to exceed 80% or 70%, respectively, under the RPC 6 climate scenario. This was then validated against the location of recent known land use change to these crops within the Tukituki catchment.

[6] The potential for increasing irrigation through storage is provided for in other scenarios.

If this initial scenario failed to achieve the water quality outcomes as specified in the NPS-FM, then constraints were increased or relaxed as required to drive land use change. These largely related to relaxing the restrictions on where new forestry could be established, allowing greater areas of land use change to occur within a farm property and directing the model to achieve overt reductions in the level of primary contaminant reduction.

Given the high potential economic value of water to agriculture in the Tukituki catchment, a second iteration of each scenario was run that provided for up to an additional 20,000 ha of irrigable land in the catchment. This water would be assumed to come from storage filled with water from peak flow events, as opposed to new or existing surface or groundwater takes. This 20,000 ha figure was the low end of the range of additional irrigable land that was expected to have been enabled by the now defunct Ruataniwha Water Storage Scheme (Miller, 2016). In each of these alternative scenarios, any new irrigation was constrained to flat land (polygons with an average slope of 7 degrees or less).

3.7 Business case validation

Following the scenario runs, a high-level feasibility analysis was conducted on the transition of five actual properties within the Tukituki catchment from their current state to potential futures with lower contaminant loads. The case study farms were identified by farmer self-selection from those originally surveyed. As such, it was not possible to ensure the case studies were representative of the range of land use and location within the catchment.

Each property was visited in April 2024 and preliminary results of the modelling output were discussed where available. The typological assignment for each property was compared with current land uses to identify any significant anomalies.

To protect the anonymity of participants, only average economic data was used, and specific farm area has not been reported. The key parameters of the five participant properties are summarised in Table 13 below. Of all the farms, Farm 2 would probably be considered the most typical of the Tukituki's sheep and beef farms, in terms of both scale, contour and livestock systems.

Table 13: Summary of Tukituki case study farms

Case study	Effective area	Primary land use typology	Any irrigation	Average enterprise margin ($ ha^{-1})
Farm 1	200-300 ha	SBL1	No	570
Farm 2	400-500 ha	SBL2	No	562
Farm 3	50-100 ha	SBH1	No	609
Farm 4	300-400 ha	SBL1	Yes	1016
Farm 5	400-500 ha	AL1	No	1242

Two scenarios were then assessed – the initial scenario [N30] and the scenario that was closest to achieving the NPS water quality targets [CNmax]. The period of transition chosen for analysis was twenty years, with this timeframe broadly considered being akin to the concept of a "generation".

A simple 20-year cashflow analysis was then completed for each scenario for each property, using the aggregate financial co-efficients derived from the modelling. Each property was assigned an average level of debt and owner's drawings based on industry averages for the applicable land use activity. All required land use and practice change was assumed to occur in year one. A variation on this, with land use change being phased in evenly over a 20-year period, was also explored for one of the case study farms. An annual tax rate of 28% was assumed and all existing and new debt funding used a discount rate of 5%. A provision for normalised capital expenditure on the original land use at a rate equivalent to industry average depreciation was also included. It is recognised that with any land use change to production forestry, no harvest revenue will be received within the period of assessment, being 20 years. The cash implications for the establishment of forestry and the reduction in livestock numbers were treated as operating revenue or expenses (taxable), while any orchard or vineyard establishment was treated as a capital expense (non-taxable).

The feasibility of any required land use and practice change was assessed against three key measures over time:

- Interest cover – the ratio of annual operating surplus to interest payments.
- Annual cash surplus – income less operating expenses (annual operating surplus), interest, rent, tax, normal asset replacement and owners living expenses.
- Total debt.

The transition to the new practice and land use mix was considered fully feasible if:

(i) Interest cover remained at a ratio of 1 or higher for the entire twenty-year period (noting that a sustainable level of interest cover would be >1.6, but that during development activity this metric will realistically be relaxed).

(ii) Annual cash surpluses were achieved for a minimum of fifteen of the twenty years; and

(iii) Total debt was lower at the end of the twenty years than at the start.

The transition would be partially feasible if two out of the three criteria were achieved and deemed unfeasible if one or less were achieved. It is acknowledged that debt to asset ratio is also a key consideration in lending decisions regarding loan securitisation. This metric was not estimated for this analysis, on the assumptions that (a) lending to fund capital intensive land use change would likely be associated with an increase in asset value and (b) liquidity/free cashflow would have a higher bearing on the viability of any lending decision.

Baseline (status quo) analysis was also completed for each farm business and, under the assumptions above. Using the same metrics, all five case studies were deemed to be currently feasible over a twenty-year period.

4 Mitigation cost curves

Mitigation cost curves, derived from farmer preferences for a total of 45 land use typologies across three catchments were developed for integration into the catchment models. These are presented in Appendix 15 through to Appendix 59.

4.1 Interpretation

Using the Tukituki DI1 mitigation cost curve as an example (Table 14), the mitigation cost curves should be interpreted as below.

Table 14: Mitigation cost curve for Tukituki DI1 typology

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$4,550	60.0	0.8	893.9	4,100,000,000	435
Current										**$4,550**	**44.8**	**0.2**	**552.8**	**2,776,088,843**	**422**
M1	Deferred and low rate application	4.0	-$6	-3%	-66%	0%	0%	0%	100%	$4,550	44.8	0.2	552.8	2,776,088,843	422
	Diverse pastures (i.e., plantain)	4.0	-$9	-3%	0%	0%	0%	0%	50%	$4,546	44.0	0.2	552.8	2,776,088,843	422
	Stream fencing	4.0	-$24	-13%	-15%	-70%	-58%	0%	50%	$4,534	41.0	0.2	255.2	1,642,193,400	422
	Riparian planting (incl. forestry)	4.0	-$92	-5%	-5%	-10%	-9%	-1%	50%	$4,488	39.9	0.2	242.4	1,564,108,801	420
	Variable rate fertiliser	3.5	$54	-5%	-10%	0%	0%	0%	50%	$4,515	38.9	0.2	242.4	1,564,108,801	420
	Lined effluent ponds	3.0	-$23	-4%	-1%	0%	0%	0%	50%	$4,503	38.0	0.2	242.4	1,564,108,801	420
	Reduce N fertiliser use (below 190 kg N/ha)	3.0	-$319	-18%	0%	0%	0%	-5%	50%	$4,344	34.2	0.2	242.4	1,564,108,801	409
	Use of low water soluble P fert	3.0	-$202	0%	-13%	0%	0%	0%	25%	$4,192	34.2	0.2	242.4	1,564,108,801	409
PLUC	Land retirement (permanent native forestry)	3.0	-$3,852												
M2	Reduced N to effluent area	2.0	$41	-3%	0%	0%	0%	0%	25%	$4,223	33.3	0.2	242.4	1,564,108,801	409
	Facilitated wetlands*	2.0	$0	0%	0%	0%	0%	0%	17%	$4,223	33.3	0.2	242.4	1,564,108,801	409
	Variable rate irrigation	2.0	-$55	-1%	0%	0%	0%	0%	0%	$4,168	33.0	0.2	242.4	1,564,108,801	409
	Constructed wetlands*	2.0	-$12	0%	0%	0%	0%	0%	25%	$4,159	32.9	0.2	241.7	1,559,411,777	409
M3	Stand off pads - no roof	1.0	-$343	-30%	0%	0%	0%	-3%	0%	$3,816	23.1	0.2	241.7	1,559,411,777	397
	Retention dams, bunds or sediment traps*	1.0	-$51	0%	-3%	-78%	-49%	0%	0%	$3,765	23.1	0.2	52.2	795,300,006	397
PLUC	Plantation forestry	1.0	-$3,063												
M4	Off-paddock structures - with roof	1.0	-$3,445	-2%	13%	0%	0%	13%	0%	$320	22.5	0.2	52.2	795,300,006	450
	Applying alum to pasture and crops 100%	0.5	-$105	0%	-20%	0%	0%	0%	0%	$215	22.5	0.1	52.2	795,300,006	450
	Applying alum to pasture and crops just to CSA	0.0	-$21	0%	-6%	0%	0%	0%	0%	$194	22.5	0.1	52.2	795,300,006	450

4.1.1 Bundles and mitigations

The bundles (M1 through M4) and their respective mitigations are listed for each typology. Partial land use changes ("PLUC") to either indigenous forestry or exotic forestry are listed in the order in which they would ordinarily appear in the mitigation curve. Other than the difference between the current typology's level of profitability and that of the land use change, no data is provided.

"Unmitigated" represents the base typology outputs, while "Current" is the baseline outputs used in the models, reflecting the effect of current mitigation adoption. This could also be referred to a "M0".

Mitigations denominated with a "*" denotes mitigations that farmers within the typology may have indicated as being of interest for adoption, but for which the typology may have limited suitability for deployment.

4.1.2 Preference score

This score reflects the average survey responses of farmers of the appropriate typology with regards to their preference for the implementation of the mitigation. A score of 4 is highest and 0 is lowest.

4.1.3 Changes in economic and environmental co-efficients

The Δ EM, Δ N, Δ P, Δ TSS, Δ E. coli and ΔCH_4 columns list the average $ per hectare change in average enterprise margin (Δ EM) or the percentage change in contaminant yield from the complete implementation of these mitigations for the typology.

4.1.4 Current level of implementation

This column provides the existing level of effect that is assumed from the existing adoption of mitigations by farmers of this typology in the catchment. This figure is derived from multiplying the proportion of farmers in the catchment who indicated they had already adopted the mitigation (a preference score of 4) by either 100% (for mitigations that are considered binary in implementation i.e., reduce N fertiliser below 190 kg N ha^{-1} yr^{-1}) or by 50% for mitigations for which a positive response for adoption was likely to include a range in the extent of implementation (i.e., riparian planting). So, for diverse pastures, 100% of irrigated dairy farmers indicated they were using/had adopted this mitigation, but in the absence of definitive data on the extent to which they had implemented this practice a 50% level of implementation was assumed, delivering an overall level of effect on that typology of 50% (i.e., 100% adoption x 50% implementation). This means that 50% of the benefit from further implementation remains available to impact water quality from this typology.

4.1.5 Margin

This column provides the absolute average per hectare enterprise margin for the typology after the sequential implementation of each mitigation. So, after the full implementation of the M1 bundle, the average enterprise margin for an irrigated dairy farm in the Tukituki might be expected to have decreased from $4,550 ha^{-1} yr^{-1} to $4,192 ha^{-1} yr^{-1}.

4.1.6 Contaminant losses

These columns provide the absolute average per hectare contaminant yield for the typology after the sequential implementation of each mitigation. So, after the full implementation of the M1 bundle, the average N loss for an irrigated dairy farm in the Tukituki might be expected to have decreased to 34.2 kg N ha^{-1} yr^{-1} with a commensurate reduction in methane emissions to 409 kg CH_4 ha^{-1} yr^{-1}.

4.2 At what cost mitigation?

Given its larger number of participants in the mitigation preference analysis, the Tukituki catchment is probably the most appropriate catchment in which to examine trends in the cost of mitigations. When farmers were asked about their preferences for mitigation adoption, this was done in the absence of information being supplied by the interviewer about the potential cost of implementation. In interpreting this information, it is important to remember that the mitigations in the M3 bundles all had a preference score that aligned with farmers indicating they were willing to adopt the mitigation.

Table 15 below presents the average absolute change in enterprise margin for each major land use category associated with each mitigation bundle.

Table 15: Average absolute change in enterprise margin ($ ha^{-1} yr^{-1}) associated with the sequential and cumulative adoption of mitigation bundles for major land uses in the Tukituki.

Mitigation bundle	Dairy	Sheep & beef	Deer	Arable	Field horticulture	Permanent horticulture	Lifestyle
M1	-11%	-20%	-150%	1%	-8%	0%	-23%
M2	-11%	-42%	-171%	-60%	-49%	-1%	-23%
M3	-17%	-53%	-479%	-61%	-49%	-1%	-40%
M4	-110%	-80%	-715%	-66%	-51%	-1%	-51%

It can be observed that significant profit decline (being a reduction >30%, a threshold suggested as being materially significant for a typical farming business) occurs (as modelled) with the implementation of the M4 bundle for dairy, after M2 for lifestyle properties and after M1 for sheep & beef properties, arable systems and vegetable production. By way of clear contrast, the financial impact of water quality mitigation for permanent horticultural systems (pipfruit, viticulture) is insignificant.

While on average the adoption of water quality mitigations on deer properties is predicted to be associated with incredibly high profit erosion to a point of potential financial collapse.

In practice, it is suggested as being unlikely that a farmer would ordinarily and consistently implement individual mitigations (or complete bundles) across all their property. They are more likely to choose to implement mitigations strategically or tactically as they feel appropriate or could afford. The strongly observed preference of farmers across typologies and catchments to retire land to establish indigenous forest is a case in point. While being “popular” with farmers (based on preference score), its high ultimate cost to a farm business makes it all but impossible that a farmer will willingly retire their entire operation and establish native trees.

The development of mitigation cost curves from data on farmer preference for mitigation adoption and lands use change offers potential insight into farmer decision making. In their supplementary analysis on the Tukituki preference data, Stone et al. (2024) observed that farmer preference for mitigation adoption broadly aligned with the order in which mitigations might be sequenced based on cost of implementation. Hence, suggesting that farmers have a reasonably high understanding of the relative cost-benefit of mitigations to their farm system. However, it is unknown to what extent this considers a potential inability to optimise their farm system in response to that mitigation. For example, the use of barns in dairy systems scored low on farmer preference and was subsequently modelled as having a strongly negative impact on dairy farm gross margin. It could be, however, that the low farmer ranking was due to the well-recognised high capital cost, as opposed to the likelihood that, as reported by Journeaux and Newman (2015), return on investment might be negligible or negative when used as an environmental mitigation (which precludes the opportunity to intensify the farm system post-investment). This is an area that might warrant further research.

5 Catchment outcomes

5.1 Tukituki

The current land use mix in the Tukituki based on the typologies defined by this research is presented in Figure 6 below.

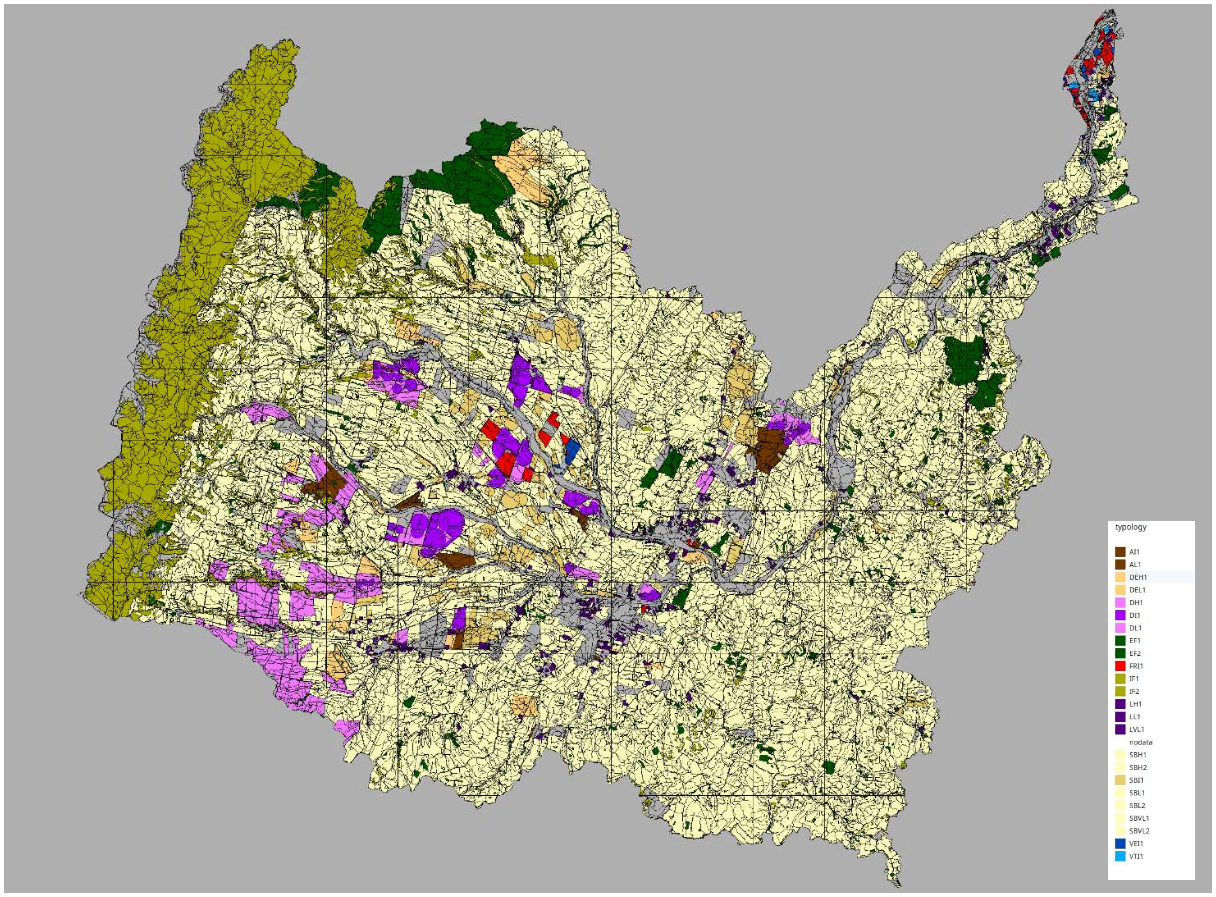


Figure 6: Representation of current land use in the Tukituki catchment

The breakdown of current land use in the Tukituki catchment is also summarised Table 16.

Table 16: Current land use in the Tukituki catchment

Land use	Area (ha)	Proportion
Dairy (irrigated)	3,011	1.4%
Dairy (non-irrigated)	7,559	3.4%
Sheep & beef (irrigated)	6,019	2.7%
Sheep & beef (non-irrigated)	158,777	71.7%
Deer	2,970	1.3%
Arable (irrigated)	577	0.3%
Arable (non-irrigated)	899	0.4%

Land use	Area (ha)	Proportion
Pipfruit	800	0.4%
Viticulture	102	0.0%
Vegetables	202	0.1%
Lifestyle farming	2,296	1.0%
Indigenous forest	26,829	12.1%
Exotic forest	11,387	5.1%

5.1.1 Modelled scenarios

A total of four scenarios (three with an increased water access variant) were modelled (Table 17).

Table 17: Scenario definition for the Tukituki

	N30 (N30-*iex*)	**F80 (F80-*iex*)**	**N60 (N60-*iex*)**	**CNmax (CNmax-*iex*)**
Objective	Minimise nitrogen loss	Minimise nitrogen loss	Maximise gross margin	Maximise gross margin
Spatial allocation constraints	allowed partial land-use change with IF, EF, FRI1, VEI1, and VTI1 according to Table 12	allowed land-use change with IF, EF, FRI1, VEI1, VTI1, AI1, AL1, DI1, DH1, SHB1, SBL1 according to Table 12	allowed land-use change with FRI1, VEI1, VTI1, AI1, AL1, DI1, DH1, SHB1, SBL1 according to Table 12 IF, EF may replace any other land-use anywhere	allowed land-use change with FRI1, VEI1, VTI1, AI1, AL1, DI1, DH1, SHB1, SBL1 according to Table 12 IF, EF may replace any other land-use anywhere
Farm-level constraints	Gross margin >= 70% of baseline Partial land-use change <= 20% of farm area Minimum area for dairy farms >= 100 ha (or baseline area if smaller) Exotic forest + retirement <= 20% of farm area	Exotic forest + retirement <= 80% of farm area		
General performance constraints	Water use <= baseline water use N30-*iex*: Water use <= baseline water use + 20,000 ha	Water use <= baseline water use N30-*iex*: Water use <= baseline water use + 20,000 ha	Water use <= baseline water use N30-*iex*: Water use <= baseline water use + 20,000 ha Nitrogen loss < 40% of baseline loss	Water use <= baseline water use N30-*iex*: Water use <= baseline water use + 20,000 ha Specific nitrogen loss constraints for each critical catchment

For implementing scenario CNmax (CNMax-*iex*) we calculated a specific reduction target for each critical catchment:

$$R_{i-1} = L_{i-1} - MAL_{i-1} - \sum_{u=1}^{n} R_{u,i}$$

with

R_i: Specific contaminant reduction for critical catchment with fork number i

$R_{u,i}$: Specific contaminant reduction for critical catchment $R_{u,i}$ of n critical catchments with fork number i draining into critical catchment R_{i-1}

L_i: Accumulated baseline contaminant load delivered to the outlet of critical catchment with fork number i

MAL_i: Maximum allowable load calculated for critical catchment with fork number i

To calculate the specific reduction target for each critical catchment, we first calculated the fork number i for each critical catchment. The fork number reflects the nested character of critical catchments and is calculated starting at the downstream most critical catchment ($i = 0$). Traversing the river network upstream, it is incremented each time a different critical catchment, defined by a different local excess load, is entered.

The calculation of R_i starts at the top of the hierarchy at the catchments with the maximum fork number and traverses the river network downstream. In small critical catchments, where R_i would become negative, R_i was set to the maximum reduction that could be achieved based on the (non-accumulated) baseline load estimated for that critical catchment. The 'surplus' reduction requirement is then 'pushed downstream' into the next lower critical catchment (identified by its fork number). The specific maximum loads set as constraints for each critical catchment are then calculated as the difference of the (non-accumulated) baseline loads and the specific reduction targets R_i.

Visual representation of the land use mix across the Tukituki under each scenario are presented in Figure 7 through Figure 14 and the predicted aggregate economic, economic and land use change outcomes summarised in Table 18, Table 19, Table 20 and Table 21.

5.1.2 Achievement of NPS-FM water quality targets

Relative to the current mix of land use in the catchment, each of the scenarios is predicted to require an increasing area of land use change to deliver an improved degree of water quality. The CNmax and CNmax-*iex* scenarios were closest to achieving NPS-FM nitrogen water quality targets, with 80 of 82 (98%) and 75 out of 82 (98%) of the critical sub-catchments predicted to achieve N targets, respectively.

Reductions in phosphorus, sediment and *E coli* losses were also associated in all the scenarios, reflecting an apparent farmer preference for mitigations that address overland flow with their commensurate positive impacts on losses of these contaminants.

5.1.3 Changes in biogenic greenhouse gas emissions

All the scenarios estimated there would be an aggregate reduction in methane emissions. The majority of which were generated from a change in pastoral land use to non-livestock production systems, like horticulture and forestry. As land use change from pastoral farming accelerated, the reduction in methane relative to reduction in nitrogen losses increased. This predicted reduction in methane emissions as a byproduct of reducing the loss of contaminants to water is consistent with observations by McDowell et al. (2022) and Matheson et al. (2018). While not directly analysed in the catchment scenarios, the predicted increase in forestry as a land use would also have a commensurate effect on the quantum of carbon being sequestered in the catchment.

5.1.4 Mitigation adoption

The degree to which water quality mitigations are estimated to be adopted by existing land uses varied with the scenarios. In general, as the extent of land use change increased, residual land uses were required to adopt fewer mitigation measures. This was evidenced by a reducing proportion of land use requiring M4 adoption from the N30 through to the N60 and CNmax scenarios. However, the relative balance between M1, M2 and M3 varied between the individual scenarios and their water availability variants.

5.1.5 Land use change

The scale and nature of the predicted land use change under even the N30 scenario is likely to be confronting. In a catchment of approximately 221,000 hectares, the N30 scenarios indicate the potential requirement for land use change of 16-20% of the catchment area. Meanwhile, the N60 and CNmax scenarios suggests that around 78% of the catchment area may require land use change, including the complete loss of the sheep, beef and deer sectors, primarily replaced with exotic production forestry. The N30 scenarios, aligning most closely with a farmer-determined approach to practice and land use change, provides an outcome resembling the often discussed "mosaic of land uses", with the F80 scenario doing so to a lesser extent. However, as the requirements for water contaminant reductions increases, land use invariably trends back towards blocks of single land use.

In all the scenarios, increasing the availability of water for irrigation resulted in an improved economic outcome for a similar degree of water quality. The "best" use for this water varied depending on the balance of the land use predicted. It should be noted that that none of the additional water was utilised in pastoral enterprises and, furthermore, as N loss reduction increased, water was ultimately allocated away from existing high value pastoral enterprises.

Reduction in N yield to water was unsurprisingly associated with a reduction in pastoral agriculture, given the higher N losses from these farm systems. Hill country sheep, beef and deer farms were the immediate candidates for land use change to forestry, despite these typologies being assessed as having lower nitrogen loss levels compared to dairy farms. This is predominantly due to the lower level of profitability per kg N loss from these systems, which is a key consideration in the model determining an economically optimal scenario.

5.1.6 Economic impact of achieving water quality improvement

The N30 and F80 scenarios both resulted in a less profitable outcome for the catchment (-17% and -31%, respectively) in the absence of there being additional water for irrigation. The individual distribution of economic outcomes varied between farms. When up to an additional 20,000 ha of irrigation water was available, the N30-*iex* and F80-*iex* scenarios reported a respective 3% and 10% improvement in catchment profitability.

Both the N60 and CNmax scenarios resulted in a significantly more profitable outcome for the catchment than the earlier scenarios, which the addition of water (the -*iex* variants) accelerated further.

These results highlight the economic cost of potentially "sticky" farmer behaviour, with the first two scenarios both having limited the extent of land use change that could occur (in line with reported and observed farmer preference) and forcing farmers to down the mitigation cost curve (from M0 to M4) ahead of land use change.

While the profitable scenarios clearly had a greater proportion of what is widely accepted as high value, lower impact land use (which access to additional water enabled more of), the major driver of increased profit was the conversion of non-dairy pastoral farming to exotic forestry. Under the assumptions used, forestry was considered to have a higher level of economic return than the sheep, beef and deer systems it replaced. However, the case study analysis (see 6.1.1 and 6.1.2 below) identifies that even with assumed carbon revenues, the cash flow implications for the adoption of forestry at scale are likely to be challenging, if not impossible, for operations with even industry average debt levels. As such, predictions of significant uplift in the catchment's economic performance under the N60 and CNmax scenario runs are potentially misleading and provide little insight into the likely challenges of implementation from a financial perspective, let alone the wider socio-economic and socio-cultural ones.

It is also important to recognise that alternative pathways to achieving the water quality targets in the Tukituki might exist, but potentially at greater cost. While the attainment of NPS-FM bottom lines is not currently negotiable, the cost that a community (and the individuals within it) might be prepared to bear is. It *might* be possible to identify solutions that provide for less afforestation and the retention of more sheep and beef farming if more expensive mitigations on pastoral land uses can be funded by the higher revenues from increased orcharding. Given the fact that N loss from forestry is still significantly lower than even the most aggressively mitigated pastoral farming system, it seems likely that to achieve NPS-FM targets that significant afforestation of pasture will be required. But exploring scenarios that relax economic performance will add additional value to the inevitable conversations.

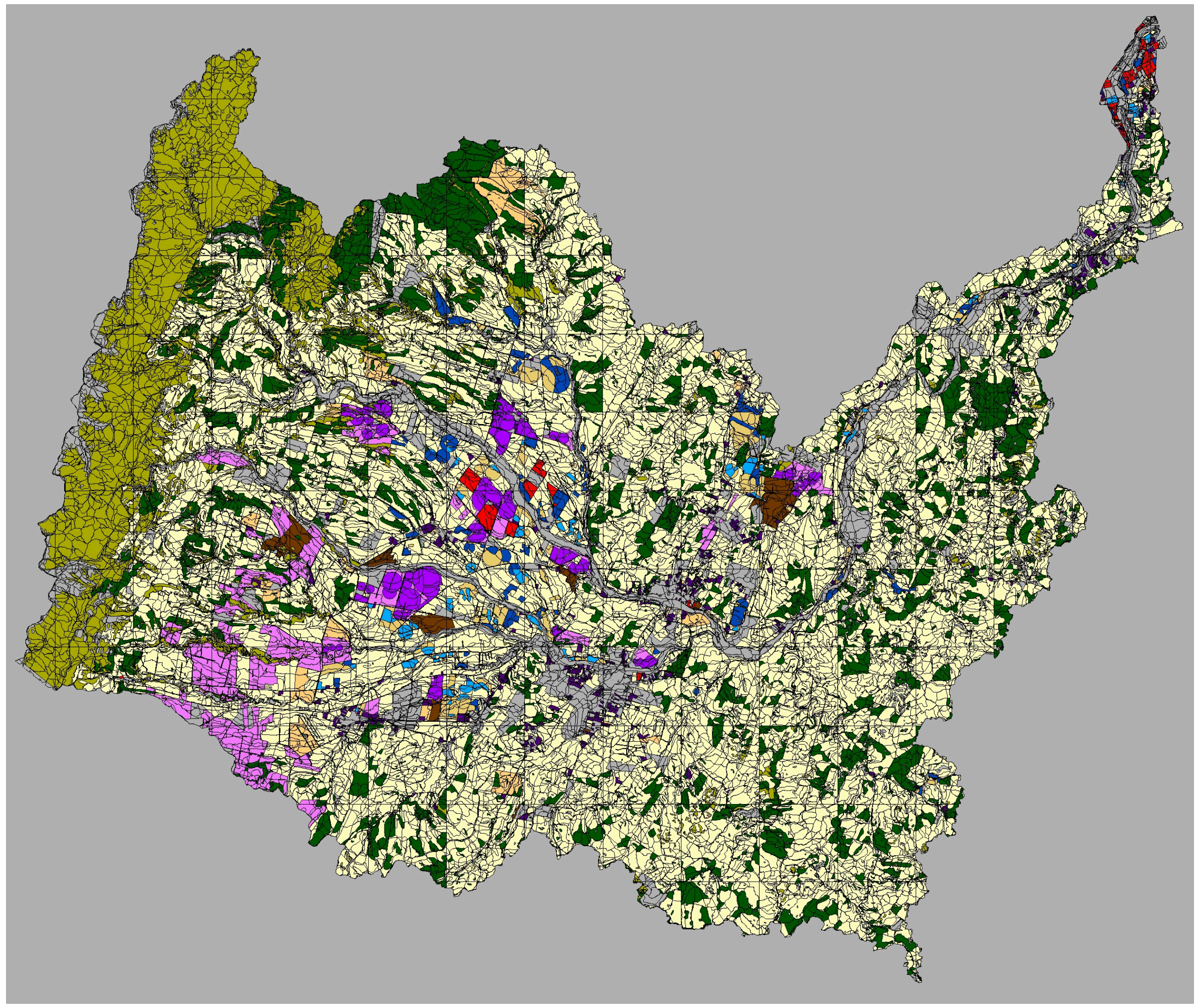


Figure 7: Projected land use in the Tukituki catchment the N30 scenario

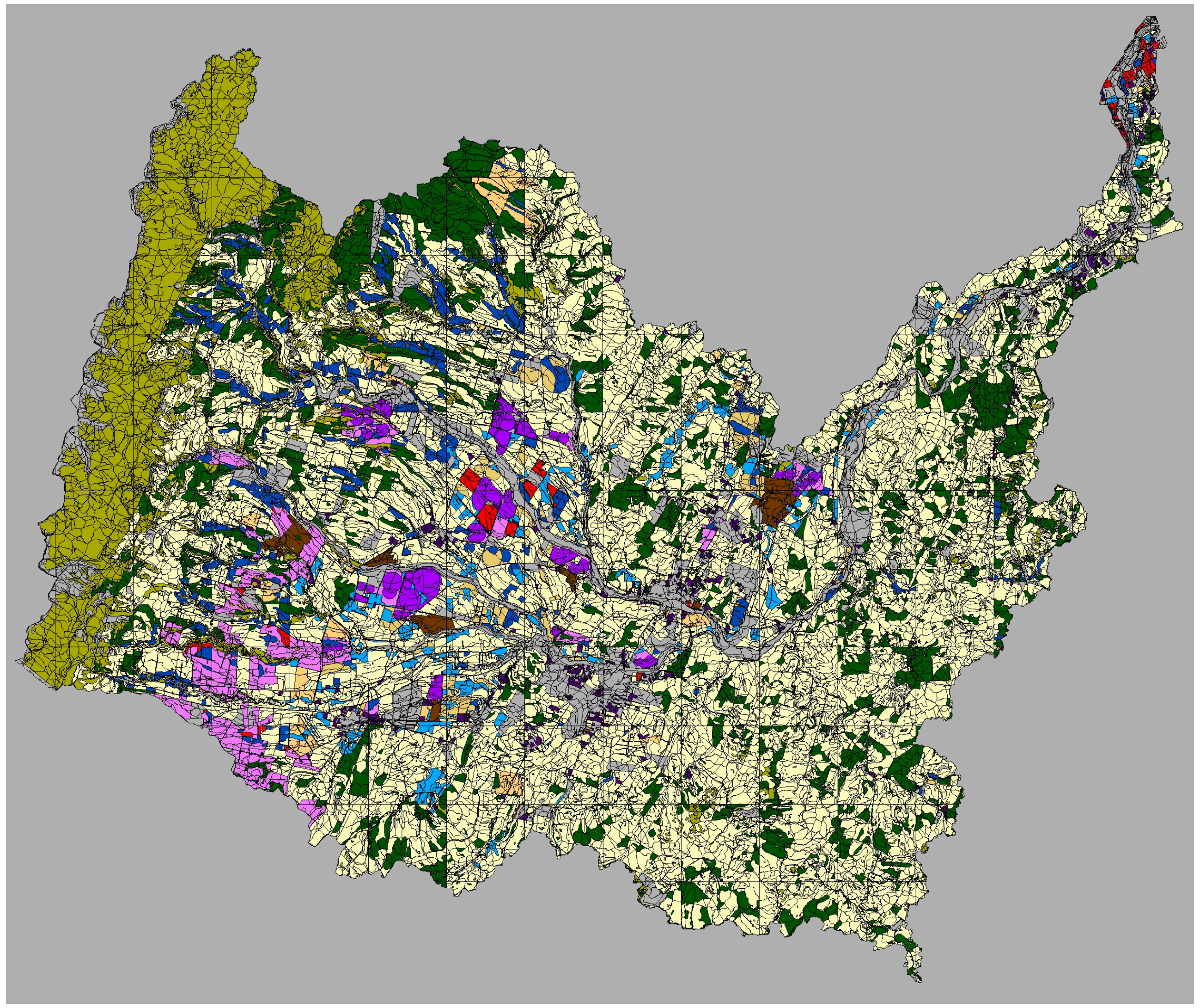


Figure 8: Projected land use in the Tukituki catchment under the N30-*iex* scenario

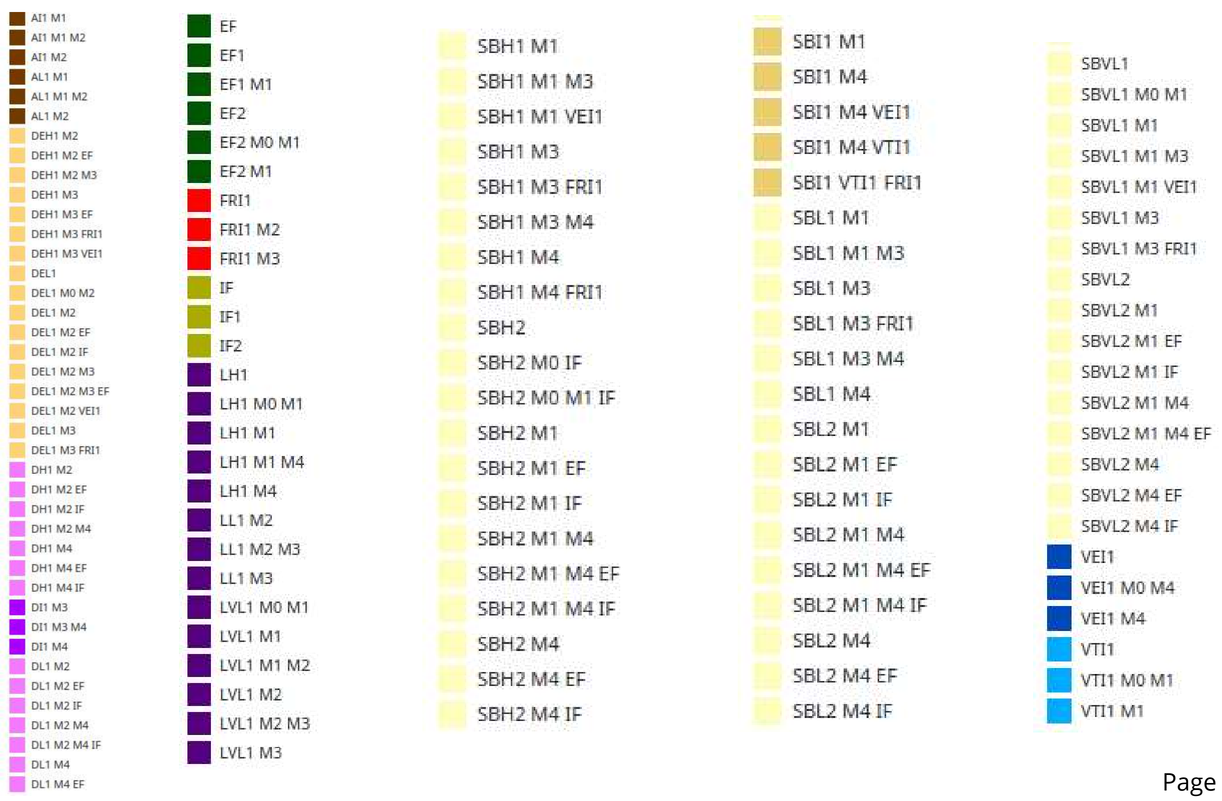


Table 18: Summary of N30 scenarios without and with access to additional irrigation water

Observed change	No increase in irrigation	Increased irrigation	Land use change	No increase in irrigation	Increased irrigation
Profitability	-17%	3%	From	ha	ha
N	-49%	-51%	Dairy	-855	-2,327
P	-41%	-46%	Sheep & beef	-33,904	-41,979
TSS	-60%	-62%	Deer	-481	-708
E. coli	-63%	-62%			
CH_4	-21%	-27%			
			To	ha	ha
Sub-catchment achievement of NPS-FM targets			Indigenous forestry	1,414	1,461
N	5%	6%	Exotic forestry	30,396	30,311
P	46%	50%	Viticulture	1,166	4,861
TSS	85%	85%	Pipfruit	136	359
E. coli	46%	42%	Vegetables	2,125	8,018

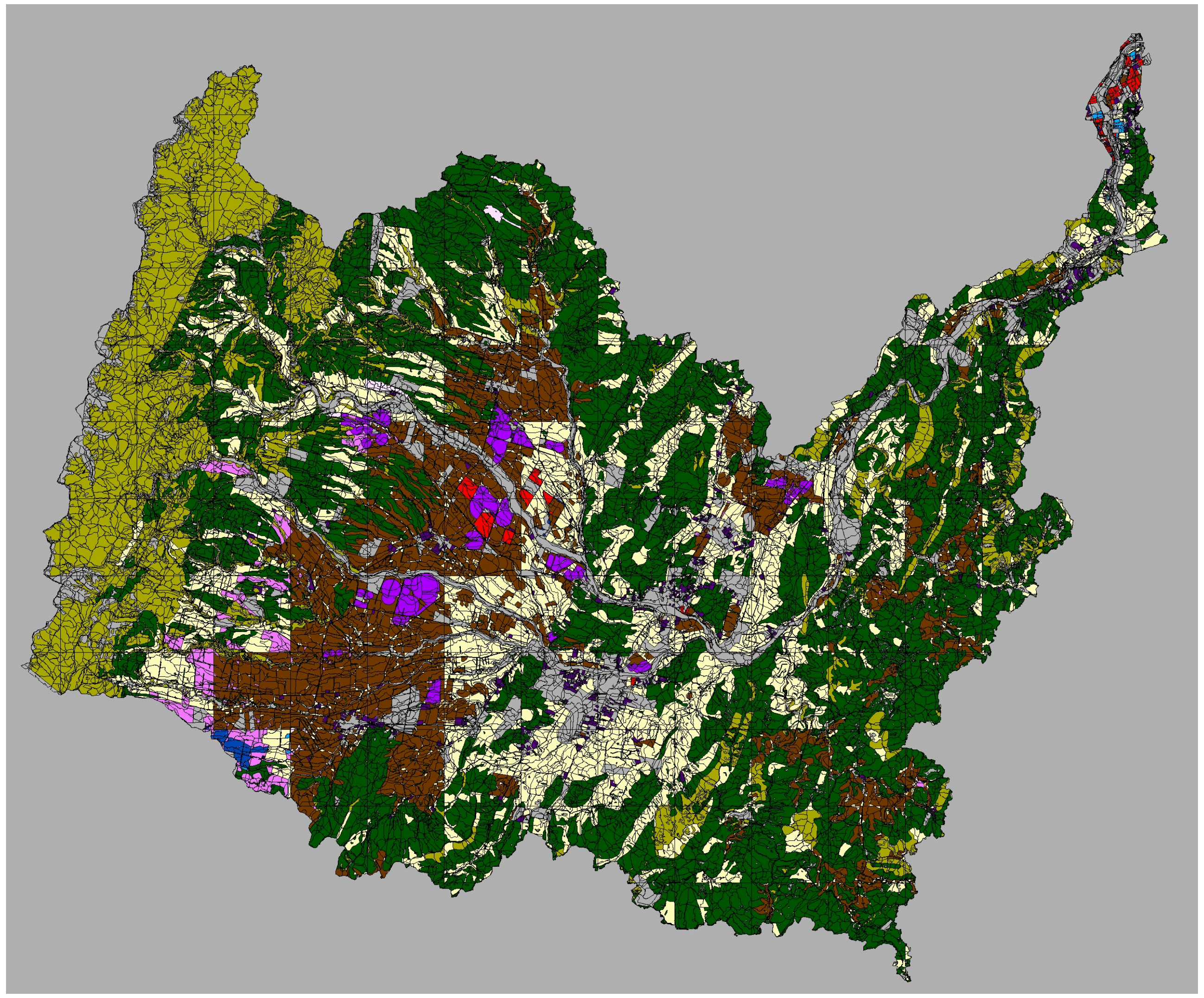


Figure 9: Projected land use in the Tukituki catchment under the F80 scenario

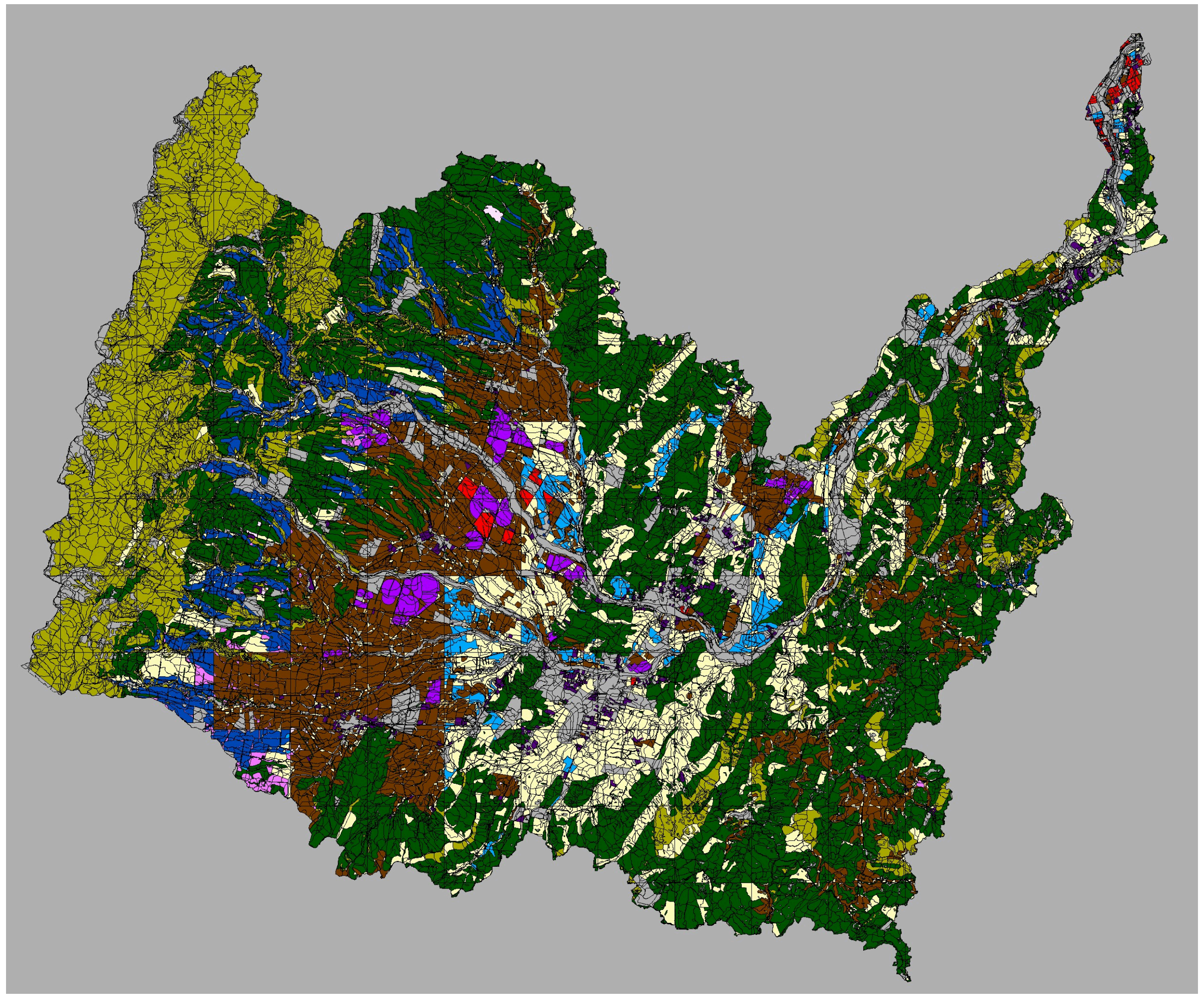


Figure 10: Projected land use in the Tukituki catchment under the F80-*iex* scenario

Table 19: Summary of F80 scenarios without and with access to additional irrigation water

Observed change	No increase in irrigation	Increased irrigation
Profitability	-31%	10%
N	-67%	-69%
P	-65%	-66%
TSS	-68%	-69%
E. coli	-79%	-77%
CH_4	-48%	-56%
Sub-catchment achievement of NPS-FM targets		
N	60%	59%
P	80%	80%
TSS	85%	85%
E. coli	89%	83%

Land use change	No increase in irrigation	Increased irrigation
From	ha	ha
Dairy	-4,791	-6,270
Sheep & beef	-121,470	-131,959
Deer	-2,529	-2,689
To	ha	ha
Indigenous forestry	13,738	13,738
Exotic forestry	85,616	85,616
Viticulture	17	3,786
Arable	29,237	29,237
Pipfruit	-	-
Vegetables	320	8,679

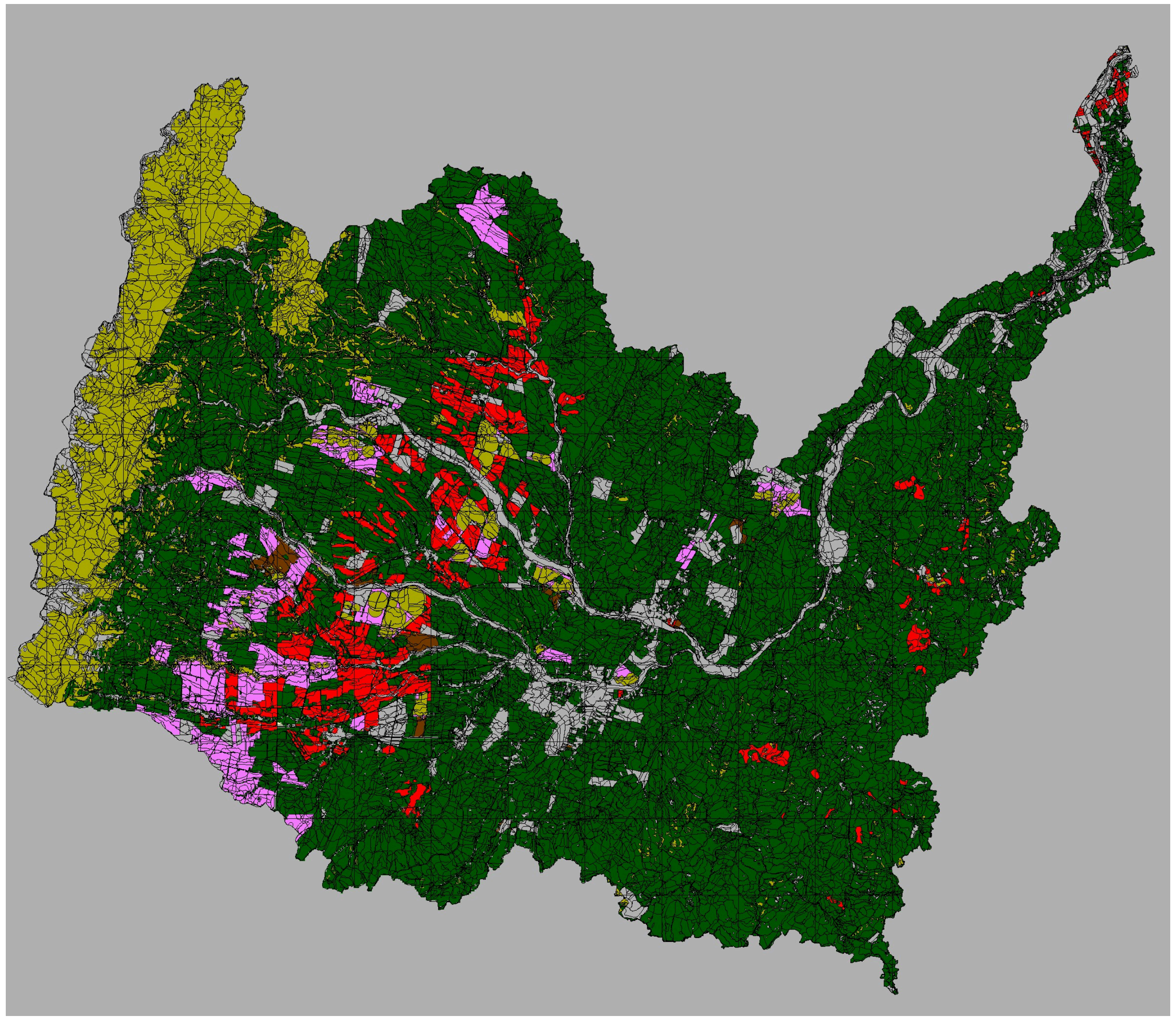


Figure 11: Projected land use in the Tukituki catchment under the N60 scenario

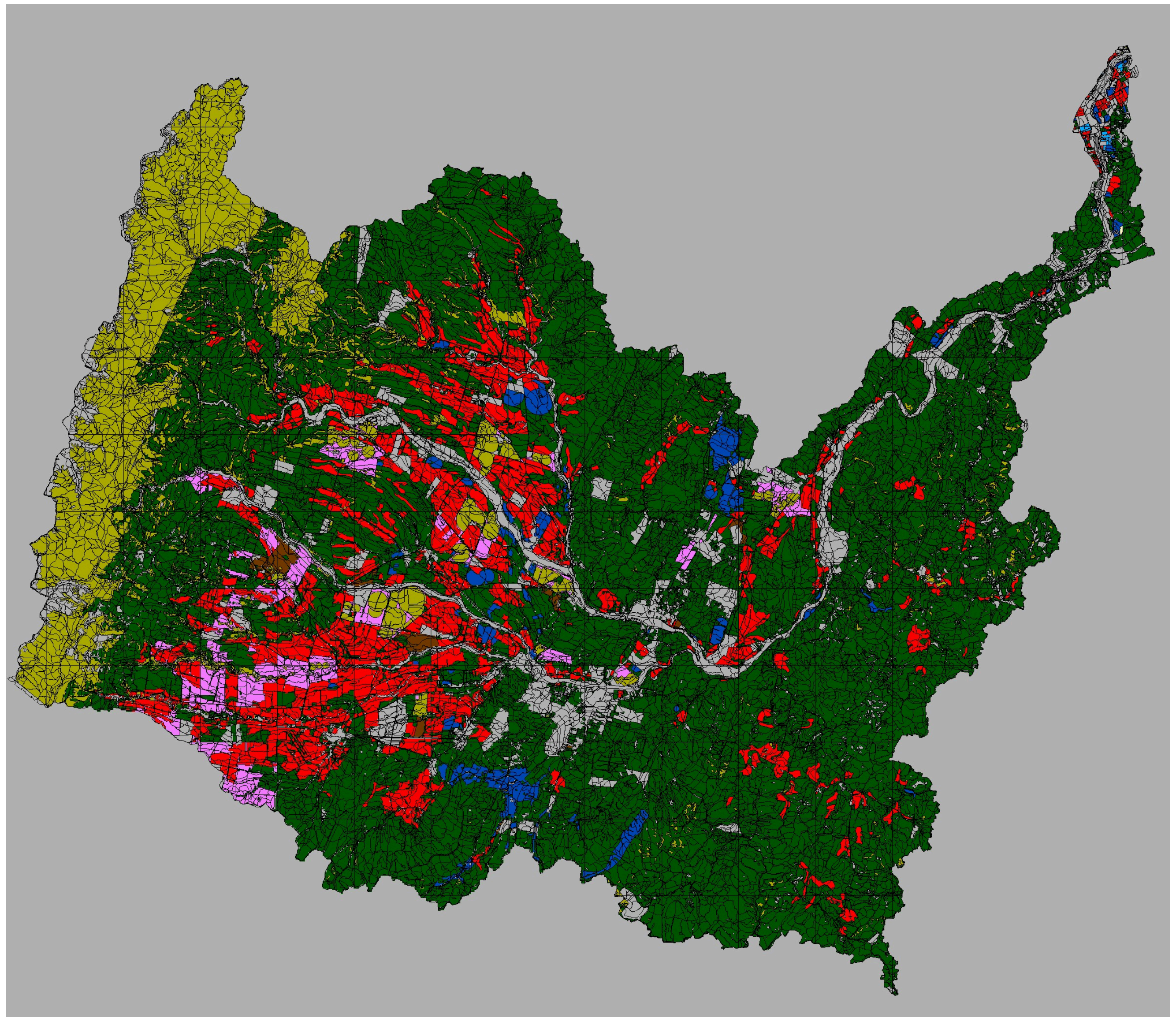


Figure 12: Projected land use in the Tukituki catchment under the N60-*iex* scenario

Table 20: Summary of N60 scenarios without and with access to additional irrigation water

Observed change	No increase in irrigation	Increased irrigation	Land use change	No increase in irrigation	Increased irrigation
Profitability	120%	303%	From	ha	ha
N	-72%	-70%	Dairy	-1,663	-4,999
P	-64%	-64%	Sheep & beef	-164,797	-164,797
TSS	-68%	-68%	Deer	-2,970	-2,970
E. coli	-77%	-75%	Arable	-577	-577
CH_4	-87%	-93%	Vegetables	-202	-
			Viticulture	-102	-
			Lifestyle	-2,296	-2,296
Sub-catchment achievement of NPS-FM targets			To	ha	ha
N	78%	74%	Indigenous forestry	3,012	3,012
P	80%	81%	Exotic forestry	159,683	143,020
TSS	85%	85%	Pipfruit	9,914	25,757
E. coli	84%	79%	Vegetables	-	3,852

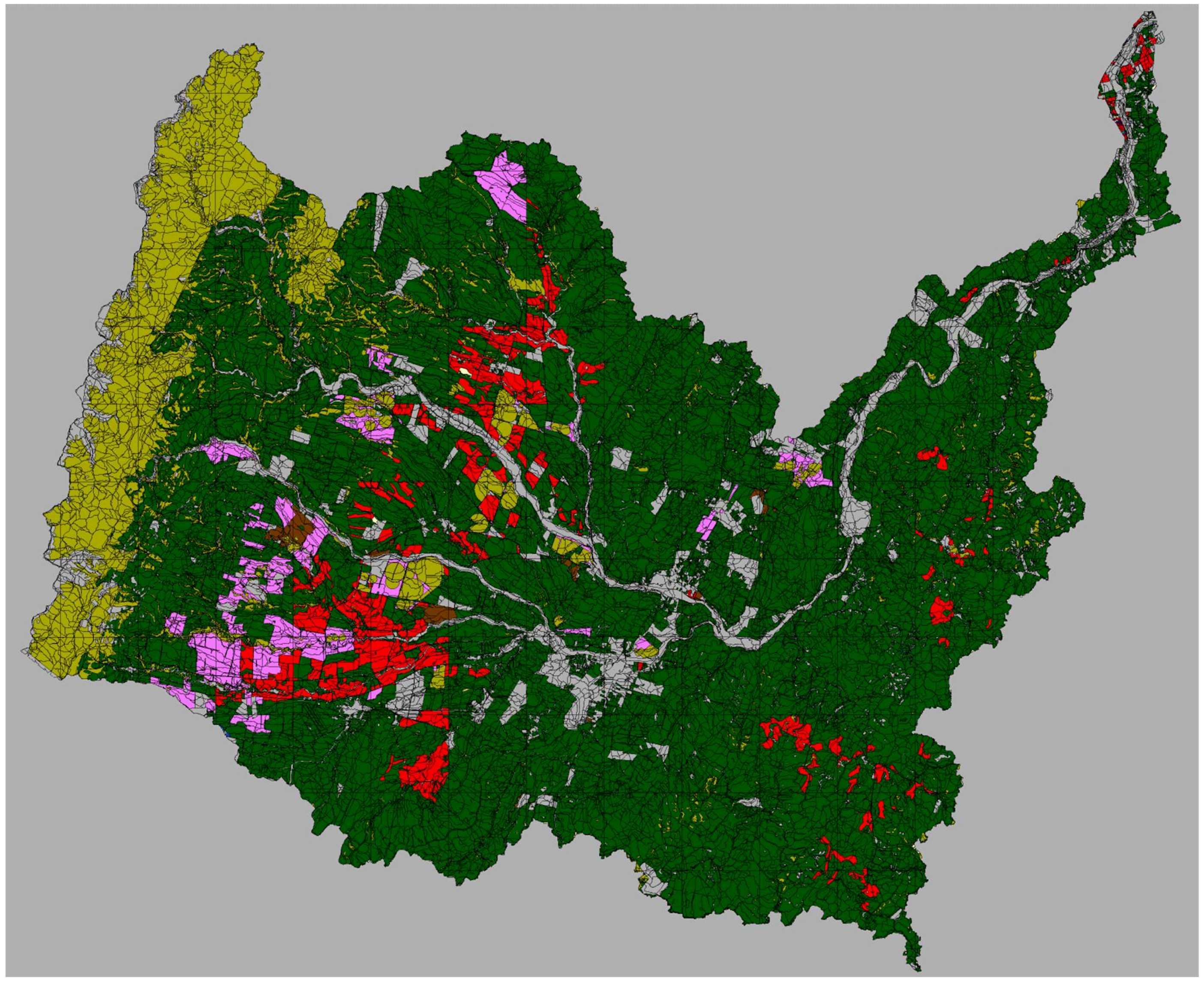


Figure 13: Projected land use in the Tukituki catchment under the CNmax scenario

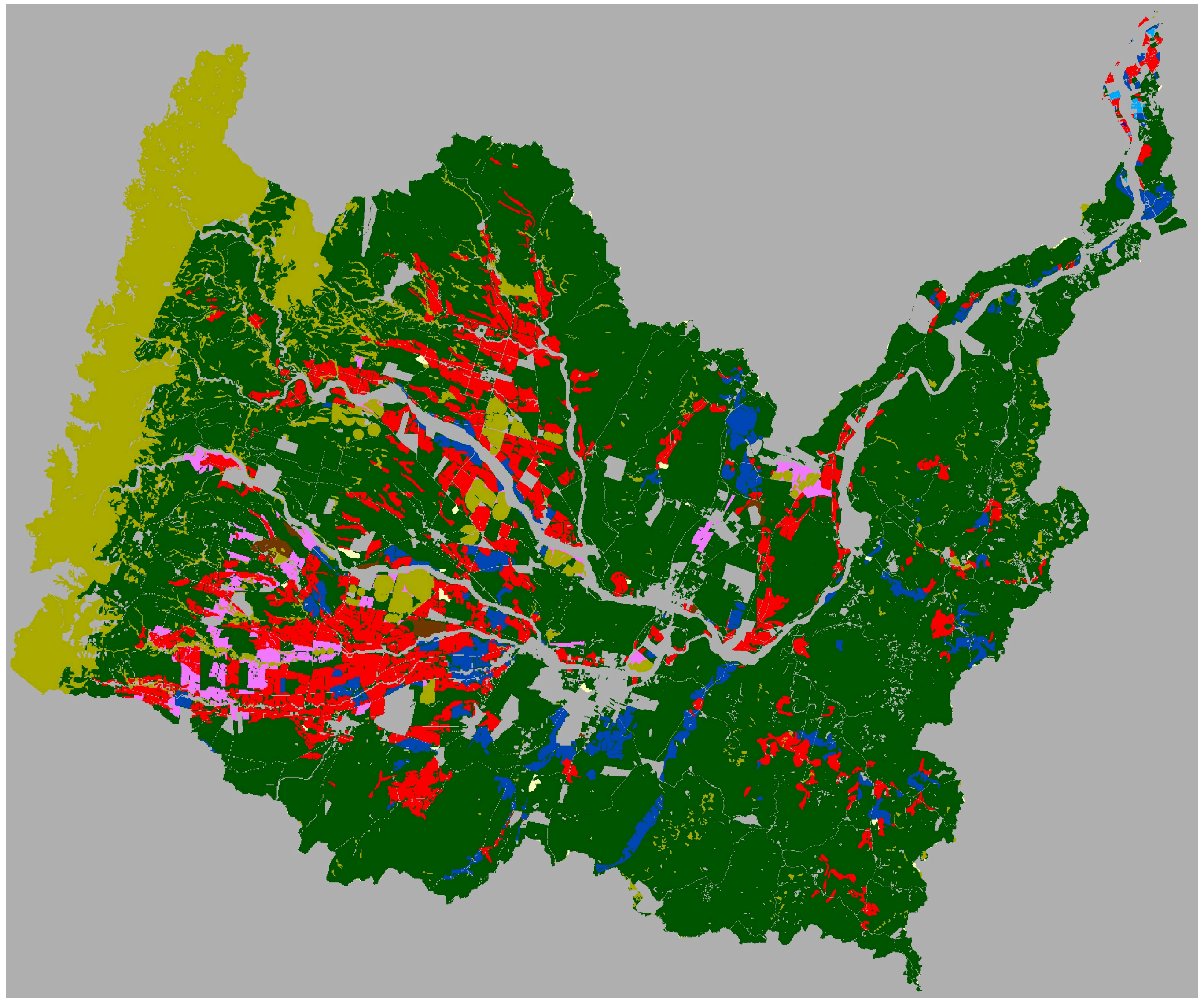
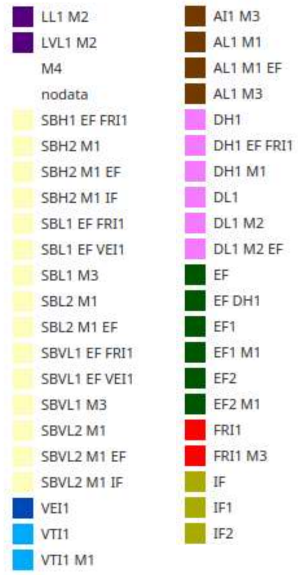


Figure 14: Projected land use in the Tukituki catchment under the CNmax-*iex* scenario

Table 21: Summary of CNmax scenarios without and with access to additional irrigation water

Observed change	No increase in irrigation	Increased irrigation	Land use change	No increase in irrigation	Increased irrigation
Profitability	120%	280%	From	ha	ha
N	-74%	-71%	Dairy	-3,752	-7,489
P	-64%	-65%	Sheep & beef	-164,797	-164,797
TSS	-68%	-68%	Deer	-2,970	-2,970
E. coli	-78%	-75%	Arable	-655	-851
CH_4	-90%	-96%	Vegetables	-202	-92
			Viticulture	-102	-
			Lifestyle	-2,296	-2,296
Sub-catchment achievement of NPS-FM targets			To	ha	ha
N	98%	93%	Indigenous forestry	3,012	3,012
P	80%	82%	Exotic forestry	161,070	145,003
TSS	85%	85%	Pipfruit	9,953	22,423
E. coli	86%	78%	Vegetables	-	7,322



5.2 Te Hoiere

The current land use mix in Te Hoiere based on the typologies defined by this research is presented in Figure 15 below.

Figure 15: Representation of current land use in the Te Hoiere catchment

Table 22: Current land use in the Te Hoiere catchment

Land use	Area (ha)	Proportion
Dairy (irrigated)	6,611	8.4%
Dairy (non-irrigated)	4,741	6.0%
Sheep & beef (non-irrigated)	6,097	7.7%
Gorse/broom	2,033	2.6%
Lifestyle farming	1,251	1.6%
Indigenous forestry	36,953	46.8%
Exotic forestry	21,357	27.0%

5.2.1 Modelled scenarios

Two contrasting scenarios were modelled for the Te Hoiere (Table 23)

Table 23: Scenario definition for Te Hoiere

	allCons	minEC
Objective	Minimise nitrogen loss	Minimise *E. coli*
Spatial allocation constraints	allowed partial land-use change with IF and EF according to Table 12 `	allowed land-use change with IF, EF, SBI1, SBH1, SBH2, DI1, DH1 according to Table 12 IF and EF were allowed anywhere in critical catchments for *E. coli* Mitigation and land-use change was restricted to critical catchments for *E. coli*
Farm-level constraints	Gross margin >= 70% of baseline Minimum area for dairy farms >= 100 ha (or baseline area if smaller) Exotic forest + retirement <= 20% of farm area	
General performance constraints	Water use <= baseline water use	Water use <= baseline water use

Visual representation of the land use mix across the catchments under each scenario are presented in Figure 16 and Figure 17 and the predicted aggregate economic, economic and land use change outcomes summarised in Table 24 and Table 25.

5.2.2 Achievement of NPS-FM water quality targets

Given the two scenarios were both targeting different contaminants, the differing results are not surprising.

The allCons scenario achieved 100% of N and P loss NPS-FM targets. However, it only had 53% and 56% of critical catchments meeting *E. coli* targets and sediment respectively, their reduction being a byproduct of a focus on N loss mitigation. The fact that N and P targets were also both achieved in the minEC scenario suggests that allCons potentially exceeded necessary N loss reductions by some extent. This scenario resulted in total N losses reducing by 48%, while minEC achieved the same level of target sub-catchment achievement for only a 20% reduction in N losses.

The minEC scenario increased the number of critical catchments meeting the primary *E. coli* targets to 81%, and while still meeting N and P targets. Sediment target achievement increased slightly to 56% of critical sub-catchments.

5.2.3 Changes in biogenic greenhouse gas emissions

Methane emissions from land use was reduced in both analysed scenarios. The greater extent of reduction in the allCons scenario was due to a greater reduction in pastoral farming area.

5.2.4 Mitigation adoption

The degree to which farm typologies had to move down the mitigation cost curve appeared to depend on the constraints of the model. The allCons scenario attempted to maximise N loss reduction for a reduction in profitability of 30%. As a result, the modelling compelled landowners to take up more costly mitigations, with 20% of the pastoral area assumed to have applied M3 or M4 bundles.

This contrasts with the minEC scenario, where only half as much area was mitigated as aggressively (and no M4 application was deemed to be required).

5.2.5 Land use change

Under both scenarios, dairy farming had the greatest exposure to the likely requirement for land use change – conversion to exotic forestry in allCons and to sheep & beef farming in minEC. This seems logical for allCons with its N focus and the higher relative N losses to water from dairying compared to other land uses in the catchment. It does, however, seem less intuitive for minEC given the similar levels of E. coli loss from all pastoral enterprises and the much higher level of profitability from dairying. When the raw output is interrogated further, what is occurring is the net conversion of dairy land to sheep & beef farming, while sheep & beef land is being converted to indigenous forest.

5.2.6 Economic impact of achieving water quality improvement

Both scenarios failed to improve water quality without a predicted erosion in aggregate catchment profitability. As a result of the climate (high rainfall) and landscape (prone to flooding) there is an assumed lack of higher value, lower impact alternate land uses available for adoption in the Te Hoiere catchment. Given this assumption and the dominance of dairy as the predominant pastoral land use, it is hypothesised that additional scenarios with fewer constraints to land use change may not have been able to determine a more profitable pathway. Additional scenario runs would be required to interrogate this.

Figure 16: Projected land use in the Te Hoiere catchment under the allCons scenario

Table 24: Summary of allCons scenario

Observed change	allCons	Land use change	allCons
Profitability	-30%	From	ha
N	-48%	Dairy	-3,152
P	-50%	Sheep & beef	-1,873
TSS	-24%	Gorse/broom	-1,785
E. coli	-48%	Lifestyle farming	-341
CH_4	-35%		
Sub-catchment achievement of NPS-FM targets		To	ha
		Indigenous forestry	1,871
N	100%	Exotic forestry	5,275
P	100%		
TSS	56%		
E. coli	53%		

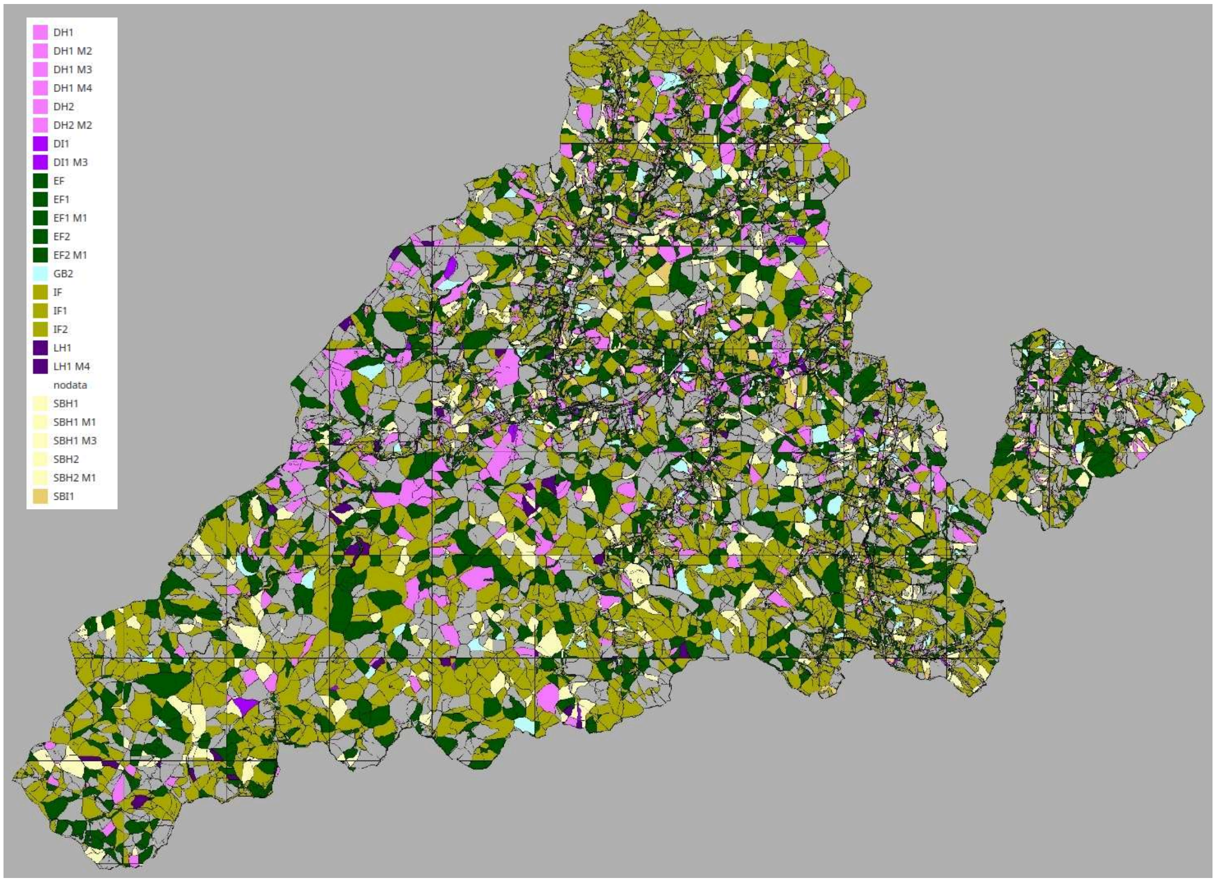


Figure 17: Projected land use in the Te Hoiere catchment under the minEC scenario

Table 25: Summary of minEC scenario

Observed change	minEC	Land use change	allCons
Profitability	-26%	From	ha
N	-19%	Dairy	-3,270
P	-25%	Sheep & beef	-
TSS	-10%	Gorse/broom	-
E. coli	-22%	Lifestyle farming	-480
CH_4	-19%		
Sub-catchment achievement of NPS-FM targets		To	ha
		Indigenous forestry	1,735
N	100%	Exotic forestry	-
P	100%	Sheep & beef	2,057
TSS	59%		
E. coli	81%		

6 Case study validation

6.1 Tukituki

6.1.1 Scenario N30

The land management and land use changes predicted for the case study farms under scenario N30, along with their nominal outcomes, are summarised in Table 26 below.

Table 26: Predicted mitigation adoption and land use changes for case study properties under scenario N30

Case study	Predicted mitigation adoption and land use change
Farm 1	Mitigations deployed to M3 on all existing pastoral land typologies. No land use change required. Profit estimated to decline by 30%, with N loss reducing by 18%.
Farm 2	SBVL2 land mitigated to M1. SBL1 land mitigated to M4. 28% of SBL2 land converted to exotic production forestry, with 62% of the land requiring M4 level mitigation and the residual mitigated to M1. Profit estimated to decline by 30%, with N loss reducing by 25%.
Farm 3	2% of SBH1 land converted to pipfruit, with the balance requiring M4 level mitigation. 73% of SBH2 land converted to exotic production forestry, with the balance requiring M1 level mitigation. Profit estimated to decline by 30%, with N loss reducing by 32%.
Farm 4	88% of SBI1 land converted to irrigated vegetable production. SBL1 land mitigated to M3. SBVL1 land mitigated to M3. 95% of SBL2 land converted to exotic production forestry, with the balance requiring M4 level mitigation. Profit estimated to increase by 67%, with N loss reducing by 38%.
Farm 5[7]	AL1 land mitigated to a combination of M1 and M2, with a single hectare developed into irrigated pipfruit. 100% of SBVL2 land converted to exotic production forestry. Profit estimated to decrease by 26%, with N loss reducing by 43%.

[7] The model's typology assignment to Farm 5 was incorrect due to an inaccurate classification of farm activity in AgriBase. For the purposes of the feasibility assessment only, the economic and environmental yields for the property's more accurate typology assignation were manually altered and the baseline and scenario predictions recalculated.

Cash flow analysis for each of the five case studies was then completed for a period of twenty years. The analysis for each property is presented in Table 28 through to Table 33 below.

As visible in these analyses, the predicted changes for Farms 1, 2 and 3 were considered unfeasible, while for Farm 4 and 5, the changes were considered feasible. This is summarised in Table 27 below. Note that for Farm 2, perhaps the most "typical" of the sheep and beef farm systems in the Tukituki, the proposed changes were still not feasible even if the land use change was phased over twenty years (Table 30).

Table 27: Summary of case study feasibility for scenario N30 outcomes (immediate implementation)

Case study	Predicted economic outcome	Interest cover	Annual cash surpluses	Total debt at year 20	Feasibility
Farm 1	Profit decline of 30%.	Declines from 2.4 to 2.1 over the period ✓	Not a single cash surplus in 20 years ✗	Total debt 16% higher after 20 years. ✗	Unfeasible
Farm 2	Profit decline of 30%.	Four years in which interest cover is below 1.0. ✗	A cash surplus achieved in only three of 20 years. ✗	Total debt 12% lower after 20 years ✓	Unfeasible
Farm 3	Profit decline of 30%.	Five years in which interest cover is below 1.0. ✗	A cash surplus achieved in only three of 20 years. ✗	Total debt 63% higher after 20 years. ✗	Unfeasible
Farm 4	Profit increase of 67%.	Interest cover comfortably above 2 for the three years in which debt remains. ✓	Significant cash surpluses achieved year on year. ✓	Existing debt paid off after three years. ✓	Feasible
Farm 5	Profit decline of 26%.	Interest cover comfortably above 2 for the 15 years in which debt remains. ✓	Cash surpluses achieved year on year. ✓	Existing and additional debt paid off after fifteen years. ✓	Feasible

Table 28: Cashflow forecast for case study Farm 1 for scenario N30 [unfeasible]

Farm 1		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574
SBVL1		15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574
Operating surplus		**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**
less																					
Interest	5%	-31,811	-31,994	-32,183	-32,379	-32,582	-32,792	-33,010	-33,236	-33,470	-33,712	-33,963	-34,224	-34,493	-34,772	-35,061	-35,361	-35,671	-35,993	-36,326	-36,671
Tax	28%	-12,414	-12,363	-12,310	-12,255	-12,199	-12,140	-12,079	-12,015	-11,950	-11,882	-11,812	-11,739	-11,664	-11,585	-11,504	-11,420	-11,334	-11,244	-11,150	-11,054
Normal asset replacement		-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934
Wages of management		-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641
Annual cash surplus		**-3,652**	**-3,784**	**-3,920**	**-4,061**	**-4,207**	**-4,359**	**-4,516**	**-4,678**	**-4,847**	**-5,021**	**-5,202**	**-5,389**	**-5,583**	**-5,784**	**-5,992**	**-6,208**	**-6,432**	**-6,663**	**-6,903**	**-7,151**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-3,652**	**-3,784**	**-3,920**	**-4,061**	**-4,207**	**-4,359**	**-4,516**	**-4,678**	**-4,847**	**-5,021**	**-5,202**	**-5,389**	**-5,583**	**-5,784**	**-5,992**	**-6,208**	**-6,432**	**-6,663**	**-6,903**	**-7,151**
Opening debt		-636,225	-639,877	-643,661	-647,581	-651,642	-655,849	-660,208	-664,723	-669,402	-674,248	-679,269	-684,471	-689,860	-695,443	-701,227	-707,220	-713,428	-719,859	-726,523	-733,425
Closing debt		-639,877	-643,661	-647,581	-651,642	-655,849	-660,208	-664,723	-669,402	-674,248	-679,269	-684,471	-689,860	-695,443	-701,227	-707,220	-713,428	-719,859	-726,523	-733,425	-740,577
Interest cover		2.4	2.4	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1

Table 29: Cashflow forecast for case study Farm 2 for scenario N30 [unfeasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387
SBL2		81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627
SBVL2		37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
EF2		-185,860	-15,441	-15,441	-15,441	-162,969	-15,441	84,622	-15,441	-231,816	-15,441	-15,441	1,077,918	-15,441	-15,441	-15,441	-15,441	841,775	-15,441	-15,441	-15,441
Operating surplus		**-63,210**	**107,208**	**107,208**	**107,208**	**-40,320**	**107,208**	**207,272**	**107,208**	**-109,166**	**107,208**	**107,208**	**1,200,568**	**107,208**	**107,208**	**107,208**	**107,208**	**964,425**	**107,208**	**107,208**	**107,208**
less																					
Interest	5%	-71,609	-81,427	-83,215	-85,093	-87,064	-96,511	-99,053	-96,719	-99,272	-112,771	-116,126	-119,649	-79,840	-81,932	-84,099	-86,344	-88,670	-60,220	-61,606	-63,041
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-223,186	-7,663	-7,077	-6,471	-5,842	-245,211	-13,157	-12,769	-12,367
Normal asset replacement		-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**-196,363**	**-35,762**	**-37,550**	**-39,428**	**-188,927**	**-50,846**	**46,675**	**-51,054**	**-269,981**	**-67,106**	**-70,461**	**796,190**	**-41,838**	**-43,344**	**-44,905**	**-46,521**	**569,000**	**-27,712**	**-28,709**	**-29,743**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-196,363**	**-35,762**	**-37,550**	**-39,428**	**-188,927**	**-50,846**	**46,675**	**-51,054**	**-269,981**	**-67,106**	**-70,461**	**796,190**	**-41,838**	**-43,344**	**-44,905**	**-46,521**	**569,000**	**-27,712**	**-28,709**	**-29,743**
Opening debt		-1,432,184	-1,628,547	-1,664,309	-1,701,859	-1,741,287	-1,930,214	-1,981,060	-1,934,385	-1,985,439	-2,255,420	-2,322,526	-2,392,987	-1,596,798	-1,638,636	-1,681,980	-1,726,884	-1,773,405	-1,204,405	-1,232,117	-1,260,827
Closing debt		-1,628,547	-1,664,309	-1,701,859	-1,741,287	-1,930,214	-1,981,060	-1,934,385	-1,985,439	-2,255,420	-2,322,526	-2,392,987	-1,596,798	-1,638,636	-1,681,980	-1,726,884	-1,773,405	-1,204,405	-1,232,117	-1,260,827	-1,290,570
Interest cover		-0.9	1.3	1.3	1.3	-0.5	1.1	2.1	1.1	-1.1	1.0	0.9	10.0	1.3	1.3	1.3	1.2	10.9	1.8	1.7	1.7

Table 30: Cashflow forecast for case study Farm 2 for scenario N30 with land use change phased [unfeasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387
SBL2		111,175	109,619	108,064	106,509	104,954	103,399	101,844	100,289	98,733	97,178	95,623	94,068	92,513	90,958	89,403	87,847	86,292	84,737	83,182	81,627
SBVL2		37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
EF2		-9,293	-10,065	-10,837	-11,609	-19,758	-20,530	-16,299	-17,071	-28,661	-29,434	-30,206	23,690	22,918	22,146	21,374	20,602	62,691	61,919	61,147	60,375
Operating surplus		**142,904**	**140,577**	**138,250**	**135,923**	**126,219**	**123,892**	**126,568**	**124,241**	**111,095**	**108,768**	**106,440**	**158,781**	**156,454**	**154,127**	**151,800**	**149,472**	**190,006**	**187,679**	**185,351**	**183,024**
less																					
Interest	5%	-71,609	-72,120	-72,732	-73,451	-74,279	-75,486	-76,821	-78,107	-79,524	-81,464	-83,559	-85,812	-86,262	-86,812	-87,466	-88,227	-89,100	-88,544	-88,053	-87,627
Tax	28%	-19,963	-19,168	-18,345	-17,492	-14,543	-13,554	-13,929	-12,917	-8,840	-7,645	-6,407	-20,431	-19,654	-18,848	-18,013	-17,149	-28,254	-27,758	-27,244	-26,711
Normal asset replacement		-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**-10,211**	**-12,254**	**-14,371**	**-16,564**	**-24,146**	**-26,691**	**-25,725**	**-28,327**	**-38,812**	**-41,885**	**-45,068**	**-9,005**	**-11,005**	**-13,077**	**-15,223**	**-17,447**	**11,109**	**9,833**	**8,512**	**7,143**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-10,211**	**-12,254**	**-14,371**	**-16,564**	**-24,146**	**-26,691**	**-25,725**	**-28,327**	**-38,812**	**-41,885**	**-45,068**	**-9,005**	**-11,005**	**-13,077**	**-15,223**	**-17,447**	**11,109**	**9,833**	**8,512**	**7,143**
Opening debt		-1,432,184	-1,442,395	-1,454,649	-1,469,019	-1,485,583	-1,509,729	-1,536,420	-1,562,146	-1,590,473	-1,629,285	-1,671,170	-1,716,238	-1,725,244	-1,736,249	-1,749,326	-1,764,549	-1,781,996	-1,770,887	-1,761,054	-1,752,542
Closing debt		-1,442,395	-1,454,649	-1,469,019	-1,485,583	-1,509,729	-1,536,420	-1,562,146	-1,590,473	-1,629,285	-1,671,170	-1,716,238	-1,725,244	-1,736,249	-1,749,326	-1,764,549	-1,781,996	-1,770,887	-1,761,054	-1,752,542	-1,745,399
Interest cover		2.0	1.9	1.9	1.9	1.7	1.6	1.6	1.6	1.4	1.3	1.3	1.9	1.8	1.8	1.7	1.7	2.1	2.1	2.1	2.1

Table 31: Cashflow forecast for case study Farm 3 for scenario N30 [unfeasible]

Farm 3		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBH1		8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273
SBH2		2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161
EF2		-21,568	-2,634	-2,634	-2,634	-27,798	-2,634	14,434	-2,634	-39,541	-2,634	-2,634	183,862	-2,634	-2,634	-2,634	-2,634	143,582	-2,634	-2,634	-2,634
FRI1		1,591	528	6,829	13,131	19,432	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733
Operating surplus		**-9,544**	**8,327**	**14,629**	**20,930**	**2,067**	**33,533**	**50,601**	**33,533**	**-3,374**	**33,533**	**33,533**	**220,028**	**33,533**	**33,533**	**33,533**	**33,533**	**179,749**	**33,533**	**33,533**	**33,533**
less																					
Interest	5%	-12,422	-19,173	-20,590	-21,763	-22,680	-24,586	-25,013	-24,609	-25,038	-27,333	-27,898	-28,491	-22,004	-22,464	-22,941	-23,434	-23,946	-19,212	-19,571	-19,943
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-44,295	-3,228	-3,099	-2,966	-2,828	-43,625	-4,010	-3,909	-3,805
Normal asset replacement		-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051
Wages of management		-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448
Annual cash surplus		**-39,464**	**-28,345**	**-23,461**	**-18,332**	**-38,112**	**-8,552**	**8,088**	**-8,575**	**-45,911**	**-11,299**	**-11,864**	**129,742**	**-9,198**	**-9,529**	**-9,873**	**-10,228**	**94,680**	**-7,188**	**-7,446**	**-7,715**
less																					
Capital required to fund land use change		-95,560	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-135,024**	**-28,345**	**-23,461**	**-18,332**	**-38,112**	**-8,552**	**8,088**	**-8,575**	**-45,911**	**-11,299**	**-11,864**	**129,742**	**-9,198**	**-9,529**	**-9,873**	**-10,228**	**94,680**	**-7,188**	**-7,446**	**-7,715**
Opening debt		-248,439	-383,464	-411,808	-435,269	-453,601	-491,713	-500,265	-492,176	-500,751	-546,662	-557,961	-569,826	-440,083	-449,281	-458,811	-468,683	-478,911	-384,232	-391,419	-398,866
Closing debt		-383,464	-411,808	-435,269	-453,601	-491,713	-500,265	-492,176	-500,751	-546,662	-557,961	-569,826	-440,083	-449,281	-458,811	-468,683	-478,911	-384,232	-391,419	-398,866	-406,580
Interest cover		-0.8	0.4	0.7	1.0	0.1	1.4	2.0	1.4	-0.1	1.2	1.2	7.7	1.5	1.5	1.5	1.4	7.5	1.7	1.7	1.7

Table 32: Cashflow forecast for case study Farm 4 for scenario N30 [feasible]

Farm 4		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBI1		14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443	14,443
SBL1		132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328	132,328
SBL2		1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248
SBVL1		3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984	3,984
VEI1		753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293
EF2		-177,475	-14,745	-14,745	-14,745	-155,617	-14,745	80,804	-14,745	-221,358	-14,745	-14,745	1,029,290	-14,745	-14,745	-14,745	-14,745	803,800	-14,745	-14,745	-14,745
Operating surplus		**727,822**	**890,552**	**890,552**	**890,552**	**749,680**	**890,552**	**986,101**	**890,552**	**683,939**	**890,552**	**890,552**	**1,934,586**	**890,552**	**890,552**	**890,552**	**890,552**	**1,709,097**	**890,552**	**890,552**	**890,552**
less																					
Interest	5%	-60,245	-39,337	-12,162	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax	28%	-186,922	-245,226	-245,226	-245,226	-166,338	-245,226	-298,734	-245,226	-129,523	-245,226	-245,226	-829,885	-245,226	-245,226	-245,226	-245,226	-703,611	-245,226	-245,226	-245,226
Normal asset replacement		-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494
Wages of management		-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000	-38,000
Annual cash surplus		**418,161**	**543,495**	**570,670**	**582,831**	**520,848**	**582,831**	**624,873**	**582,831**	**491,922**	**582,831**	**582,831**	**1,042,207**	**582,831**	**582,831**	**582,831**	**582,831**	**942,991**	**582,831**	**582,831**	**582,831**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**418,161**	**543,495**	**570,670**	**582,831**	**520,848**	**582,831**	**624,873**	**582,831**	**491,922**	**582,831**	**582,831**	**1,042,207**	**582,831**	**582,831**	**582,831**	**582,831**	**942,991**	**582,831**	**582,831**	**582,831**
Opening debt		-1,204,891	-786,730	-243,235	327,434	910,266	1,431,114	2,013,945	2,638,818	3,221,650	3,713,571	4,296,403	4,879,234	5,921,441	6,504,272	7,087,104	7,669,935	8,252,767	9,195,758	9,778,589	10,361,421
Closing debt		-786,730	-243,235	327,434	910,266	1,431,114	2,013,945	2,638,818	3,221,650	3,713,571	4,296,403	4,879,234	5,921,441	6,504,272	7,087,104	7,669,935	8,252,767	9,195,758	9,778,589	10,361,421	10,944,252
Interest cover		12.1	22.6	73.2																	

Table 33: Cashflow forecast for case study Farm 5 for scenario N30 [feasible]

Farm 5		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
AL1		387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116	387,116
EF2		-154,982	-12,876	-12,876	-12,876	-135,895	-12,876	70,564	-12,876	-193,303	-12,876	-12,876	898,841	-12,876	-12,876	-12,876	-12,876	701,929	-12,876	-12,876	-12,876
FRI1		577	463	5,990	11,518	17,045	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572	22,572
Operating surplus		**232,133**	**374,240**	**374,240**	**374,240**	**251,221**	**374,240**	**457,679**	**374,240**	**193,812**	**374,240**	**374,240**	**1,285,957**	**374,240**	**374,240**	**374,240**	**374,240**	**1,089,045**	**374,240**	**374,240**	**374,240**
less																					
Interest	5%	-115,930	-119,486	-113,864	-108,040	-102,005	-100,182	-93,865	-84,317	-77,429	-76,788	-69,629	-62,211	-21,706	-12,563	-3,092	-	-	-	-	-
Tax	28%	-32,537	-71,331	-72,905	-74,536	-41,780	-76,736	-101,868	-81,178	-32,587	-83,287	-85,291	-342,649	-98,710	-101,269	-103,921	-104,787	-304,932	-104,787	-104,787	-104,787
Normal asset replacement		-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322
Wages of management		-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657
Annual cash surplus		**12,688**	**112,444**	**116,492**	**120,685**	**36,457**	**126,343**	**190,967**	**137,766**	**12,817**	**143,187**	**148,341**	**810,118**	**182,846**	**189,428**	**196,248**	**198,474**	**713,133**	**198,474**	**198,474**	**198,474**
less																					
Capital required to fund land use change		-83,820																			
Net cash change		**-71,132**	**112,444**	**116,492**	**120,685**	**36,457**	**126,343**	**190,967**	**137,766**	**12,817**	**143,187**	**148,341**	**810,118**	**182,846**	**189,428**	**196,248**	**198,474**	**713,133**	**198,474**	**198,474**	**198,474**
Opening debt		-2,318,595	-2,389,727	-2,277,284	-2,160,792	-2,040,106	-2,003,650	-1,877,307	-1,686,340	-1,548,574	-1,535,757	-1,392,570	-1,244,229	-434,111	-251,265	-61,837	134,411	332,885	1,046,018	1,244,492	1,442,966
Closing debt		-2,389,727	-2,277,284	-2,160,792	-2,040,106	-2,003,650	-1,877,307	-1,686,340	-1,548,574	-1,535,757	-1,392,570	-1,244,229	-434,111	-251,265	-61,837	134,411	332,885	1,046,018	1,244,492	1,442,966	1,641,440
Interest cover		2.0	3.1	3.3	3.5	2.5	3.7	4.9	4.4	2.5	4.9	5.4	20.7	17.2	29.8	121.0					

Given four of the five case study properties were expected to generate lower profitability (as much as a 30% reduction) under the N30 scenario than their current situation, analysis of feasibility might seem to be a moot point, particularly from a farmer's perspective. However, achievement of improved water quality outcomes is regularly associated with reduced farm profitability, often because of the need to "unwind" prior intensification. As such, understanding whether existing business can implement changes and withstand any resultant changes to financial viability is important.

As reported above, in three of the five case studies, the required mitigation adoption and land use change was considered unfeasible based on two or more of the critical criteria. The assumption of pre-existing debt appears to be a significant driver of this. If the case study businesses were assumed to have no existing debt, then the proposed change for Farm 1 becomes feasible, Farm 2 partially feasible (fails on the interest cover test) while the change for Farm 3 remains unfeasible (see Table 34). If the proposed land use change was to be phased in over twenty years (Appendix 62), the proposed changes for Farm 2 moves from being partially to fully feasible.

Table 34: Summary of case study feasibility for scenario N30 outcomes assuming no pre-existing debt (immediate implementation).

Case study	Predicted economic outcome	Interest cover	Annual cash surpluses	Total debt at year 20	Feasibility
Farm 1	Profit decline of 30%.	Not relevant as no debt is incurred. ✓	Annual cash surpluses projected ✓	No debt incurred and ongoing cash surpluses ✓	Feasible
Farm 2	Profit decline of 30%.	Interest cover falls below 1.0 in the years associated with silvicultural activity. Lender may look past this. ✗	A cash surplus achieved in only 17 of 20 years. Cash deficits all associated with silvicultural activity. ✓	The debt incurred by forest establishment repaid within 12 years ✓	Partially feasible. Becomes fully feasible if land use change is phased in over 20 years
Farm 3	Profit decline of 30%.	Interest cover falls below 1.0 in the years associated with silvicultural activity. Lender may look past this. ✗	A cash surplus achieved in 13 of the 20 years, but the first five years are all deficits. ✗	Debt incurred by the forestry and orchard establishment repaid within 17 years ✓	Unfeasible

Both Farms 2 and 3 are predicted to require 20% of their pastoral area to convert to production forestry, which even with no debt places considerable pressure on cash flow until carbon revenues begin to materialise. Property size also appears to be a factor in the feasibility of land use change to forestry, with the smaller Farm 3 (between 50-100 ha in size) having to meet existing owner drawings (represented in the analysis by residual wages of management) from a much lower residual revenue stream. The full cash flow analyses for these three supplementary assessments are presented in Appendix 60 through Appendix 63.

6.1.2 Scenario CNmax

The land management and land use changes predicted for the five case study farms under the CNmax scenario, along with their nominal outcomes, are provided in Table 35 below. The extent of land use change is significantly more extreme than in the N30 scenario. In a key contrast to N30, four of the farms are also expected to have their profitability enhanced under the land use changes expected under CNmax (after fully accounting for the cost of land use change).

Table 35: Predicted mitigation adoption and land use changes for case study properties under the CNmax scenario

Case study	Predicted mitigation adoption and land use change
Farm 1	100% of SBVL1 land converted to exotic production forestry 97% of SBL1 land (119 ha) converted to pipfruit. The balance converted to exotic production forestry. Profit estimated to increase by 1988%, with N loss reducing by 23%.
Farm 2	100% of SBVL2 land converted to exotic production forestry. 67% of SBL1 land (5 ha) converted to pipfruit. The balance converted to exotic production forestry. 100% of SBL2 land converted to exotic production forestry. Profit estimated to increase by 62%, with N loss reducing by 67%.
Farm 3	100% of the farm converted to exotic production forestry. Profit estimated to increase by 67%, with N loss reducing by 87%.
Farm 4	88% of SBI1 land (67 ha) converted to irrigated vegetable production. 13 ha converted to pipfruit. The balance of the farm converted to exotic production forestry. Profit estimated to increase by 53%, with N loss reducing by 79%.
Farm 5	100% of AL1 land converted to exotic production forestry 100% of SBVL2 land converted to exotic production forestry. Profit estimated to decline by 46%, with N loss reducing by 77%.

As can be observed in Table 36 below, on the basis that all land use change is immediately implemented, only Farm 4 is expected to be feasible, largely due to significant expected revenues from large scale vegetable production. Farm 1 would likely be feasible if the significant pipfruit development was considered by a lender to contribute positively to total equity. The balance of the case studies are deemed unable to implement the proposed changes from their current situations. As with the N30 scenario, the phasing of forestry land use change evenly over the twenty-year period and pipfruit over a five-year window is expected to potentially make that land use change feasible. The full cash flows are presented in Table 37 to Table 42 below.

Table 36: Summary of case study feasibility for scenario CNmax outcomes

Case study	Predicted economic outcome	Interest cover	Annual cash surpluses	Total debt at year 20	Feasibility
Farm 1	Profit increase of 1988%.	Negative in the first two years. Lender might look past this.	Negative for first two years only.	New and existing debt paid off after 11 years.	Partially feasible. Given the significant debt capital involved, equity levels will be critical.
		✗	✓	✓	
Farm 2	Profit increase of 62%.	Interest cover only >1 in the three years with carbon revenue	A cash surplus achieved in only six of 20 years, including the last four.	New and existing debt paid off after 17 years.	Unfeasible
		✗	✗	✓	
Farm 3	Profit increase of 67%.	Interest cover only >1 in the three years with carbon revenue	A cash surplus achieved in only three of 20 years.	Total debt 15% lower after 20 years	Unfeasible
		✗	✗	✓	
Farm 4	Profit increase of 53%.	Interest cover comfortably above 2 for the seven years in which debt remains.	Significant cash surpluses achieved year on year.	New and existing debt paid off after seven years.	Feasible
		✓	✓	✓	
Farm 5	Profit decline of 46%.	Interest cover is only above 1 in the three years with significant carbon revenues	A cash surplus achieved in only three of 20 years.	Total debt 31% higher after 20 years.	Unfeasible
		✗	✗	✗	

Unlike in the N30 scenario, the absence of pre-existing debt made no significant difference to the assessed feasibility of the potential land use change for any of the case study farms. This is likely due to the scale (100% of existing farming area) of the land use change required.

Table 37: Cashflow forecast for case study Farm 1 for scenario CNmax [partially feasible]

Farm 1		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF1		-104,226	-13,554	-13,554	-13,554	-143,053	-13,554	74,280	-13,554	-203,486	-13,554	-13,554	946,187	-13,554	-13,554	-13,554	-13,554	738,903	-13,554	-13,554	-13,554
FRI1		-132,063	64,702	836,916	1,609,130	2,381,344	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557
Operating surplus		**-236,289**	**51,148**	**823,362**	**1,595,576**	**2,238,291**	**3,140,003**	**3,227,838**	**3,140,003**	**2,950,072**	**3,140,003**	**3,140,003**	**4,099,744**	**3,140,003**	**3,140,003**	**3,140,003**	**3,140,003**	**3,892,460**	**3,140,003**	**3,140,003**	**3,140,003**
less																					
Interest	5%	-31,811	-632,528	-663,375	-657,155	-615,498	-558,856	-467,713	-370,128	-272,191	-177,566	-72,697	-	-	-	-	-	-	-	-	-
Tax	28%	-	-	-	-69,700	-454,382	-722,721	-772,835	-775,565	-749,807	-829,482	-858,846	-1,147,928	-879,201	-879,201	-879,201	-879,201	-1,089,889	-879,201	-879,201	-879,201
Normal asset replacement		-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934
Wages of management		-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641
Annual cash surplus		**-303,675**	**-616,955**	**124,411**	**833,146**	**1,132,836**	**1,822,851**	**1,951,715**	**1,958,735**	**1,892,499**	**2,097,380**	**2,172,885**	**2,916,241**	**2,225,227**	**2,225,227**	**2,225,227**	**2,225,227**	**2,766,996**	**2,225,227**	**2,225,227**	**2,225,227**
less																					
Capital required to fund land use change		-11,710,655	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-12,014,330**	**-616,955**	**124,411**	**833,146**	**1,132,836**	**1,822,851**	**1,951,715**	**1,958,735**	**1,892,499**	**2,097,380**	**2,172,885**	**2,916,241**	**2,225,227**	**2,225,227**	**2,225,227**	**2,225,227**	**2,766,996**	**2,225,227**	**2,225,227**	**2,225,227**
Opening debt		-636,225	-12,650,555	-13,267,509	-13,143,098	-12,309,952	-11,177,116	-9,354,265	-7,402,550	-5,443,815	-3,551,316	-1,453,936	718,950	3,635,190	5,860,418	8,085,645	10,310,872	12,536,099	15,303,095	17,528,322	19,753,550
Closing debt		-12,650,555	-13,267,509	-13,143,098	-12,309,952	-11,177,116	-9,354,265	-7,402,550	-5,443,815	-3,551,316	-1,453,936	718,950	3,635,190	5,860,418	8,085,645	10,310,872	12,536,099	15,303,095	17,528,322	19,753,550	21,978,777
Interest cover		-7.4	0.1	1.2	2.4	3.6	5.6	6.9	8.5	10.8	17.7	43.2									

Table 38: Cashflow forecast for case study Farm 2 for scenario CNmax [unfeasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRI1		-6,547	3,208	41,491	79,774	118,057	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340
EF		-862,444	-71,816	-71,816	-71,816	-757,953	-71,816	393,568	-71,816	-1,078,151	-71,816	-71,816	5,013,287	-71,816	-71,816	-71,816	-71,816	3,915,009	-71,816	-71,816	-71,816
Operating surplus		**-868,991**	**-68,608**	**-30,325**	**7,958**	**-639,896**	**84,525**	**549,909**	**84,525**	**-921,810**	**84,525**	**84,525**	**5,169,627**	**84,525**	**84,525**	**84,525**	**84,525**	**4,071,349**	**84,525**	**84,525**	**84,525**
less																					
Interest	5%	-71,609	-149,869	-162,994	-174,861	-185,407	-228,873	-238,292	-224,912	-234,133	-294,131	-306,813	-320,129	-93,070	-95,698	-98,458	-101,356	-104,399	-	-	-
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-264,303	-	-	-	-	-1,096,611	-23,667	-23,667	-23,667
Normal asset replacement		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**-984,624**	**-262,500**	**-237,342**	**-210,926**	**-869,327**	**-188,373**	**267,593**	**-184,412**	**-1,199,967**	**-253,630**	**-266,312**	**4,541,172**	**-52,569**	**-55,197**	**-57,957**	**-60,855**	**2,826,316**	**16,834**	**16,834**	**16,834**
less																					
Capital required to fund land use change		-580,566	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-1,565,190**	**-262,500**	**-237,342**	**-210,926**	**-869,327**	**-188,373**	**267,593**	**-184,412**	**-1,199,967**	**-253,630**	**-266,312**	**4,541,172**	**-52,569**	**-55,197**	**-57,957**	**-60,855**	**2,826,316**	**16,834**	**16,834**	**16,834**
Opening debt		-1,432,184	-2,997,374	-3,259,874	-3,497,216	-3,708,143	-4,577,469	-4,765,842	-4,498,249	-4,682,661	-5,882,628	-6,136,258	-6,402,570	-1,861,399	-1,913,968	-1,969,165	-2,027,122	-2,087,978	738,339	755,173	772,007
Closing debt		-2,997,374	-3,259,874	-3,497,216	-3,708,143	-4,577,469	-4,765,842	-4,498,249	-4,682,661	-5,882,628	-6,136,258	-6,402,570	-1,861,399	-1,913,968	-1,969,165	-2,027,122	-2,087,978	738,339	755,173	772,007	788,841
Interest cover		-12.1	-0.5	-0.2	0.0	-3.5	0.4	2.3	0.4	-3.9	0.3	0.3	16.1	0.9	0.9	0.9	0.8	39.0			

Table 39: Cashflow forecast for case study Farm 2 for scenario CNmax with land use phased [partially feasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		5,630	5,318	5,005	4,693	4,380	4,160	3,863	3,566	3,269	2,971	2,674	2,377	2,080	1,783	1,486	1,189	891	594	297	0
SBL2		196,044	185,163	174,281	163,399	152,518	144,848	134,502	124,156	113,809	103,463	93,117	82,770	72,424	62,078	51,731	41,385	31,039	20,693	10,346	0
SBVL2		41,932	39,604	37,277	34,949	32,622	30,981	28,768	26,555	24,343	22,130	19,917	17,704	15,491	13,278	11,065	8,852	6,639	4,426	2,213	0
EF2		-43,122	-46,713	-50,304	-53,895	-91,792	-95,383	-75,705	-79,295	-133,203	-136,794	-140,384	110,280	106,689	103,098	99,508	95,917	291,667	288,076	284,486	280,895
FRI		-1,309	-668	7,630	23,585	47,197	79,774	110,401	133,370	148,684	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340
Operating surplus		**199,175**	**182,704**	**173,889**	**172,732**	**144,924**	**164,381**	**201,829**	**208,352**	**156,901**	**148,111**	**131,663**	**369,471**	**353,024**	**336,577**	**320,130**	**303,683**	**486,577**	**470,130**	**453,682**	**437,235**
less																					
Interest	5%	-71,609	-75,280	-79,676	-84,548	-89,637	-95,910	-95,902	-94,547	-92,907	-93,061	-93,537	-94,622	-87,186	-80,073	-73,297	-66,868	-60,801	-47,930	-35,189	-22,581
Tax	28%	-35,718	-30,079	-26,380	-24,691	-15,480	-19,172	-29,659	-31,865	-17,918	-15,414	-10,675	-76,958	-74,435	-71,821	-69,113	-66,308	-119,217	-118,216	-117,178	-116,103
Normal asset replacement		-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130	-5,130
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**42,693**	**28,191**	**18,680**	**14,339**	**-9,347**	**145**	**27,113**	**32,786**	**-3,078**	**-9,518**	**-21,703**	**148,738**	**142,250**	**135,529**	**128,566**	**121,353**	**257,405**	**254,830**	**252,162**	**249,397**
less																					
Capital required to fund land use change		-116,113	-116,113	-116,113	-116,113	-116,113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-73,420**	**-87,922**	**-97,433**	**-101,775**	**-125,460**	**145**	**27,113**	**32,786**	**-3,078**	**-9,518**	**-21,703**	**148,738**	**142,250**	**135,529**	**128,566**	**121,353**	**257,405**	**254,830**	**252,162**	**249,397**
Opening debt		-1,432,184	-1,505,604	-1,593,526	-1,690,959	-1,792,734	-1,918,194	-1,918,049	-1,890,935	-1,858,149	-1,861,227	-1,870,746	-1,892,449	-1,743,711	-1,601,461	-1,465,932	-1,337,366	-1,216,013	-958,608	-703,778	-451,617
Closing debt		-1,505,604	-1,593,526	-1,690,959	-1,792,734	-1,918,194	-1,918,049	-1,890,935	-1,858,149	-1,861,227	-1,870,746	-1,892,449	-1,743,711	-1,601,461	-1,465,932	-1,337,366	-1,216,013	-958,608	-703,778	-451,617	-202,220
Interest cover		2.8	2.4	2.2	2.0	1.6	1.7	2.1	2.2	1.7	1.6	1.4	3.9	4.0	4.2	4.4	4.5	8.0	9.8	12.9	19.4

Table 40: Cashflow forecast for case study Farm 3 for scenario CNmax [unfeasible]

Farm 3		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBH1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBH2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF		-43,268	-12,586	-12,586	-12,586	-132,838	-12,586	68,976	-12,586	-188,955	-12,586	-12,586	878,620	-12,586	-12,586	-12,586	-12,586	686,138	-12,586	-12,586	-12,586
Operating surplus		**-43,268**	**-12,586**	**-12,586**	**-12,586**	**-132,838**	**-12,586**	**68,976**	**-12,586**	**-188,955**	**-12,586**	**-12,586**	**878,620**	**-12,586**	**-12,586**	**-12,586**	**-12,586**	**686,138**	**-12,586**	**-12,586**	**-12,586**
less																					
Interest	5%	-12,422	-16,081	-18,390	-20,813	-23,358	-32,043	-35,150	-34,333	-37,554	-49,754	-53,746	-57,938	-19,219	-21,684	-24,272	-26,990	-29,844	-5,097	-6,856	-8,703
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-28,798	-	-	-	-	-143,859	-	-	-
Normal asset replacement		-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051
Wages of management		-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448
Annual cash surplus		**-73,188**	**-46,167**	**-48,475**	**-50,899**	**-173,695**	**-62,128**	**16,328**	**-64,418**	**-244,008**	**-79,840**	**-83,832**	**774,385**	**-49,304**	**-51,769**	**-54,358**	**-57,075**	**494,935**	**-35,182**	**-36,942**	**-38,789**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-73,188**	**-46,167**	**-48,475**	**-50,899**	**-173,695**	**-62,128**	**16,328**	**-64,418**	**-244,008**	**-79,840**	**-83,832**	**774,385**	**-49,304**	**-51,769**	**-54,358**	**-57,075**	**494,935**	**-35,182**	**-36,942**	**-38,789**
Opening debt		-248,439	-321,627	-367,794	-416,269	-467,168	-640,862	-702,991	-686,663	-751,081	-995,089	-1,074,929	-1,158,760	-384,375	-433,679	-485,448	-539,806	-596,881	-101,946	-137,128	-174,070
Closing debt		-321,627	-367,794	-416,269	-467,168	-640,862	-702,991	-686,663	-751,081	-995,089	-1,074,929	-1,158,760	-384,375	-433,679	-485,448	-539,806	-596,881	-101,946	-137,128	-174,070	-212,858
Interest cover		-3.5	-0.8	-0.7	-0.6	-5.7	-0.4	2.0	-0.4	-5.0	-0.3	-0.2	15.2	-0.7	-0.6	-0.5	-0.5	23.0	-2.5	-1.8	-1.4

Table 41: Cashflow forecast for case study Farm 4 for scenario CNmax [feasible]

Farm 4		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBI1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRI		-15,459	7,574	97,969	188,364	278,759	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153
VEI1		753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293
EF2		-534,925	-70,078	-70,078	-70,078	-739,610	-70,078	384,044	-70,078	-1,052,059	-70,078	-70,078	4,891,962	-70,078	-70,078	-70,078	-70,078	3,820,263	-70,078	-70,078	-70,078
Operating surplus		**202,908**	**690,789**	**781,184**	**871,579**	**292,441**	**1,052,368**	**1,506,490**	**1,052,368**	**70,387**	**1,052,368**	**1,052,368**	**6,014,408**	**1,052,368**	**1,052,368**	**1,052,368**	**1,052,368**	**4,942,709**	**1,052,368**	**1,052,368**	**1,052,368**
less																					
Interest	5%	-60,245	-126,644	-110,121	-89,517	-64,629	-56,232	-16,910	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax	28%	-39,946	-173,799	-199,110	-224,420	-	-149,834	-529,349	-275,041	-	-173	-275,041	-3,053,783	-275,041	-275,041	-275,041	-275,041	-2,453,632	-275,041	-275,041	-275,041
Normal asset replacement		-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494
Wages of management		-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379
Annual cash surplus		**42,844**	**330,472**	**412,079**	**497,768**	**167,939**	**786,429**	**900,357**	**717,453**	**10,514**	**992,321**	**717,453**	**2,900,750**	**717,453**	**717,453**	**717,453**	**717,453**	**2,429,203**	**717,453**	**717,453**	**717,453**
less																					
Capital required to fund land use change		-1,370,842	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-1,327,998**	**330,472**	**412,079**	**497,768**	**167,939**	**786,429**	**900,357**	**717,453**	**10,514**	**992,321**	**717,453**	**2,900,750**	**717,453**	**717,453**	**717,453**	**717,453**	**2,429,203**	**717,453**	**717,453**	**717,453**
Opening debt		-1,204,891	-2,532,889	-2,202,417	-1,790,338	-1,292,570	-1,124,632	-338,203	562,154	1,279,607	1,290,121	2,282,442	2,999,895	5,900,645	6,618,099	7,335,552	8,053,005	8,770,458	11,199,661	11,917,114	12,634,568
Closing debt		-2,532,889	-2,202,417	-1,790,338	-1,292,570	-1,124,632	-338,203	562,154	1,279,607	1,290,121	2,282,442	2,999,895	5,900,645	6,618,099	7,335,552	8,053,005	8,770,458	11,199,661	11,917,114	12,634,568	13,352,021
Interest cover		3.4	5.5	7.1	9.7	4.5	18.7	89.1													

Table 42: Cashflow forecast for case study Farm 5 for scenario CNmax [unfeasible]

Farm 5		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
AL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF2		-557,875	-65,595	-65,595	-65,595	-692,299	-65,595	359,477	-65,595	-984,760	-65,595	-65,595	4,579,032	-65,595	-65,595	-65,595	-65,595	3,575,888	-65,595	-65,595	-65,595
FRI1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Operating surplus		**-557,875**	**-65,595**	**-65,595**	**-65,595**	**-692,299**	**-65,595**	**359,477**	**-65,595**	**-984,760**	**-65,595**	**-65,595**	**4,579,032**	**-65,595**	**-65,595**	**-65,595**	**-65,595**	**3,575,888**	**-65,595**	**-65,595**	**-65,595**
less																					
Interest	5%	-115,930	-153,169	-164,593	-176,429	-188,691	-223,955	-237,928	-237,101	-251,547	-299,603	-316,300	-333,597	-184,310	-196,855	-209,853	-223,318	-237,267	-120,626	-130,879	-141,501
Tax	28%	-	61,254-	64,453-	67,767-	246,677-	81,074-	-34,034	84,755-	346,166-	102,256-	106,930-	-1,188,722	69,973-	73,486-	77,125-	80,896-	-934,814	52,142-	55,013-	57,987-
Normal asset replacement		-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322
Wages of management		-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657
Annual cash surplus		**-744,784**	**-228,489**	**-236,714**	**-245,236**	**-705,291**	**-279,455**	**16,536**	**-288,920**	**-961,121**	**-333,922**	**-345,943**	**2,985,734**	**-250,910**	**-259,943**	**-269,301**	**-278,996**	**2,332,828**	**-205,058**	**-212,440**	**-220,088**
less																					
Capital required to fund land use change		-																			
Net cash change		**-744,784**	**-228,489**	**-236,714**	**-245,236**	**-705,291**	**-279,455**	**16,536**	**-288,920**	**-961,121**	**-333,922**	**-345,943**	**2,985,734**	**-250,910**	**-259,943**	**-269,301**	**-278,996**	**2,332,828**	**-205,058**	**-212,440**	**-220,088**
Opening debt		-2,318,595	-3,063,379	-3,291,867	-3,528,582	-3,773,818	-4,479,110	-4,758,565	-4,742,028	-5,030,948	-5,992,069	-6,325,991	-6,671,934	-3,686,199	-3,937,110	-4,197,053	-4,466,354	-4,745,350	-2,412,522	-2,617,580	-2,830,020
Closing debt		-3,063,379	-3,291,867	-3,528,582	-3,773,818	-4,479,110	-4,758,565	-4,742,028	-5,030,948	-5,992,069	-6,325,991	-6,671,934	-3,686,199	-3,937,110	-4,197,053	-4,466,354	-4,745,350	-2,412,522	-2,617,580	-2,830,020	-3,050,108
Interest cover		-4.8	-0.4	-0.4	-0.4	-3.7	-0.3	1.5	-0.3	-3.9	-0.2	-0.2	13.7	-0.4	-0.3	-0.3	-0.3	15.1	-0.5	-0.5	-0.5

7 Discussion

7.1 Key results

The primary objective of the research was to demonstrate how a water quality target can be met through mitigating and changing land use in three high profile catchments, without (hopefully) compromising profitability or GHG emissions requirements. For the Tukituki catchment, this was essentially achieved under the CNmax scenario, at least with respect to nitrogen bottom lines, with phosphorus and *E. coli* targets also very close (≥80%) to full achievement. In reaching these targets, biogenic GHG emissions (using methane as a proxy) were forecast to reduce by 90% and aggregate catchment profitability was forecast to increase by 120%. If additional irrigation water became available to the catchment, the forecasted uplift in profit was expected to treble, with only a minimal impact on achieving water quality targets.

The pathway to achieving this is, however, likely to be confronting. To reach these targets, the modelling predicts the need for the complete removal of pastoral drystock farming from the Tukituki and its conversion to exotic forestry – in the order of 170,000 ha of land use change. Large scale land use change has not been uncommon in New Zealand's recent past. By way of comparison, the area planted in vineyards in Marlborough increased by 18,500 ha between 2003 and 2018 (NZ Winegrowers Inc., 2021), the conversion of exotic forestry to pasture in the Central North Island in the early 2000's was approximately 33,600 ha (Waikato Times, 2013; Wairakei Estate, 2024), and the conversion of dryland sheep and beef land to dairying in Canterbury has been in the order of 275,000 ha (LIC & DairyNZ, 2023).

Despite there being clear examples of significant shifts in land use change within New Zealand's supposedly static farmed landscapes, giving effect to land use change of this magnitude is not easy and poses significant logistical, financial, and societal challenges.

Putting aside potential errors or oversights within the modelling assumptions and the limitations inherent with modelling at catchment scale, the CNmax outcome outwardly represents a significant increase in long-term profitability for the Tukituki catchment when evaluated using a conventional financial approach. The case study analyses highlight the potential challenges in giving effect to this at a speed that would see the complete transformation of the catchment within a generation (20 years). While the land use change required for the Tukituki is nominally profitable, moving from land uses that require relatively low additional[8] levels of capital with regular revenues of moderate volatility to those with a high requirement for capital investment, more volatile/uncertain returns and/or irregular or delayed revenues can be difficult. These challenges are exacerbated as the speed or scale of change that is required is increased and the more constrained a farmer or grower's balance sheet is (i.e., their level of pre-existing debt). Reduced familiarity with new land uses and uncertainty over long-term revenue expectations, potentially act as barriers to both change and engagement with such modelled predictions. As the supplementary analysis for Farm 2 highlighted, the phasing in of land use change does provide a possible mechanism to improve the financial feasibility of transitioning from current to future state. While not explored in this analysis, the gradual phasing of land use change is likely to be beneficial from a market, supply chain, social and stakeholder expectation process. It also allows time for those who don't want to change to exit, and alternative owners come in who are willing to make the change with less disruption than in a rapid change. Phasing assists in the expansion or development or

[8] Over above investment in the land

markets, the required investment in supporting infrastructure, the development of institutional knowledge and in the socialisation of any change with the community.

7.2 Mitigation versus land use change

The N30 and F80 Tukituki scenarios both point to the potentially higher "cost" of restricting, avoiding, or "democratising" land use change, with the commensurate need to achieve more through mitigation. The mitigation cost curves, and the subsequent catchment-level modelling highlight the economic and environmental limits of primarily looking to address water quality through mitigation in catchments that have significantly poor water quality. Persevering with ever increasing (and more costly) mitigation in the face of more profitable alternative land uses would appear to increase the cost of and potentially limit the attainment of improved water quality. This does, however, represent a reality where some landowners will try to continue with specific land use before changing (or selling to someone else to change) due to personal preference on what land use they choose to own/manage.

The allCons and minEC models for the Te Hoiere catchment also demonstrate the negative impact that a lack of viable alternative land uses might have for the economic consequences of improving water quality. The Tukituki appears fortunate in that its geophysical parameters are likely to support the adoption of higher value [horticultural] land use. However, there remains uncertainty over the capacity of the [current] supply chain and markets to accommodate significant increases in the production of these foods, the availability of financial capital to change land use, access to skilled labour, and the regulatory frameworks (like the Emissions Trading Scheme) that might underpin expected revenue streams.

The point at which landowner decisions to undertake substantive land use change intersects with the adoption of water quality mitigations appears difficult to precisely determine and will likely differ by personal landowner preference.

The physical capacity to change to either accepted or nominally more profitable land uses with lower environmental footprints in a catchment with existing water quality issues is clearly insufficient in of itself to trigger change. While farmers in the Te Hoiere were considered to have few options for land use change without significant reduction in their long-term profitability, the *potential* for profitable land use change appears to exist the Tukituki, even in the absence of additional water for irrigation. Yet the catchment remains dominated by sheep and beef farming. As discussed above this is likely to be a result of factors such as access to capital and landowner desirability as not all individuals are profit-maximising.

Surveyed farmers in all three catchments indicated a high degree of mitigation activity, already actioned or planned, was being undertaken. Indeed, the potential appetite (a preference score >2) for mitigation actions by farmers went some way along the mitigation cost curves, including specific actions or practice changes that would start to significantly reduce profitability. While farmers weren't directly questioned about the precise points at which they would choose land use change over mitigations, the extent of self-reported mitigation actions and current choices on land use suggest it is not a simple cost-benefit trigger.

7.3 Feasibility of transition

While it may not be possible to identify the point at which land use trumps mitigation from an actual farmer decision perspective, this research points to factors that could functionally affect the capacity of farmers to implement actions on farm that will improve water quality, including land use change, even where such changes are considered to improve profitability. Specifically, these are:

- Scale of the farm business and its underlying level of profitability. Higher performing business have greater capacity to absorb reductions in profit from the adoption of mitigations or to fund land use change. Fixed costs also tend to be proportionally lower for larger businesses than smaller ones, which improves their ability to meet these if revenues temporarily or permanently reduce as a result of land use change decisions.

- The level of pre-existing debt. Even with relatively high levels of equity (low debt), permanent or temporary reduction in revenue reduces interest cover and free cashflow as interest costs as a proportion of revenue increase.

- The cadence of revenue from any new land use. While exotic forestry is, at a minimum, currently considered no less profitable than many sheep and beef operations, the timing of revenue and expenses can be difficult for businesses to cashflow, even with carbon revenue over the first 16-17 years in the first rotation. Horticultural operations also tend to have low to negative operating revenues in the first 4-7 years following establishment until trees or vines achieve maturity. While these negative cashflows may well be "funded" by a lender as part of the development, they still add to the risk profile of the business and can be significant when establishment is undertaken at scale.

- The rate of change required. Conventional economic theory and the time value of money would generally indicate that the net present value of a profitable development or land use change is increased the faster it is completed i.e., it is more profitable to establish a 100-hectare forest in year one than to establish 10 hectares annually for the next ten years. However, as the case study analysis demonstrated, phasing land use change like forestry is potentially advantageous from a liquidity perspective.

- The availability of water. A transition away from pastoral land use is greatly enabled by the potential for change to higher value land uses that are suitable at the same location, particularly horticulture. Where irrigation is critical to the establishment and/or operation of horticultural activities, greater availability of reliable water provides for the greater adoption of these farm systems and ultimately greater profitability. In the context of embedded climate change and the associated implications for rainfall volumes and distribution, increased water availability and reliability (through overflow storage systems) may be critical for just maintaining existing levels of irrigation.

A key tenant of this project was the idea that any required transition of farms should ideally be possible by the current owners or within the framework of intergenerational succession, rather than requiring the sale or transfer of land to third parties. While the increased profitability of the Tukituki CNmax scenarios is supportive of the catchment being able to attract the capital required to deliver the land use change required to meet NPS-FM bottom lines, the case study analysis suggests that farmers with typical performance and average sector debt may be unable to effect the necessary change themselves, and a change in ownership might be unavoidable.

The challenge for policy makers is that only some of these potential barriers can be addressed through regulation or a reasonable/socially acceptable deployment of the public purse. Farm size, level of performance and pre-existing debt levels are outside the ability of government to change or influence. The inherent financial returns of suitable land uses are a function of their biophysical characteristics and the market they supply.

Muller et al. (2023) determined that where required land changes are not profitable, have significant capital costs and/or can't access finance through traditional measures, novel financing solutions may be required to enable land use change. Unfortunately, most of the concepts identified in this work have limited applicability to overcoming the barriers identified here, particularly if the changes required are anticipated to be profitable (as opposed, say, to large scale indigenous afforestation). Any financial intervention by government in such situations is also at risk of being deemed corporate welfare. Guarantees of funding or provision of security from government or philanthropic entities *might* assist where cashflows are constrained in the early stages of transition or where liquidity or solvency metrics move outside required bounds temporarily. There is a precedent for the public to [partially] fund land use change, as occurred in the high-profile Lake Taupō and Lake Rotorua catchments, but this approach is unlikely to be fiscally sustainable and hasn't been subsequently utilised by regional or central government.

The time to effect change clearly needs to be balanced with the urgency to achieve change. Subject, however, to the level of contaminant attenuation in a catchment and the capacity of the receiving environment to cope with longer recovery times, allowing sufficient time for transition would seem to be the most effective lever available to policy makers.

Ascertaining the wider social feasibility of potentially required change in any of the three catchments was out of scope for this research. Individual engagement with case study farmers provided an informal opportunity to gauge a degree of response to the degree of change in early (less extreme) scenario runs, but there was no deliberate research into farmer (or wider community) attitudes to the prescribed change. However, given the nature and scale of the substantive change in land use this research suggests might be required to achieve NPS-FM water quality targets in the Tukituki, the risks to any underlying social license from the community, both rural and urban, for this level of change needs to be acknowledged. As identified in 7.4 below, the assessment of the economic consequence of the potential changes within the catchment is limited to an aggregate estimate of farm gate profitability over a medium-term horizon. The broader socio-economic impacts on the community of either rapid or phased land use away from pastoral agriculture to forestry is not considered, either under continued or changed ownership.

While a requirement to de-intensify or implement a degree of land use change is increasingly common in many catchment areas across New Zealand, few (if any) regional authorities have yet mandated the extent of change that the results of this research indicate might be required in the Tukituki to meet prescribed national bottom lines for water quality. While not within the scope of this work, these results do raise a question of communities as to whether they will be able or be prepared to collectively implement the level of change needed to achieve the quality of water they want or have been prescribed they need to have.

7.4 Limitations of the analysis

A significant effort has been made to ensure that the economic and environmental yields attributed to land use typologies in the subject catchments are as representative of current land use systems as possible and reflect appropriate relativities in these key outputs. The timing of the work relative to key seasonal activities on farm precluded the use of proposed farmer reference groups (see Figure 4) to review key input data prior to modelling, but subsequent review of the baseline and mitigation cost curve output with the five case study farmers in the Tukituki, three farmers in Te Hoiere and two in South Coastal Canterbury indicated most of the assumptions and subsequent outputs were within the bounds of participant farmer expectations. Despite this, all the modelled outcomes are still limited by the granularity and accuracy of the data sets utilised, the assumptions made when determining the efficacy of mitigations and the necessary simplification of the biophysical and hydrological processes attempting to be represented.

Assumptions around forestry land uses tend to be the most contentious. This is due to the long-time frames involved, uncertainty around our infant carbon market and its exposure to regulatory disruption and the methods necessarily used to derive annual profit metrics for forestry that can be appropriately compared to pastoral farming systems. Altering these assumptions will influence the relative profitability of forestry to pastoral farming which in situations where only small reductions in nitrogen loss are required might influence the "optimal" mix of mitigation and land use change required to meet targets. Where, however, significant nitrogen reductions are required, differing assumptions on the profitability of forestry are only likely to impact the cost of the required change, rather than the extent of the change itself.

The suitability of individual polygons to support specific land uses is limited by the GIS layers available to assign attributes to polygons and the scale of polygons that can be analysed. It is also critical to ensure that the level of detail and complexity introduced to the delineation of the current and future make-up of the catchment doesn't exceed the inherent granularity of the model. Criticism of the proposed location of specific land uses in the catchment may be justified in some cases and property level validation is likely to identify inaccuracies in assessed suitability. It is important to also recognise that recent historical land use isn't necessarily a definitive indicator of current or future suitability. Both pipfruit and grapes have recently been established in the Tukituki catchment in locations that have not been used for these crops before and that many local farmers would have considered unsuitable. Climate change may further alter where and what land uses are suitable in a particular catchment. While future land use suitability layers (under a mid-range changing climate scenario) were used in the Tukituki to identify where pipfruit and viticulture might be established, using additional potential future climatic and water availability scenarios as constraints into the models and scenarios would likely be a useful improvement.

While geophysical parameters were used to constrain the potential adoption of new land uses, market-linked parameters were not. As such, predictions around the scale of new or expanded land uses are not constrained by the availability or size of potential markets, availability of supply chain infrastructure or access to labour pools. All are real considerations in the establishment or expansion of enterprises and are likely limiting to instantaneous adoption. In the context of a generational-scale transition, such issues are less problematic, but will still need to be taken into account at some stage.

No regional or national economic analysis was conducted. This would involve taking the catchment level farm impacts and extrapolating these through an appropriate method to ascertain information such as changes in employment and regional economic performance (e.g. through gross domestic product). While these models can be criticised as adding additional uncertainty, they help consider the implication of such land use changes on other factors that are important to the community such as employment. Understanding these factors would help the community understand the trade-offs between the desired water quality outcomes and the cost to the community (not just the landowners) of achieving these.

Greater numbers of respondents in the farmer surveys in the Te Hoiere and South Coastal Canterbury catchments would increase the confidence in the estimates of farmer preference for mitigation adoption and the extent of current adoption. Ensuring participants were fully representative of the land uses in the catchments would also have strengthened the outputs from the survey. This was, however, a novel approach to the development of mitigation cost curves for catchment modelling in New

Zealand and further work would be valuable to determine this method's merits in helping understand the likely cost of and outcomes for water from farmer decision making on mitigations.

The full modelling of all three catchments to a point where NPS-FM water quality targets were achieved would also have allowed more robust interrogation of the potential for and feasibility of changes to land use and practices to deliver currently mandated water quality. While this was unable to be completed within the timeframes of the Challenge, the inputs now exist for such modelling to be undertaken outside of this project.

The outputs presented in the research cannot be considered an unequivocal blueprint or definitive solution for the achievement of NPS-FM water quality targets, either at catchment or individual property level. They do, however, provide a robust indication of the direction of travel and magnitude of change required to improve water quality in the respective catchments relative to today.

7.5 Potential further work

The inputs to model the South Coastal Canterbury catchment have been fully developed during this research. Undertaking the planned modelling for this catchment, along with additional scenario runs for Te Hoiere to the point the desired water quality targets are achieved, would be a valuable extension of the work completed here.

The expanded use of climate change layers to the modelled scenarios to explore the medium-term viability of existing land uses within the landscape would also inform the discussion about potential land use change.

Our understanding of the dynamics of farmer decision making between mitigations and land use change might be improved by additional research on how farmer preference might change when the potential costs of action is available or investigating the scale (amount and speed) at which a mitigation or land use preference might change (i.e., establishing 4 ha of native forest is doable, but 100 ha is not).

Finally, given the significant scale of the land use change that might be required in the Tukituki catchment, there would be value in soliciting feedback from both the wider rural and urban community on the model outputs to ascertain how feasible the trade-off between desired environmental outcomes and economic/catchment implications is perceived to be. This would ultimately require scaling the catchment results to the broader socio-economic impacts.

8 Conclusion

While the necessary levers to improve water quality in the rivers, lakes and estuaries of New Zealand are widely understood, the potential magnitude of the change in on-farm practices and land use change decisions required to meet water quality outcomes are probably less well socialised.

The interview responses from farmers in three catchments with water quality that is below nationally mandated bottom lines indicated they had a willingness to continue to adopt and implement a wide range of mitigations. Based on the evaluation of mitigation efficacy on land uses within the specific catchments, these included mitigations that invariably reduced productivity or took land away from productive use, including land retirement. In general terms, farmer preference aligned with the order of adoption that conventional assessment of mitigation cost would determine, but the sequential adoption of mitigations is ultimately expected reduce farm profitability. Where required contaminant load reductions are high, moving away from mitigation activity to land use change will ultimately be needed to deliver desired water quality outcomes for a reduced economic cost.

Critically, where higher value land uses with low levels of water contaminant loss are suitable, like in the Tukituki, such land use change does have the potential to deliver improved economic outcomes, for both individuals and catchments. This a way, it seems water quality targets *can* be met through mitigating and changing land use.

The capacity to transition to the changed land uses is much less clear.

At an individual property level, pre-existing levels of debt and the speed at which such change needs to be implemented are particularly important factors in the financial capacity to move away from pastoral land use activities, even when the ultimate land uses will be more profitable. Where increased profitability is expected from land use change, this is invariably supportive of the ability to attract any capital required. However, it seems unlikely that all farmers will have the financial capacity to effect the necessary change themselves (even if they desired to), and changes in ownership might be an inevitable outcome. Optionality for higher value land uses is also important, with access to irrigation water potentially important in water-limited catchments like the Tukituki. This could be additionally important where there might be a social imperative to preserve pre-existing land uses that ultimately requires the cost of more aggressive mitigations to be offset by investment in higher value land uses. While the wider capacity of the community to enable land use change at scale was not evaluated in this research, it is also an important consideration from the perspectives of not only capital infrastructure and supply chain capability, but critically social license.

The necessary compromises in complexity and detail that are required to model catchment scale outcomes, like those in this research, appropriately place limitations on the scope of their interpretation and the granularity to which outputs might be extrapolated. However, they do provide a robust indication of the direction of travel and magnitude of change required to improve water quality.

While not providing a definitive solution to addressing this wicked challenge, the Catchment Synthesis Scenarios project does indicate that potential pathways to profitable water quality outcomes might exist. However, when interrogated through even a single perspective (like financial capacity), the feasibility of the change required is potentially uncertain and, even if change is desired, it might not always be possible to achieve. This should not be interpreted as grounds to dismiss action or targets as meaningless or misguided, but rather as an opportunity to continue to explore the pathways towards the better future our communities both desire and require.

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10 Appendices

10.1 Typology definitions

Appendix 1. Tukituki dairy typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
DI1	**Dairy - irrigated**	3,011	AgriBase data	Farm type - Dairy	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is flat (2.4 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = Irrigated	
DH1	**Dairy - wet dryland**	3,535	AgriBase data	Farm type - Dairy	
			Land cover data from MfE (Name_2018)	High producing exotic grass land, low production exotic grassland, short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average rolling (8.3 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200 mm (high)	
DL1	**Dairy - low/verylow dryland**	4,032	AgriBase data	Farm type - Dairy	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is flat (5.5 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	900-1200 mm (low) and <900 mm (very low)	

Appendix 2. Tukituki sheep and beef typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
SBI1	Sheep/beef - finishing (irrigated)	6,026	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling. Weighted average slope is flat (2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = yes	
SBH1	Sheep/beef - finishing (high rainfall)	9,942	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (4.2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	
SBL1	Sheep/beef - finishing (low rainfall)	22,292	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (3.2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	900-1200 mm (low)	
SBVL1	Sheep/beef - finishing (very low rainfall)	25,092	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (5.2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	<900 mm (very low)	
SBVL2	Sheep/beef - breeding (very low rainfall)	33,166	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (22°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	<900 mm (very low)	
SBH2	Sheep/beef - breeding (high rainfall)	26,116	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (25°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	
SBL2	Sheep/beef - breeding (low rainfall)	42,285	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (23°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	900-1200 mm (low)	

Appendix 3. Tukituki deer typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
DEH1	Deer - finishing/breeding (high rainfall)	1,478	AgriBase data	Farm type - Deer	Overseer slope - flat, rolling, easy hills, steep. Weighted average slope is stringly rolling (19.1°)
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	
			AND		
			AgriBase data	Farm type - Deer	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	
DEL1	Deer finishing/breeding (low/very low rainfall)	1,492	AgriBase data	Farm type - Deer	Overseer slope - flat, rolling. Weighted average slope is undulating (6.7°)
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	900-1200 mm (low) and <900 mm (very low)	
			AND		
			AgriBase data	Farm type - Deer	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	

Appendix 4. Tukituki arable, fruit, vegetable, and viticulture typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
AI1	Arable (irrigated)	578	AgriBase data	Farm type - Arable	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (1.8°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
AL1	Arable dryland	900	AgriBase data	Farm type - Arable	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (2.2°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall (<1400 mm; low and a small portion of high)	
VEI1	Vegetable (irrigated)	203	AgriBase data	Farm type - Vegetable, Fruit	
			Land cover data from MfE (Name_2018)	Short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (1.5°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
FRI1	Fruit (irrigated)	805	AgriBase data	Farm type - Vegetable, Fruit	
			Land cover data from MfE (Name_2018)	Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (1.5°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
VTI1	Viticulture (irrigated)	102	AgriBase data	Farm type - Viticulture	
			Land cover data from MfE (Name_2018)	Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (1.5°)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	

Appendix 5. Tukituki forestry typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
EF2	Exotic forestry (steep)	9,087	AgriBase data	Farm type - All types	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (24°)
			Land cover data from MfE (Name_2018)	Exotic forestry and forest harvested	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
IF1	Indigenous forestry (gentle)	1,325	AgriBase data	Farm type - All types	Overseer slope - flat, rolling. Weighted average slope is undulating (5°)
			Land cover data from MfE (Name_2018)	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
IF2	Indigenous forestry (steep)	25,540	AgriBase data	Farm type - All types	Overseer slope - flat, rolling. Weighted average slope is steep (34°)
			Land cover data from MfE (Name_2018)	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	

Appendix 6. Tukituki lifestyle typology definitions

Tukituki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
LH1	Lifestyle (high rainfall)	104	AgriBase data	Farm type - Lifestyle	Overseer slope - flat, rolling, easy and steep. Weighted average slope is strongly
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland and Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	
			Average annual rainfall (1972-2016) MfE (DN)	>1200mm (high)	
LL1	Lifestyle (low rainfall)	683	AgriBase data	Farm type - Lifestyle	Overseer slope - flat, rolling, easy and steep. Weighted average slope is
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland and Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	
			Average annual rainfall (1972-2016) MfE (DN)	900-1200 mm (low)	
LVL1	Lifestyle (very low rainfall)	1,516	AgriBase data	Farm type - Lifestyle	Overseer slope - flat, rolling, easy and steep. Weighted average slope is rolling
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland and Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	
			Average annual rainfall (1972-2016) MfE (DN)	<900 mm (very low)	

Appendix 7: Te Hoiere dairy typology definitions

Te Hoiere - Typologies		Area (ha)	Data Source	Selection criteria	Comments
DI1	Dairy - irrigated	632	AgriBase data	Farm type - Dairy, Beef, Unspecified land and blank AB data	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy hill and steep. Weighted average slope is
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = Irrigated	
DH1	Dairy - wet dryland	4,256	AgriBase data	Farm type - Dairy	
			Land cover data from MfE (Name_2018)	High producing exotic grass land, low production exotic grassland, short-rotation cropland	
			NZLRI data (slope)	Slope = A/B/C	Overseer slope - flat, rolling. Weighted average undulating (5.2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	1200-1700 mm (high)	
DH2	Dairy - wet dryland (steep)	1,595	AgriBase data	Farm type - Dairy	
			Land cover data from MfE (Name_2018)	High producing exotic grass land, low production exotic grassland, short-rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average steep (28.4 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE (DN)	1200-1700 mm (high)	

Appendix 8: Te Hoiere sheep & beef and exotic forestry typology definitions

Te Hoiere - Typologies		Area (ha)	Data Source	Selection criteria	Comments
SBH1	**Sheep/beef - finishing (high rainfall)**	3,361	AgriBase data	Farm type - Grazing, Beef, Drystock, Deer, Sheep, Sheep and Beef, unspecified land and blank	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (4.9 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = No	
			Average annual rainfall (1972-2016) MfE (DN)	1200-1700 mm (high)	
SBH2	**Sheep/beef - breeding (high rainfall)**	2,916	AgriBase data	Farm type - Grazing, Beef, Drystock, Deer, Sheep, Sheep and Beef, unspecified land and blank	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is steep (29.5 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited (type)	Irrigated = No	
			Average annual rainfall (1972-2016) MfE (DN)	1200-1700 mm (high)	
EF1	**Exotic forestry (gentle)**	1,243	AgriBase data	Farm type - All types	
			Land cover data from MfE (Name_2018)	Exotic forestry and forest harvested	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is undulating (7.2°)
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
EF2	**Exotic forestry (steep)**	14,255	AgriBase data	Farm type - All types	
			Land cover data from MfE (Name_2018)	Exotic forestry and forest harvested	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (29.3°)
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	

Appendix 9: Te Hoiere indigenous forestry, lifestyle and scrub typology definitions

Te Hoiere - Typologies		Area (ha)	Data Source	Selection criteria	Comments
IF1	Indigenous forestry (gentle)	1,512	AgriBase data	Farm type - All types	
			Land cover data from MfE (Name_2018)	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data (slope)	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is undulating (6.8°)
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
IF2	Indigenous forestry (steep)	76,537	AgriBase data	Farm type - All types	
			Land cover data from MfE (Name_2018)	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data (slope)	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - flat, rolling. Weighted average slope is steep (31.1°)
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
GB2	Gorse/Broom	935	AgriBase data	Farm type - All types	
			Land cover data from MfE (Name_2018)	Gorse and/or broom	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is steep
			Average annual rainfall (1972-2016) MfE (DN)	All rainfall	
LH1	Lifestyle (high rainfall)	369	AgriBase data	Farm type - Lifestyle	
			Land cover data from MfE (Name_2018)	High producing exotic grass land and low production exotic grassland and Orchard, vineyard or other perennial crop	
			NZLRI data (slope)	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is rolling
			Average annual rainfall (1972-2016) MfE (DN)	1200 - 1700mm (high)	

Appendix 10: South Coastal Canterbury dairy typology definitions

Lower Waitaki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
DI1	**Dairy - irrigated - flat/rolling**	19411	AgriBase data	Farm type - Dairy	Overseer slope - flat, rolling. Weighted average slope is undulating (3.9 degrees)
			Land cover data from MfE	High producing exotic grass land short-rotation cropland	
			NZLRI data	Slope = A/B/C - 0-15 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = Irrigated	
			AND		
			AgriBase data	Farm type - Dairy	
			Land cover data from MfE	High producing exotic grass land short-rotation cropland	
			NZLRI data	Slope = A/B - 0-7 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	Have included non-irrigated flat land as largely mis-mapped land
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
DI2	**Dairy - irrigated - easy/steep**	379	AgriBase data	Farm type - Dairy	
			Land cover data from MfE	High producing exotic grass land short-rotation cropland	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy and steep. Weighted average slope is moderately steep (21.5 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = Irrigated	
DVL2	**Dairy - dryland (extensive) - very low rainfall - rolling/easy/steep**	3,802	AgriBase data	Farm type - Dairy	Overseer slope - easy and steep. Weighted average slope is strongly rolling (17.9 degrees)
			Land cover data from MfE	High producing exotic grass land short-rotation cropland	
			NZLRI data	Slope = C/D/E/F/G/H - 8-37 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
			AND		
			AgriBase data	Farm type - Dairy	
			Land cover data from MfE	Low producing exotic grass land and Tall Tussock grassland	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	

Appendix 11: South Coastal Canterbury sheep & beef typology definitions

Lower Waitaki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
SBI1	Sheep/beef - finishing (irrigated)	6,184	AgriBase data	Farm type - Grazing, Beef, Drystock, Deer, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is undulating (6.2 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = yes	
SBVL1	Sheep/beef - finishing (very low rainfall)	26,071	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is rolling (7.5 degrees)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
SBVL2	Sheep/beef - breeding (very low rainfall)	15,012	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef and unspecified land	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (23.3°)
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
			AND		
			AgriBase data	Farm type - Arable	
			Land cover data from MfE	Low production exotic grassland	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
SBVL3	Sheep/beef - breeding (high country)	6,746	AgriBase data	Farm type - Grazing, Beef, Drystock, Sheep, Sheep and Beef	
			Land cover data from MfE	Alpine grass/herbfield, Depleted grassland, Tall Tussock Grassland	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy hill, steep. Weighted average slope is steep (26.5°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	900-1200 mm (low) and <900 mm (very low)	

Appendix 12: South Coastal Canterbury deer, arable and pipfruit typology definitions

Lower Waitaki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
DEVL1	Deer - finishing (very low rainfall)	902	AgriBase data	Farm type - Deer	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is undulating (6°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
DEVL2	Deer - breeding (very low rainfall)	345	AgriBase data	Farm type - Deer	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (21.4°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
AI1	Arable (irrigated)	2,238	AgriBase data	Farm type - Arable	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (2.3°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = irrigated	
			Average annual rainfall (1972-2016) MfE	All rainfall	
AVL1	Arable dryland	7,760	AgriBase data	Farm type - Arable	
			Land cover data from MfE	High producing exotic grass land and short rotation cropland	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy hill, steep. Weighted average slope is undulating (4.0°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = non-irrigated	
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
FRI1	Fruit (irrigated)	20	AgriBase data	Farm type - Fruit	
			Land cover data from MfE	Orchard, vineyard or other perennial crop	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is flat (1.5°)
			Irrigated land area - 2020 - Aqualinc Research Limited	Irrigated = irrigated, non-irrigated	
			Average annual rainfall (1972-2016) MfE	All rainfall	

Appendix 13: South Coastal Canterbury forestry typology definitions

Lower Waitaki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
EF1	Exotic forestry (gentle)	4,401	AgriBase data	Farm type - All types	
			Land cover data from MfE	Exotic forestry and forest harvested	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is rolling (8.2°)
			Average annual rainfall (1972-2016) MfE	All rainfall	
EF2	Exotic forestry (steep)	6,323	AgriBase data	Farm type - All types	
			Land cover data from MfE	Exotic forestry and forest harvested	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (25.2°)
			Average annual rainfall (1972-2016) MfE	All rainfall	
IF1	Indigenous forestry (gentle)	405	AgriBase data	Farm type - All types	
			Land cover data from MfE	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is undulating (7.4°)
			Average annual rainfall (1972-2016) MfE	All rainfall	
IF2	Indigenous forestry (steep)	3,872	AgriBase data	Farm type - All types	
			Land cover data from MfE	Broadleaved Indigenous Hardwoods & Fernland & Indigenous Forest & Manuka and/or Kanuka	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is moderately steep (25°)
			Average annual rainfall (1972-2016) MfE	All rainfall	

Appendix 14: South Coastal Canterbury lifestyle and scrub typology definitions

Lower Waitaki - Typologies		Area (ha)	Data Source	Selection criteria	Comments
LVL1	Lifestyle (very low rainfall)	1,250	AgriBase data	Farm type - Lifestyle, Alpaca, Pig, Poultry	
			Land cover data from MfE	High producing exotic grass land and low production exotic grassland and short rotation cropland and Orchard, vineyard or other perennial crop	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy and steep. Weighted average slope is undulating (3.5°)
			Average annual rainfall (1972-2016) MfE	<900 mm (very low)	
GB1	Gorse/Broom (gentle)	916	AgriBase data	Farm type - All types	
			Land cover data from MfE	Gorse and/or broom	
			NZLRI data	Slope = A/B/C - 0-15 degrees	Overseer slope - flat, rolling. Weighted average slope is undulating (5.8°)
			Average annual rainfall (1972-2016) MfE	All rainfall	
GB2	Gorse/Broom (steep)	1,900	AgriBase data	Farm type - All types	
			Land cover data from MfE	Gorse and/or broom	
			NZLRI data	Slope = D/E/F/G/H - 15-37 degrees	Overseer slope - easy hill, steep. Weighted average slope is moderately steep (25.5°)
			Average annual rainfall (1972-2016) MfE	All rainfall	
MS2	Matagouri/ grey scrub	2,645	AgriBase data	Farm type - All types	
			Land cover data from MfE	Matagouri and grey scrub	
			NZLRI data	Slope = A/B/C/D/E/F/G/H	Overseer slope - flat, rolling, easy hill, steep. Weighted average slope is moderately steep (24.2°)
			Average annual rainfall (1972-2016) MfE	All rainfall	

10.2 Phone survey

Catchment Synthesis – Farmer phone interview questions

Note: red text is not be read out but to help you categorise/interpret answers

Hello, my name is ______ ________ from Perrin Ag Consultants. I am ringing to interview you as part of a project that we are working on and you have indicated your interest in being involved.

I'll just give you a quick background then we will begin with the interview. The project is seeking to understand farmer perspectives on water quality mitigations and how you might look to apply mitigations to meet water quality targets. The research is funded by Our Land and Water and we will be interview 30 to 50 farmers across three catchments. This research is important to be done alongside some modelling to ensure that any outcomes from the models take into account how farmers would practically apply these mitigations on the ground. The interview will be recorded for the purpose of data collection.

Before we begin, we want you to know that participation is voluntary and all data collected is anonymous and will be analysed at an aggregated level. You will receive a koha of $150 for participation in the phone interview. If you choose to complete the written survey, we will compensate you with an additional $100 koha at the conclusion of the survey.

Background

- What number of farming properties do you own in **this** catchment?

Unique identifier	
# properties	

- Which sub-catchment(s) is your property located in? Note: if they don't know, don't worry.

Unique identifier	
Sub-catchment	

- To the nearest hectare, what is the total area of your farm(s)? individual farm
- To the nearest hectare, what is the total effective area of your farm(s)?

Unique identifier	
Area	
Effective area	
Ineffective area	

- Can you please describe the current land uses on your property?

NOTE: do not read this list out to interviewees – just record "yes" as appropriate to the land uses farmers mention

(enter 'Y' under appropriate land uses)

Typology	*e.g C4*
Dairy – dryland	
Dairy – irrigated	
Dairy support	
Drystock – breeding	
Drystock – breeding and finishing	
Drystock – finishing (incl. velveting)	
Mixed arable	
Arable	
Horticulture – field	
Horticulture – orchard	
Viticulture	
Exotic forest	
Indigenous forest	
Other (describe)	

- Are you in a catchment where land use activity is regulated?

(0=no; 1=yes; 2=unsure)

Unique identifier	
Regulated?	

- If you answered "yes" to Q6, do you know what your activity status is? (i.e., permitted activity, controlled, discretionary etc.).

If participant is unsure, don't worry about this question.

(0=unsure, 1=permitted, 2=controlled, 3=restricted discretionary, 4=discretionary, non-complying)

Unique identifier	
Activity status?	

- How is your business structured (i.e., trust, partnership, company, sole proprietorship)

(0 =unsure, 1= Sole proprietorship; 2=partnership; 3=Trust; 4=company 5=other (& record))

Unique identifier	
Business structure	

- How many people work on the property and undertake the day-to-day/weekly operations and management? (estimate of FTE i.e., "me and a part-time casual" = 1.5 FTE)

May be paid/unpaid/both – best representation of the people working on farm.

Unique identifier	
FTE	

Actions to address water quality

- What actions or things have been done on your farm that you think have improved water quality? [PROMPTS: can be actions, training, infrastructure, or technology investment; might be low tech options etc] Note: even things undertaken by the previous owners…

(enter 'Y' under appropriate actions, if other describe)

Master mitigation list – NOTE: do not read this list out to interviewees – just record "yes" as appropriate to the actions farmers mention

Practice Change

1	Reduce soil P test to optimum	
2	Coated N fertiliser	
3	Use of RPR where appropriate	
4	Irrigating based on soil moisture	

5	Increased effluent area	
6	Deferred and low rate application	
7	Reduced N to effluent area	
8	Minimum tillage	
9	Zero tillage	
10	Variable rate fertiliser	
11	Cover crops	
12	Catch crops for forage cropping	
13	Diverse pastures (i.e., plantain)	
14	Applying alum to pasture and crops	
15	Forestry setbacks	

System change

18	Reduced stocking rates	
19	Increased sheep:cattle ratio	
20	Reduced forage cropping	
21	Reduce N fertiliser use (below 190 kg N/ha)	
22	Other (please list)	

Infrastructure actions

23	Lined effluent ponds	
24	Variable rate irrigation	
25	Off-paddock structures	

26	Other (please list)	

Edge of field

27	Retention dams, bunds or sediment traps	
28	Facilitated wetlands (restoring/enhancing existing wetlands)	
29	Constructed wetlands	
30	Stream fencing	
31	Riparian planting	
32	Vegetated buffer strips (for arable cropping)	
33	Space planted trees (like poplar poles)	
34	Other (please list)	

Partial land use changes

35	Land retirement	
36	Plantation forestry	
37	Alternative agricultural land use (with a lower environmental footprint)	
38	Other (please list)	

- What were the main reasons for undertaking those actions? (Responses to be categorized as below, record all that are relevant)

(0=none; 1 = environmental benefit, 2=regulatory compliance 3=access to grants/funding;, 4=pre-existing on farm; 6=ability to diversify income; 7=social good, 8= personal preference; 9=other. Add others in later if necessary)

Unique identifier	
Reasons	

- Are there any other actions you are planning to do in the future?

(0=no; 1=yes; 2=unsure)

Unique identifier	
Actions?	

- If "yes", what are these?

Future actions: (record as per 1-38 from mitigation list)

- Thinking of those actions that you plan to do (i.e., answered "yes" to), in what timeframe do you plan to undertake these? *(e.g 1-2 years, 3-5 years, 6-10 yrs, beyond 10 years)* (record as per table above)

(1=1-2 years; 2=3-5 years, 3=6-10 years; 4=>10 years)

Timeframe: (1=1-2 years; 2=3-5 years, 3=6-10 years; 4=>10 years)

- Thinking about the actions that you have indicated you are planning to do that are at least 10 years away, what are the reasons for this? (Responses to be categorized as below)

Timeframe reasons: (0=none; 1=current lack of capital 2= current lack of access to grants/funding; 3= current lack of access to good advice/support, 4=negative financial impact; 5 = not enough time 6=insufficient environmental benefit; 7=community/social disruption, 8=personal preference; 9=other (record). Add others in later if necessary)

Unique identifier	
Future actions	
Timeframe	
Why timeframe	

- Are there any actions that you have considered that would improve water quality but have not been able to do and are not planning on doing?

(0=no; 1=yes; 2=unsure)

- If yes, what were these? (record in table below)

- Thinking of any actions you have decided not to do, what was the main reason for this decision? (Responses to be categorized as below, record all that are relevant)

(0=none; 1=lack of capital 2= lack of access to grants/funding; 3= lack of access to good advice/support, 4=negative financial impact; 5 = not enough time 6=insufficient environmental benefit; 7=community/social disruption, 8=personal preference; 9=other. Add others in later if necessary)

Unique identifier	
Any actions?	
What are they?	
Why not?	

Farmer preferences for land use change

- I am going to list a range of land uses, and would like you to tell me on a scale of 1-7 your potential willingness or interest to adopt or expand this land use within your existing farming operation at some stage in the future, 1 being extremely unwilling and 7 being extremely willing.

  (enter 1-7 answer next to appropriate land use)

  I'm now going to repeat back to you the land uses that you scored 3 or less.

- (For land uses that have been scored 3 or less) What are the main reasons for these rankings?

  (0=none; 1=lack of capital 2= lack of access to grants/funding; 3= lack of access to good advice/support, 4=negative financial impact; 5 = uncertainty of regulatory environment 6=lack of environmental benefit; 7=community/social disruption, 8=personal preference; 9= lack of suitability, 10=other. Add others in later if necessary)

  Note: do not read out the existing land use of the farmer for land use change.

Land use	**Score (1-7)**	**Reason (if ≤3)**	**Commentary**
Dairy – dryland			
Dairy – irrigated			
Drystock – breeding			
Drystock – breeding and finishing			
Drystock – finishing (incl. velveting)			
Mixed arable			
Arable			
Horticulture – field			
Horticulture – orchard			
Viticulture			

Exotic forest			
Indigenous forest			
Other – non-producing land use *Don't read this but if they mention something else*			

Adoption drivers/barriers of future actions within the catchment

- What are the barriers and/or challenges you see with land use change for farmers like yourself in your catchment? [PROMPTS: dig to explore this question more - for example, cost, identification of land use change that will work, risk assessment/management, personal choice of farming style; control, change in employment in community, access to good information, science backed…])

  Ensure that the farmer knows that we are referring to land use change (the alteration of how the land is used) rather than practice change (more the methods/processes of the operation)

- What do you think will be the biggest drivers of land use change in the catchment over the next twenty years?

Unique identifier	
Barriers/challenges	
Drivers	

-END-

- Online survey in next week or so

- Koha following this

- Thank you for participating

10.3 Online survey

(As extracted from SurveyMonkey ®)

Q1. What is your unique identifier? (please see in initial project email from Perrin Ag)

Q2. What is your address? (for posting the prezzy cards)

Q3. Which catchment area are you in?

Tukituki (Hawkes Bay)

South Coastal (South Canterbury)

Te Hoiere (Marlborough)

Q4. What are the current land uses on your property/s?

Dairy -dryland

Dairy - irrigated

Dairy support

Drystock - breeding

Drystock - breeding and finishing

Drystock - finishing (incl. velveting)

Mixed arable

Arable

Horticulture - field

Horticulture - orchard

Viticulture

Exotic forest

Indigenous forest

Other (please specify)

Q5. How willing are you to implement any of these practice changes on your property? [Not applicable, not familiar with this, already implemented, willing to implement, already planning to implement, obstacles to implementation]

Reduce soil P tests to optimums

Coated N fertiliser (i.e., SustaiN, N-Protect)

Use of RPR or low solubility P fertiliser where appropriate

Irrigating based on soil moisture

Increased effluent area

Deferred and low rate effluent application

Reduced N fertiliser to effluent area

Minimum tillage

Zero tillage (i.e., direct drilling)

Variable rate fertiliser application

Cover crops

Catch crops for forage cropping

Diverse pastures (i.e., plantain, multi-species mixes)

Applying alum (aluminium sulphate) to pasture and crops

Forestry setbacks from riparian areas

On-off grazing in autumn/winter

Sheep only in paddocks with unfenced streams

No synthetic N

Precision fertiliser application

Buffer strips for fertiliser application (ground spread/aerial)

Grazing management in winter (e.g. top down grazing)

Managing CSA's (e.g. runoff from stockyards, woolshed)

Other (please specify)

Q6. Where you have indicated there are obstacles to implementing any of these practice changes, what are the reasons for these?

Q7. How willing are you to implement any of these system changes on your property? [Not applicable, not familiar with this, already implemented, willing to implement, already planning to implement, obstacles to implementation]

Reduced stocking rates

Increased sheep:cattle ratio

Reduced forage cropping

Matching stock class to land use capability

Reduce N fert to pasture (below 190 kg N/ha)

Other (please specify)

Q8. Where you have indicated there are obstacles to implementing any of these system changes, what are the reasons for these?

Q9. How willing are you to implement any of these infrastructure actions on your property? [Not applicable, not familiar with this, already implemented, willing to implement, already planning to implement, obstacles to implementation]

Lined effluent pond

Variable rate irrigation

Reticulated water for stock in hill country

Install culverts and bridges for crossings

Off-paddock structures (stand-off pads, wintering barns)

Fence pacing prevention

Other (please specify)

Q10. Where you have indicated there are obstacles to implementing any of these infrastructure actions, what are the reasons for these?

Q11. How willing are you to implement any of these edge of field actions on your property? [Not applicable, not familiar with this, already implemented, willing to implement, already planning to implement, obstacles to implementation]

Retention dams, bunds or sediment traps

Enhancing/restoring existing wetlands

Constructed wetlands

Stream fencing

Riparian planting

Vegetated buffer strips (for arable cropping)

Space planted trees (like poplar poles)

Alternative wallows

Other (please specify)

Q12. Where you have indicated there are obstacles to implementing any of these edge of field actions, what are the reasons for these?

Q13. How willing are you to implement any of these partial land use changes on your property? [Not applicable, not familiar with this, already implemented, willing to implement, already planning to implement, obstacles to implementation]

Land retirement

Plantation forestry

Alternative agricultural land use (with a lower environmental footprint)

If alternative agricultural land use, please specify:

Q14. Where you have indicated there are obstacles to implementing any of these partial land use changes, what are the reasons for these?

Q15. What are the main reasons you have implemented these actions?

Environmental benefit

Regulatory compliance

Access to grants/funding

Pre-existing on farm

Ability to diversify income

Social good

Personal preference

Other (please specify)

Q16. If you did want to change some of your land use in future, what top 3 things would you need?

Q17. Is there anything else that you would like to share?

Q18. To what extent (area, size, application, or other details) have you implemented any of these actions?

Reduce soil P tests to optimums

Coated N fertiliser (i.e., SustaiN, N-Protect)

Use of RPR or low solubility P fertiliser where appropriate

Irrigating based on soil moisture

Increased effluent area

Deferred and low rate effluent application

Reduced N fertiliser to effluent area

Minimum tillage

Zero tillage (i.e., direct drilling)

Variable rate fertiliser application

Cover crops

Catch crops for forage cropping

Diverse pastures (i.e., plantain, multi-species mixes)

Applying alum (aluminium sulphate) to pasture and crops

Forestry setbacks from riparian areas

On-off grazing in autumn/winter

Sheep only in paddocks with unfenced streams

No synthetic N

Precision fertiliser application

Buffer strips for fertiliser application (ground spread/aerial)

Grazing management in winter (e.g. top down grazing)

Managing CSA's (e.g. runoff from stockyards, woolshed)

Q19. To what extent (area, size, application, or other details) have you implemented any of these actions?

Reduced stocking rates

Increased sheep:cattle ratio

Reduced forage cropping

Matching stock class to land use capability

Reduce N fert to pasture (below 190 kg N/ha)

Q20. To what extent (area, size, application, or other details) have you implemented any of these actions?

Lined effluent pond

Variable rate irrigation

Reticulated water for stock in hill country

Install culverts and bridges for crossings

Off-paddock structures (stand-off pads, wintering barns)

Fence pacing prevention

Q21. To what extent (area, size, application, or other details) have you implemented any of these actions?

Retention dams, bunds or sediment traps

Enhancing/restoring existing wetlands

Constructed wetlands

Stream fencing

Riparian planting

Vegetated buffer strips (for arable cropping)

Space planted trees (like poplar poles)

Alternative wallows

Q22. To what extent (area, size, application, or other details) have you implemented any of these actions?

Land retirement

Plantation forestry

Alternative agricultural land use (with a lower environmental footprint)

Q23. Where you have indicated you are planning to implement, what is the estimated timeframe (e.g. 1-2, 3-5, 6-10 or >10 years)?

Reduce soil P tests to optimums

Coated N fertiliser (i.e., SustaiN, N-Protect)

Use of RPR or low solubility P fertiliser where appropriate

Irrigating based on soil moisture

Increased effluent area

Deferred and low rate effluent application

Reduced N fertiliser to effluent area

Minimum tillage

Zero tillage (i.e., direct drilling)

Variable rate fertiliser application

Cover crops

Catch crops for forage cropping

Diverse pastures (i.e., plantain, multi-species mixes)

Applying alum (aluminium sulphate) to pasture and crops

Forestry setbacks from riparian areas

On-off grazing in autumn/winter

Sheep only in paddocks with unfenced streams

No synthetic N

Precision fertiliser application

Buffer strips for fertiliser application (ground spread/aerial)

Grazing management in winter (e.g. top down grazing)

Managing CSA's (e.g. runoff from stockyards, woolshed)

Q24. Where you have indicated you are planning to implement, what is the estimated timeframe (e.g. 1-2, 3-5, 6-10 or >10 years)?

Reduced stocking rates

Increased sheep:cattle ratio

Reduced forage cropping

Matching stock class to land use capability

Reduce N fert to pasture (below 190 kg N/ha)

Q25. Where you have indicated you are planning to implement, what is the estimated timeframe (e.g. 1-2, 3-5, 6-10 or >10 years)?

Lined effluent pond

Variable rate irrigation

Reticulated water for stock in hill country

Install culverts and bridges for crossings

Off-paddock structures (stand-off pads, wintering barns)

Fence pacing prevention

Q26. Where you have indicated you are planning to implement, what is the estimated timeframe (e.g. 1-2, 3-5, 6-10 or >10 years)?

Retention dams, bunds or sediment traps

Enhancing/restoring existing wetlands

Constructed wetlands

Stream fencing

Riparian planting

Vegetated buffer strips (for arable cropping)

Space planted trees (like poplar poles)

Alternative wallows

Q27. Where you have indicated you are planning to implement, what is the estimated timeframe (e.g. 1-2, 3-5, 6-10 or >10 years)?

Land retirement

Plantation forestry

Alternative agricultural land use (with a lower environmental footprint).

10.4 Mitigation cost curves

10.4.1 Tukituki mitigation cost curves

Appendix 15: Tukituki DI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$4,550	60.0	0.8	893.9	4,100,000,000	435
Current										**$4,550**	**44.8**	**0.2**	**552.8**	**2,776,088,843**	**422**
M1	Deferred and low rate application	4.0	-$6	-3%	-66%	0%	0%	0%	100%	$4,550	44.8	0.2	552.8	2,776,088,843	422
	Diverse pastures (i.e., plantain)	4.0	-$9	-3%	0%	0%	0%	0%	50%	$4,546	44.0	0.2	552.8	2,776,088,843	422
	Stream fencing	4.0	-$24	-13%	-15%	-70%	-58%	0%	50%	$4,534	41.0	0.2	255.2	1,642,193,400	422
	Riparian planting (incl. forestry)	4.0	-$92	-5%	-5%	-10%	-9%	-1%	50%	$4,488	39.9	0.2	242.4	1,564,108,801	420
	Variable rate fertiliser	3.5	$54	-5%	-10%	0%	0%	0%	50%	$4,515	38.9	0.2	242.4	1,564,108,801	420
	Lined effluent ponds	3.0	-$23	-4%	-1%	0%	0%	0%	50%	$4,503	38.0	0.2	242.4	1,564,108,801	420
	Reduce N fertiliser use (below 190 kg N/ha)	3.0	-$319	-18%	0%	0%	0%	-5%	50%	$4,344	34.2	0.2	242.4	1,564,108,801	409
	Use of low water soluble P fert	3.0	-$202	0%	-13%	0%	0%	0%	25%	$4,192	34.2	0.2	242.4	1,564,108,801	409
PLUC	Land retirement (permanent native forestry)	3.0	-$3,852												
M2	Reduced N to effluent area	2.0	$41	-3%	0%	0%	0%	0%	25%	$4,223	33.3	0.2	242.4	1,564,108,801	409
	Facilitated wetlands*	2.0	$0	0%	0%	0%	0%	0%	17%	$4,223	33.3	0.2	242.4	1,564,108,801	409
	Variable rate irrigation	2.0	-$55	-1%	0%	0%	0%	0%	0%	$4,168	33.0	0.2	242.4	1,564,108,801	409
	Constructed wetlands*	2.0	-$12	0%	0%	0%	0%	0%	25%	$4,159	32.9	0.2	241.7	1,559,411,777	409
M3	Stand off pads - no roof	1.0	-$343	-30%	0%	0%	0%	-3%	0%	$3,816	23.1	0.2	241.7	1,559,411,777	397
	Retention dams, bunds or sediment traps*	1.0	-$51	0%	-3%	-78%	-49%	0%	0%	$3,765	23.1	0.2	52.2	795,300,006	397
PLUC	Plantation forestry	1.0	-$3,063												
M4	Off-paddock structures - with roof	1.0	-$3,445	-2%	13%	0%	0%	13%	0%	$320	22.5	0.2	52.2	795,300,006	450
	Applying alum to pasture and crops 100%	0.5	-$105	0%	-20%	0%	0%	0%	0%	$215	22.5	0.1	52.2	795,300,006	450
	Applying alum to pasture and crops just to CSA	0.0	-$21	0%	-6%	0%	0%	0%	0%	$194	22.5	0.1	52.2	795,300,006	450

Appendix 16: Tukituki DH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$2,964	42.0	1.0	1890.7	4,100,000,000	307
Current										**$2,964**	**33.1**	**0.3**	**1169.9**	**2,777,385,648**	**304**
M1	Deferred and low rate application	4.00	-$4	-3%	-66%	0%	0%	0%	100%	$2,964	33.1	0.3	1169.9	2,777,385,648	304
	Stream fencing	4.00	-$20	-13%	-15%	-70%	-58%	0%	50%	$2,954	30.8	0.3	539.9	1,642,960,524	304
	Riparian planting (incl. forestry)	4.00	-$83	-5%	-5%	-10%	-9%	-1%	50%	$2,912	30.0	0.2	513.0	1,564,839,449	303
	Reduced stocking rates	4.00	-$210	-12%	0%	0%	0%	-12%	0%	$2,702	26.5	0.2	513.0	1,564,839,449	267
	Variable rate fertiliser	3.67	$54	-5%	-10%	0%	0%	0%	67%	$2,720	26.0	0.2	513.0	1,564,839,449	267
	Constructed wetlands*	3.67	-$5	-0.1%	-0.1%	-0.2%	-0.2%	0.0%	33%	$2,717	26.0	0.2	512.4	1,563,169,396	267
	Diverse pastures (i.e., plantain)	3.33	-$9	-5%	0%	0%	0%	0%	33%	$2,711	25.1	0.2	512.4	1,563,169,396	267
	Reduce N fertiliser use (below 190 kg N/ha)	3.33	-$59	-7%	0%	0%	0%	-1%	67%	$2,692	24.5	0.2	512.4	1,563,169,396	266
	Facilitated wetlands*	3.25	$0	0%	0%	0%	0%	0%	25%	$2,692	24.5	0.2	512.4	1,563,169,396	266
M2	Lined effluent ponds	2.33	-$18	-5%	-1%	0%	0%	0%	33%	$2,680	23.7	0.2	512.4	1,563,169,396	266
	Retention dams, bunds or sediment traps*	2.33	-$40	0%	-2%	-61%	-38%	0%	0%	$2,640	23.7	0.2	200.9	969,165,025	266
PLUC	Plantation forestry	2.33	-$1,789												
M3	Use of low water soluble P fert	2.33	-$93	0%	-13%	0%	0%	0%	33%	$2,578	23.7	0.2	200.9	969,165,025	266
PLUC	Land retirement (permanent native forestry)	2.33	-$2,578												
M4	Stand off pads - no roof	1.25	-$293	-30%	0%	0%	0%	-3%	0%	$2,285	16.6	0.2	200.9	969,165,025	258
	Off-paddock structures - with roof	1.25	-$2,151	-2%	13%	0%	0%	13%	0%	$134	16.2	0.2	200.9	969,165,025	293
	Applying alum to pasture and crops 100%	1.00	-$105	0%	-20%	0%	0%	0%	0%	$29	16.2	0.2	200.9	969,165,025	293
	Applying alum to pasture and crops just to CSA	0.00	-$21	0%	-6%	0%	0%	0%	0%	$8	16.2	0.2	200.9	969,165,025	293

Appendix 17: Tukituki DL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 2,053	29.0	0.6	1,103.8	4,100,000,000	256
Current										**$2,053**	**22.3**	**0.2**	**597.7**	**2,222,501,344**	**253**
M1	Deferred and low rate application	4.0	-$ 4	-3%	-66%	0%	0%	0%	100%	$2,053	22.3	0.2	597.7	2,222,501,344	253
	Stream fencing	4.0	-$ 18	-13%	-15%	-70%	-58%	0%	50%	$2,044	20.8	0.1	275.9	1,314,719,105	253
	Riparian planting (incl. forestry)	4.0	-$ 77	-5%	-5%	-10%	-9%	-1%	50%	$2,005	20.2	0.1	262.1	1,252,205,569	252
	Reduced stocking rates	4.0	-$ 97	-7%	0%	0%	0%	-13%	0%	$1,908	18.8	0.1	262.1	1,252,205,569	218
	Variable rate fertiliser	3.7	$ 54	-5%	-10%	0%	0%	0%	67%	$1,926	18.5	0.1	262.1	1,252,205,569	218
	Constructed wetlands*	3.7	-$ 2	0.0%	0.0%	-0.1%	-0.1%	0.0%	33%	$1,925	18.5	0.1	262.0	1,251,537,548	218
	Reduce N fertiliser use (below 190 kg N/ha)	3.3	-$ 58	-3%	0%	0%	0%	-1%	67%	$1,905	18.3	0.1	262.0	1,251,537,548	218
	Facilitated wetlands	3.3	-$ 205	-24%	-26%	-50%	-80%	-1%	25%	$1,751	14.8	0.1	149.7	312,884,387	217
M2	Reduced N to effluent area	2.7	$ 13	-3%	0%	0%	0%	0%	0%	$1,764	14.3	0.1	149.7	312,884,387	217
	Lined effluent ponds	2.3	-$ 15	-6%	-1%	0%	0%	0%	33%	$1,754	13.7	0.1	149.7	312,884,387	217
PLUC	Plantation forestry	2.3	-$ 878												
M3	Retention dams, bunds or sediment traps*	2.3	-$ 47	0%	-3%	-71%	-45%	0%	0%	$1,708	13.7	0.1	43.1	173,650,835	217
	Use of low water soluble P fert	2.3	-$ 93	0%	-13%	0%	0%	0%	33%	$1,646	13.7	0.1	43.1	173,650,835	217
PLUC	Land retirement (permanent native forestry)	2.3	-$ 1,667												
M4	Stand off pads - no roof	1.3	-$ 250	-30%	0%	0%	0%	-3%	0%	$1,396	9.6	0.1	43.1	173,650,835	210
	Off-paddock structures - with roof	1.3	-$ 1,980	-2%	13%	0%	0%	13%	0%	-$585	9.4	0.1	43.1	173,650,835	238
	Applying alum to pasture and crops 100%	1.0	-$ 105	0%	-20%	0%	0%	0%	0%	-$690	9.4	0.1	43.1	173,650,835	238
	Applying alum to pasture and crops just to CSA	0.0	-$ 21	0%	-6%	0%	0%	0%	0%	-$711	9.4	0.1	43.1	173,650,835	238

Appendix 18: Tukituki SBI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 1,792	32.0	0.9	1,186.7	4,000,000,000	112
Current										**$1,792**	**29.4**	**0.8**	**702.5**	**2,678,207,595**	**111**
M1	Stream fencing	3.81	-$ 44	-13%	-15%	-70%	-58%	0%	44%	$1,767	27.1	0.7	303.8	1,507,332,918	111
	Riparian planting (incl. forestry)	3.24	-$ 107	-5%	-5%	-10%	-10%	-1%	32%	$1,695	26.1	0.7	282.1	1,404,806,632	110
	Diverse pastures (i.e., plantain)	3.13	-$ 9	-3%	0%	0%	0%	0%	28%	$1,689	25.5	0.7	282.1	1,404,806,632	110
M2	Facilitated wetlands*	2.76	$ -	0%	0%	0%	0%	0%	24%	$1,689	25.5	0.7	282.1	1,404,806,632	110
	Constructed wetlands*	2.38	-$ 24	-0.5%	-0.5%	-0.8%	-0.6%	0.0%	16%	$1,669	25.4	0.7	280.2	1,398,281,844	110
PLUC	Land retirement (permanent native forestry)	2.33	-$ 1,836												
M3	Retention dams, bunds or sediment traps*	2.24	-$ 52	0%	-15%	-79%	-50%	0%	15%	$1,625	25.4	0.6	66.0	761,570,159	110
PLUC	Plantation forestry	2.00	-$ 1,047												
M4	Use of low water soluble P fert	2.00	-$ 69	0%	-13%	0%	0%	0%	20%	$1,570	25.4	0.5	66.0	761,570,159	110
	Increased sheep : cattle ratio	1.27	$ 69	-3%	0%	0%	0%	-4%	0%	$1,639	24.6	0.5	66.0	761,570,159	107
	Applying alum to pasture and crops 100%	1.00	-$ 105	0%	-20%	0%	0%	0%	0%	$1,534	24.6	0.4	66.0	761,570,159	107

Appendix 19: Tukituki SBH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$461	22.0	1.0	5,940	4,000,000,000	144
Current										**$461**	**20.5**	**0.9**	**3,824**	**2,840,188,685**	**144**
M1	Stream fencing	3.70	-$41	-13%	-15%	-70%	-58%	0%	40%	$437	18.9	0.8	1,593	1,553,228,187	143
	Diverse pastures (i.e., plantain)	3.10	-$9	0%	0%	0%	0%	0%	30%	$431	18.9	0.8	1,593	1,553,228,187	143
	Facilitated wetlands*	3.10	$0	0%	0%	0%	0%	0%	25%	$431	18.9	0.8	1,593	1,553,228,187	143
	Riparian planting (incl. forestry)	3.09	-$98	-5%	-5%	-10%	-10%	-1%	27%	$359	18.1	0.8	1,472	1,440,223,380	143
PLUC	Land retirement (permanent native forestry)	2.22	-$582												
M2	Use of low water soluble P fert	2.11	-$69	0%	-13%	0%	0%	0%	22%	$306	18.1	0.7	1,472	1,440,223,380	143
	Retention dams, bunds or sediment traps	2.10	-$52	0%	-15%	-80%	-50%	0%	10%	$259	18.1	0.6	320	758,012,305	143
	Constructed wetlands*	2.10	-$7	-0.1%	-0.1%	-0.2%	-0.2%	0.0%	15%	$253	18.1	0.6	319	756,948,930	143
M3	Reduced forage cropping	1.78	-$161	-9%	-10%	0%	0%	0%	0%	$92	16.4	0.5	319	756,948,930	143
PLUC	Plantation forestry	1.67	206.8568												
M4	Increased sheep : cattle ratio	1.56	-$60	-5%	-10%	0%	0%	-2%	0%	$32	15.7	0.5	319	756,948,930	140
	Applying alum to pasture and crops 100%	0.90	-$105	0%	-20%	0%	0%	0%	0%	-$73	15.7	0.4	319	756,948,930	140

Appendix 20: Tukituki SBL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$543	12.0	0.4	2,102.1	4,000,000,000	98
Current										**$543**	**11.2**	**0.4**	**1,352.4**	**2,839,016,818**	**97**
M1	Stream fencing	3.70	-$41	-13%	-15%	-70%	-58%	0%	40%	$519	10.3	0.3	563.5	1,552,587,322	97
	Facilitated wetlands*	3.10	$0	0%	0%	0%	0%	0%	25%	$519	10.3	0.3	563.5	1,552,587,322	97
	Riparian planting (incl. forestry)	3.09	-$99	-5%	-5%	-10%	-10%	-1%	27%	$447	9.9	0.3	520.5	1,439,629,141	97
PLUC	Land retirement (permanent native forestry)	2.22	-$664												
M2	Use of low water soluble P fert	2.11	-$69	0%	-13%	0%	0%	0%	22%	$393	9.9	0.3	520.5	1,439,629,141	97
	Retention dams, bunds or sediment traps	2.10	-$52	0%	-15%	-80%	-50%	0%	10%	$346	9.9	0.2	113.1	757,699,548	97
	Constructed wetlands*	2.10	-$19	-0.4%	-0.4%	-0.6%	-0.4%	0.0%	15%	$330	9.8	0.2	112.5	754,863,880	97
M3	Reduced forage cropping	1.78	$18	-8%	0%	0%	0%	-1%	0%	$348	9.0	0.2	112.5	754,863,880	95
PLUC	Plantation forestry	1.67	$125												
M4	Applying alum to pasture and crops 100%	0.90	-$105	0%	-20%	0%	0%	0%	0%	$243	9.0	0.2	112.5	754,863,880	95

Appendix 21: Tukituki SBVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$253	14.0	0.3	1,657.5	4,000,000,000	78
Current										**$253**	**13.1**	**0.3**	**1,066.3**	**2,839,016,818**	**78**
	Stream fencing	3.70	-$40	-13%	-15%	-70%	-58%	0%	40%	$229	12.0	0.2	444.3	1,552,587,322	78
M1	Facilitated wetlands*	3.10	$0	0%	0%	0%	0%	0%	25%	$229	12.0	0.2	444.3	1,552,587,322	78
	Riparian planting (incl. forestry)	3.09	-$97	-5%	-5%	-10%	-10%	-1%	27%	$159	11.5	0.2	410.4	1,439,629,141	78
PLUC	Land retirement (permanent native forestry)	2.22	-$374												
	Use of low water soluble P fert	2.11	-$69	0%	-13%	0%	0%	0%	22%	$105	11.5	0.2	410.4	1,439,629,141	78
M2	Retention dams, bunds or sediment traps	2.10	-$52	0%	-15%	-80%	-50%	0%	10%	$58	11.5	0.2	89.2	757,699,548	78
	Constructed wetlands*	2.10	-$19	-0.4%	-0.4%	-0.6%	-0.4%	0.0%	15%	$42	11.5	0.2	88.7	754,863,880	78
M3	Reduced forage cropping	1.78	$5	-7%	0%	0%	0%	-7%	0%	$47	10.7	0.2	88.7	754,863,880	72
PLUC	Plantation forestry	1.67	$415												
M4	Applying alum to pasture and crops 100%	0.90	-$105	0%	-20%	0%	0%	0%	0%	-$58	10.7	0.1	88.7	754,863,880	72

Appendix 22: Tukituki SBH2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$292	15.0	1.1	8,790.7	4,000,000,000	101
Current										**$292**	**14.2**	**1.0**	**5,599.2**	**3,213,148,508**	**101**
	Stream fencing	3.17	-$47	-13%	-15%	-70%	-58%	0%	31%	$259	12.9	0.9	2,146	1,645,758,992	101
M1	Riparian planting (incl. forestry)	3.14	-$93	-4%	-4%	-8%	-8%	-1%	26%	$190	12.5	0.8	2,012	1,547,601,436	100
	Variable rate fertiliser	3.00	$54	0%	0%	0%	0%	0%	48%	$219	12.5	0.8	2,012	1,547,601,436	100
PLUC	Plantation forestry	2.88	$369												
M2	Space planted trees	2.85	-$100	0%	-20%	-70%	0%	0%	24%	$143	12.5	0.7	726	1,547,601,436	100
PLUC	Land retirement (permanent native forestry)	2.78	-$420												
M3	Use of low water soluble P fert	2.17	-$65	0%	-13%	0%	0%	0%	21%	$92	12.5	0.6	726	1,547,601,436	100
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	-$13	12.5	0.5	726	1,547,601,436	100

Appendix 23: Tukituki SBL2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$500	9.0	1.0	6,171.4	4,000,000,000	111
Current										**$500**	**8.5**	**0.9**	**3,930.8**	**3,213,148,508**	**111**
	Stream fencing	3.17	-$48	-13%	-15%	-70%	-58%	0%	31%	$468	7.7	0.8	1,506.5	1,645,758,992	111
M1	Riparian planting (incl. forestry)	3.14	-$94	-4%	-4%	-8%	-8%	-1%	26%	$398	7.5	0.8	1,412.2	1,547,601,436	111
	Variable rate fertiliser	3.00	$54	0%	0%	0%	0%	0%	48%	$426	7.5	0.8	1,412.2	1,547,601,436	111
PLUC	Plantation forestry	2.88	$112												
M2	Space planted trees	2.85	-$100	0%	-20%	-70%	0%	0%	24%	$350	7.5	0.6	509.5	1,547,601,436	111
PLUC	Land retirement (permanent native forestry)	2.78	-$677												
M3	Use of low water soluble P fert	2.17	-$65	0%	-13%	0%	0%	0%	21%	$299	7.5	0.6	509.5	1,547,601,436	111
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	$194	7.5	0.5	509.5	1,547,601,436	111

Appendix 24: Tukituki SBVL2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$369	7.0	0.5	3,203.2	4,000,000,000	86
Current										**$369**	**6.6**	**0.4**	**2,040.3**	**3,213,148,508**	**86**
	Stream fencing	3.17	-$47	-13%	-15%	-70%	-58%	0%	31%	$337	6.0	0.4	782.0	1,645,758,992	86
M1	Riparian planting (incl. forestry)	3.14	-$94	-4%	-4%	-8%	-8%	-1%	26%	$267	5.8	0.4	733.0	1,547,601,436	86
	Variable rate fertiliser	3.00	$54	0%	0%	0%	0%	0%	48%	$296	5.8	0.4	733.0	1,547,601,436	86
PLUC	Plantation forestry	2.88	$299												
M2	Space planted trees	2.85	-$100	0%	-20%	-70%	0%	0%	24%	$220	5.8	0.3	264.5	1,547,601,436	86
PLUC	Land retirement (permanent native forestry)	2.78	-$490												
M3	Use of low water soluble P fert	2.17	-$65	0%	-13%	0%	0%	0%	21%	$169	5.8	0.3	264.5	1,547,601,436	86
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	$64	5.8	0.2	264.5	1,547,601,436	86

Appendix 25: Tukituki DEH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$226	23.0	0.6	2,126.8	600,000,000	118
Current										**$226**	**21.1**	**0.5**	**1,326.7**	**448,248,531**	**118**
M1	Stream fencing	3.70	-$79	-13%	-15%	-70%	-58%	0%	40%	$178	19.3	0.4	552.8	245,135,915	118
M1	Riparian planting (incl. forestry)	3.09	-$138	-5%	-5%	-10%	-10%	-1%	27%	$78	18.5	0.4	509.4	226,831,689	117
M2	Space planted trees*	2.73	-$85	0%	-17%	-60%	0%	0%	18%	$9	18.7	0.4	210.3	231,026,896	117
M2	Catch crops for forage cropping	2.22	-$6	-9%	0%	0%	0%	0%	22%	$4	17.3	0.4	231.4	226,831,689	117
PLUC	Land retirement (permanent native forestry)	2.22	-$232												
M3	Use of low water soluble P fert	2.11	-$65	0%	-13%	0%	0%	0%	22%	$1	17.3	0.3	231.4	226,831,689	117
M3	Fence-line pacing prevention	2.11	-$198	0%	-14%	0%	0%	-1%	17%	-$211	17.3	0.3	231.4	226,831,689	116
M3	Reduced forage cropping	1.78	-$72	-22%	0%	0%	0%	-2%	0%	-$283	13.5	0.3	231.4	226,831,689	114
PLUC	Plantation forestry	1.67	$557												
M4	Applying alum to pasture and crops 100%	0.90	-$105	0%	-20%	0%	0%	0%	0%	-$388	13.5	0.2	231.4	226,831,689	114
M4	Alternative wallowing	0.78	-$118	0%	-68%	0%	0%	0%	6%	-$499	13.5	0.1	231.4	226,831,689	114

Appendix 26: Tukituki DEL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$53	16.0	0.7	2,220.7	600,000,000	104
Current										**$53**	**14.7**	**0.6**	**1,428.2**	**425,618,773**	**104**
M1	Stream fencing	3.7	-$57	-13%	-15%	-70%	-58%	0%	40%	$19	13.5	0.5	595.1	232,760,266	104
M1	Diverse pastures (i.e., plantain)	3.4	-$9	0%	0%	0%	0%	0%	30%	$13	13.5	0.5	595.1	232,760,266	104
M1	Facilitated wetlands*	3.1	$0	0%	0%	0%	0%	0%	25%	$13	13.5	0.5	595.1	232,760,266	104
M1	Riparian planting (incl. forestry)	3.0	-$114	-6%	-6%	-11%	-10%	-1%	27%	-$70	13.0	0.5	547.7	215,106,978	103
M2	Catch crops for forage cropping	2.4	-$6	-6%	0%	0%	0%	0%	22%	-$75	12.3	0.5	547.7	215,106,978	103
PLUC	Land retirement (permanent native forestry)	2.3	-$59												
M3	Use of low water soluble P fert	2.3	-$69	0%	-13%	0%	0%	0%	22%	-$129	12.3	0.5	547.7	215,106,978	103
M3	Retention dams, bunds or sediment traps	2.2	-$52	0%	-15%	-80%	-50%	0%	10%	-$176	12.3	0.4	119.1	113,214,199	103
M3	Constructed wetlands*	2.2	-$2	0%	0%	0%	0%	0%	15%	-$178	12.3	0.4	119.0	113,161,267	103
M3	Fence-line pacing prevention	2.1	-$166	0%	-14%	0%	0%	-1%	17%	-$316	12.3	0.3	119.0	113,161,267	103
M3	Reduced forage cropping	2.0	-$17	-19%	0%	0%	0%	-2%	0%	-$333	10.0	0.3	119.0	113,161,267	101
PLUC	Plantation forestry	1.7	$730												
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	-$438	10.0	0.3	119.0	113,161,267	101
M4	Alternative wallowing	0.9	-$99	0%	-68%	0%	0%	0%	6%	-$531	10.0	0.1	119.0	113,161,267	101

Appendix 27: Tukituki AI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$2,637	23.1	0.8	771.2	200,000,000	116
Current										**$2,274**	**17.0**	**0.4**	**386.6**	**199,792,160**	**116**
M1	Minimum tillage	3.43	$310	-2%	-25%	-25%	0%	0%	79%	$2,340	16.9	0.3	360.8	199,792,160	116
	Zero tillage	3.00	-$149	-10%	-50%	-25%	0%	0%	57%	$2,276	16.2	0.2	315.7	199,792,160	116
M2	Riparian planting (incl. forestry)	2.93	-$54	-4%	-4%	-8%	0%	0%	21%	$2,234	15.7	0.2	296.6	199,030,081	116
	Facilitated wetlands*	2.46	$0	0%	0%	0%	0%	0%	15%	$2,234	15.7	0.2	296.6	199,030,081	116
	Cover crops	2.25	-$97	-60%	-25%	-10%	0%	0%	21%	$2,157	7.2	0.2	272.6	199,030,081	116
	Reduce N fertiliser use (below 190 kg N/ha)	2.17	-$751	-2%	0%	0%	0%	0%	50%	$1,781	7.1	0.2	272.6	199,030,081	116
	Vegetated buffer strips (for arable cropping)	2.15	-$358	-49%	-51%	-82%	0%	0%	15%	$1,478	3.9	0.1	56.1	199,030,081	116
	Retention dams, bunds or sediment traps	2.08	-$384	0%	-98%	-88%	0%	0%	15%	$1,154	3.9	0.0	7.8	199,030,081	116
PLUC	Plantation forestry	1.92	-$2,112												
M3	Constructed wetlands*	1.92	-$5	-0.1%	-0.1%	-0.2%	0.0%	0.0%	8%	$1,149	3.9	0.0	7.8	199,030,081	116
PLUC	Land retirement (permanent native forestry)	1.83	-$2,901												
M4	Applying alum to pasture and crops 100%	1.00	-$105	0%	-20%	0%	0%	0%	0%	$1,044	3.9	0.0	7.8	199,030,081	116
	Variable rate irrigation	0.54	$6	0%	0%	0%	0%	0%	0%	$1,051	3.9	0.0	7.8	199,030,081	116

Appendix 28: Tukituki AL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$1,434	17.1	0.8	1,235.1	200,000,000	140
Current										**$1,434**	**12.4**	**0.4**	**619.0**	**199,792,160**	**140**
M1	Minimum tillage	3.50	$218	-2%	-25%	-25%	0%	0%	79%	$1,481	12.3	0.3	578	199,792,160	140
	Zero tillage	3.07	-$70	-10%	-50%	-25%	0%	0%	57%	$1,451	11.8	0.2	505	199,792,160	140
M2	Riparian planting (incl. forestry)	2.71	-$48	-4%	-4%	-8%	0%	0%	21%	$1,413	11.4	0.2	475	199,030,081	140
	Cover crops	2.50	-$97	-60%	-25%	-10%	0%	0%	21%	$1,335	5.2	0.2	436	199,030,081	140
	Facilitated wetlands*	2.46	$0	0%	0%	0%	0%	0%	15%	$1,335	5.2	0.2	436	199,030,081	140
	Vegetated buffer strips (for arable cropping)	2.38	-$298	-49%	-51%	-82%	0%	0%	15%	$1,083	2.9	0.1	90	199,030,081	140
	Reduce N fertiliser use (below 190 kg N/ha)	2.25	-$690	-5%	0%	0%	0%	0%	50%	$738	2.8	0.1	90	199,030,081	140
	Retention dams, bunds or sediment traps	2.23	-$382	0%	-98%	-88%	0%	0%	15%	$415	2.8	0.0	12	199,030,081	140
PLUC	Plantation forestry	2.17	-$909												
M3	Constructed wetlands*	1.92	-$9	-0.2%	-0.2%	-0.3%	0.0%	0.0%	8%	$407	2.8	0.0	12	199,030,081	140
PLUC	Land retirement (permanent native forestry)	1.83	-$1,698												
M4	Applying alum to pasture and crops 100%	1.08	-$105	0%	-20%	0%	0%	0%	0%	$302	2.8	0.0	12	199,030,081	140

Appendix 29: Tukituki VEI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $\$ ha^{-1} yr^{-1}$	N loss $kg N ha^{-1} yr^{-1}$	P loss $kg P ha^{-1} yr^{-1}$	TSS loss $t km^{-2} yr^{-1}$	*E. coli* loss $E. coli ha^{-1} yr^{-1}$	CH_4 $kg CH_4 ha^{-1} yr^{-1}$
Unmitigated										$11,906	27.0	1.7	449.6	1,600,000,000	0
Current										**$11,906**	**27.0**	**1.7**	**449.6**	**1,600,000,000**	**0**
M1	Minimum tillage	3.4	-$990	-5%	-25%	-25%	0%	0%	0%	$10,916	25.7	1.3	337.2	1,600,000,000	0
M2	Riparian planting (incl. forestry)	2.9	-$138	-7%	-7%	-13%	-1%	0%	0%	$10,778	23.9	1.2	294.3	1,586,987,704	0
	Facilitated wetlands*	2.5	$0	0%	0%	0%	0%	0%	0%	$10,778	23.9	1.2	294.3	1,586,987,704	0
	Cover crops	2.3	-$97	-5%	-25%	-25%	0%	0%	0%	$10,680	22.7	0.9	220.7	1,586,987,704	0
	Reduce N fertiliser use (below 190 kg N/ha)	2.2	-$3,389	-1%	0%	0%	0%	0%	0%	$7,292	22.6	0.9	220.7	1,586,987,704	0
	Vegetated buffer strips (for arable cropping)	2.2	-$822	-49%	-51%	-82%	0%	0%	0%	$6,470	11.5	0.4	39.7	1,586,987,704	0
	Retention dams, bunds or sediment traps	2.1	-$396	0%	-98%	-88%	0%	0%	0%	$6,074	11.5	0.0	4.8	1,586,987,704	0
M3	Constructed wetlands*	1.9	-$57	-1%	-1%	-2%	0%	0%	0%	$6,017	11.4	0.0	4.7	1,586,987,704	0
PLUC	Plantation forestry	1.9	-$11,381												
	Land retirement (permanent native forestry)	1.8	-$12,170												
M4	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	$5,912	11.4	0.0	4.7	1,586,987,704	0
	Variable rate irrigation	0.5	-$35	-21%	0%	0%	0%	0%	0%	$5,877	9.0	0.0	4.7	1,586,987,704	0

Appendix 30: Tukituki FRI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $\$ ha^{-1} yr^{-1}$	N loss $kg N ha^{-1} yr^{-1}$	P loss $kg P ha^{-1} yr^{-1}$	TSS loss $t km^{-2} yr^{-1}$	*E. coli* loss $E. coli ha^{-1} yr^{-1}$	CH_4 $kg CH_4 ha^{-1} yr^{-1}$
Unmitigated										$26,420	14.6	0.2	380.0	1,600,000,000	0
Current										**$26,420**	**14.6**	**0.2**	**380.0**	**1,600,000,000**	**0**
M2	Riparian planting (incl. forestry)	2.93	-$ 147	-3%	-3%	-6%	0%	0%	0%	$26,273	14.1	0.2	356.3	1,593,619,876	0
	Facilitated wetlands*	2.46	$ -	0%	0%	0%	0%	0%	0%	$26,273	14.1	0.2	356.3	1,593,619,876	0
M3	Constructed wetlands*	1.92	-$ 17	0%	0%	0%	0%	0%	0%	$26,256	14.1	0.2	354.6	1,593,619,876	0
PLUC	Plantation forestry	1.92	-$ 25,895												
	Land retirement (permanent native forestry)	1.83	-$ 26,684												

Appendix 31: Tukituki VTI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $\$ ha^{-1} yr^{-1}$	N loss $kg N ha^{-1} yr^{-1}$	P loss $kg P ha^{-1} yr^{-1}$	TSS loss $t km^{-2} yr^{-1}$	*E. coli* loss $E. coli ha^{-1} yr^{-1}$	CH_4 $kg CH_4 ha^{-1} yr^{-1}$
Unmitigated										$9,082	9.0	0.6	240.2	1,600,000,000	0
Current										**$9,082**	**9.0**	**0.6**	**240.2**	**1,600,000,000**	**0**
M2	Riparian planting (incl. forestry)	2.9	-$ 66	-2.2%	-2.2%	-4.2%	-0.3%	0.0%	0.0%	$9,016	8.8	0.6	230.0	1,595,666,118	0
	Facilitated wetlands*	2.5	$ -	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	$9,016	8.8	0.6	230.0	1,595,666,118	0
M3	Constructed wetlands*	1.9	$ -	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	$9,016	8.8	0.6	230.0	1,595,666,118	0
PLUC	Plantation forestry	1.9	-$ 8,557												
	Land retirement (permanent native forestry)	1.8	-$ 9,346												

Appendix 32: Tukituki EF1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$525	2.5	0.2	2,612.0	400,000,000	0
Current										**$521**	**2.5**	**0.2**	**2,550.1**	**397,213,633**	**0**
M1	Riparian planting (incl. forestry)	3.31	-$12	-5%	-6%	-8%	-2%	0%	31%	$513	2.4	0.2	2,410.9	390,944,307	0

Appendix 33: Tukituki EF2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$525	2.5	0.2	3,561.6	400,000,000	0
Current										**$523**	**2.5**	**0.2**	**3,519.2**	**399,633,810**	**0**
M1	Riparian planting (incl. forestry)	3.54	-$8	-2%	-3%	-4%	0%	0%	31%	$517	2.4	0.2	3,423.8	398,809,882	0

Appendix 34: Tukituki LH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$367	18.5	1.1	3,460.9	4,000,000,000	101
Current										**$334**	**17.6**	**1.0**	**2,646.2**	**3,207,430,653**	**101**
M1	Stream fencing	3.17	-$35	-13%	-15%	-70%	-58%	0%	31%	$309	15.9	0.9	1,014.2	1,642,830,334	101
	Riparian planting (incl. forestry)	3.14	-$86	-5%	-5%	-9%	-9%	0%	26%	$246	15.4	0.9	945.2	1,536,277,292	101
PLUC	Plantation forestry	2.88	$219												
	Land retirement (permanent native forestry)	2.78	-$570												
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	$141	15.4	0.7	945.2	1,536,277,292	101

Appendix 35: Tukituki LL1 mitigation cost curve

Bundle	Mitigation	Preferenc e score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$527	12.5	1.0	1,820.9	4,000,000,000	111
Current										**$492**	**11.9**	**0.9**	**1,391.7**	**3,206,450,604**	**111**
M1	Stream fencing	3.17	-$36	-13%	-15%	-70%	-58%	0%	31%	$468	10.8	0.8	533.4	1,642,328,358	111
	Riparian planting (incl. forestry)	3.07	-$87	-5%	-5%	-9%	-9%	0%	26%	$403	10.4	0.8	497.1	1,535,807,874	111
PLUC	Plantation forestry	3.04	$59												
	Land retirement (permanent native forestry)	2.89	-$730												
M2	Facilitated wetlands*	2.75	$0	0%	0%	0%	0%	0%	21%	$403	10.4	0.8	497.1	1,535,807,874	111
	Constructed wetlands*	2.63	-$7	-0.1%	-0.1%	-0.2%	-0.2%	0.0%	19%	$398	10.4	0.8	496.1	1,533,742,435	111
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	$293	10.4	0.6	496.1	1,533,742,435	111

Appendix 36: Tukituki LVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$396	10.5	0.5	1,167.0	4,000,000,000	86
Current										**$362**	**10.0**	**0.5**	**892.1**	**3,207,103,970**	**86**
M1	Stream fencing	3.17	-$35	-13%	-15%	-70%	-58%	0%	31%	$338	9.1	0.4	341.9	1,642,663,009	86
	Riparian planting (incl. forestry)	3.14	-$86	-5%	-5%	-9%	-9%	0%	26%	$274	8.7	0.4	318.7	1,536,120,820	86
PLUC	Plantation forestry	2.88	$190												
	Land retirement (permanent native forestry)	2.78	-$599												
M2	Facilitated wetlands*	2.68	$0	0%	0%	0%	0%	0%	21%	$274	8.7	0.4	318.7	1,536,120,820	86
	Constructed wetlands*	2.44	-$2	0.0%	0.0%	-0.1%	-0.1%	0.0%	19%	$272	8.7	0.4	318.4	1,535,432,340	86
M4	Applying alum to pasture and crops 100%	0.88	-$105	0%	-20%	0%	0%	0%	0%	$167	8.7	0.3	318.4	1,535,432,340	86

10.4.2 Te Hoiere mitigation cost curves

Appendix 37: Te Hoiere DI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$4,794	128	2.8	3,047.8	4,100,000,000	427
Current										**$4,794**	**68.7**	**1.6**	**1,365.5**	**2,126,542,680**	**404**
M1	Stream fencing	4.00	-$27	-13.0%	-15.0%	-70.0%	-58.0%	-0.3%	50%	$4,780	63.9	1.5	630.2	1,257,954,825	404
M1	Reduce N fertiliser use (below 190 kg N/ha)	4.00	-$248	-13.3%	-3.6%	0.0%	0.0%	-5.0%	100%	$4,780	63.9	1.5	630.2	1,257,954,825	404
M1	Reduced N to effluent area	3.71	-$105	-1.6%	0.0%	0.0%	0.0%	-0.7%	0%	$4,675	62.9	1.5	630.2	1,257,954,825	401
M1	Diverse pastures (i.e., plantain)	3.67	-$9	-3.9%	0.0%	0.0%	0.0%	0.0%	42%	$4,670	61.4	1.5	630.2	1,257,954,825	401
M1	Variable rate fertiliser	3.50	$54	-5.0%	-10.0%	0.0%	0.0%	0.0%	83%	$4,679	60.9	1.4	630.2	1,257,954,825	401
M1	Riparian planting (incl. forestry)	3.50	-$107	-30.0%	-30.0%	-61.0%	-58.0%	-0.7%	38%	$4,612	48.0	1.1	318.7	675,196,200	399
M1	Lined effluent ponds	3.33	-$23	-2.1%	-0.4%	0.0%	0.0%	0.0%	83%	$4,609	47.9	1.1	318.7	675,196,200	399
M1	Reduced stocking rates	3.33	-$159	-6.3%	0.0%	0.0%	0.0%	-6.2%	0%	$4,450	44.9	1.1	318.7	675,196,200	375
M1	Use of low water soluble P fert	3.33	-$141	0.0%	-13.0%	0.0%	0.0%	0.0%	67%	$4,402	44.9	1.1	318.7	675,196,200	375
M1	Reduce soil P test to optimum	3.00	$286	0.0%	-15.0%	0.0%	0.0%	0.0%	50%	$4,545	44.9	1.0	318.7	675,196,200	375
M2	Irrigating based on soil moisture	2.67	$1,046	-38.3%	-14.3%	0.0%	0.0%	0.0%	50%	$5,068	34.3	1.0	318.7	675,196,200	375
M2	Facilitated wetlands*	2.67	$0	0.0%	0.0%	0.0%	0.0%	0.0%	25%	$5,068	34.3	0.9	318.7	675,196,200	375
M2	Variable rate irrigation	2.67	-$85	-1.0%	0.0%	0.0%	0.0%	0.0%	50%	$5,025	34.1	0.9	318.7	675,196,200	375
PLUC	Plantation forestry	2.33	-$3,494												
M3	Retention dams, bunds or sediment traps*	2.00	-$49	0.0%	-2.8%	-74.4%	-46.5%	0.0%	14%	$4,984	34.1	0.9	91.3	386,933,400	375
M3	Constructed wetlands*	2.00	$0	0.0%	0.0%	0.0%	0.0%	0.0%	7%	$4,984	34.1	0.9	91.3	386,933,400	375
PLUC	Land retirement (permanent native forestry)	2.00	-$3,942												
M4	Stand off pads - no roof	1.17	-$399	-30.0%	0.0%	0.0%	0.0%	-3.0%	0%	$4,585	23.9	0.9	91.3	386,933,400	363
M4	Off-paddock structures - with roof	1.17	-$2,734	-2.3%	12.6%	0.0%	0.0%	13.4%	0%	$1,851	23.3	1.0	91.3	386,933,400	412
M4	Applying alum to pasture and crops 100%	1.00	-$105	0.0%	-20.0%	0.0%	0.0%	0.0%	0%	$1,746	23.3	0.8	91.3	386,933,400	412
M4	Deferred and low rate application	0.00	-$6	-3.0%	-66.0%	0.0%	0.0%	0.0%	0%	$1,740	22.6	0.3	91.3	386,933,400	412
M4	Increased effluent area	0.00	-$12	1.6%	3.6%	0.0%	0.0%	1.7%	0%	$1,741	23.0	0.3	91.3	386,933,400	419
M4	Applying alum to pasture and crops just to CSA	0.00	-$21	0.0%	-6.0%	0.0%	0.0%	0.0%	0%	$1,707	23.0	0.3	91.3	386,933,400	419

Appendix 38: Te Hoiere DH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 3,920	60.0	1.5	2,579.4	4,100,000,000	343
Current										$ 3,920	41.5	0.7	1,140.8	2,095,920,000	339
	Stream fencing	4.00	-$ 30	-13.0%	-15.0%	-70.0%	-58.0%	-0.3%	50.0%	$ 3,905	38.6	0.7	526.5	1,239,840,000	338
	Reduce N fertiliser use (below 190 kg N/ha)	4.00	-$ 108	-6.7%	0.0%	0.0%	0.0%	-0.7%	100.0%	$ 3,905	38.6	0.7	526.5	1,239,840,000	338
	Minimum tillage	3.60	$ 24	-1.7%	0.0%	0.0%	0.0%	0.0%	80.0%	$ 3,910	38.5	0.7	526.5	1,239,840,000	338
M1	Riparian planting (incl. forestry)	3.60	-$ 124	-30.0%	-30.0%	-61.0%	-58.0%	-0.9%	40.0%	$ 3,835	30.6	0.5	271.6	678,037,500	336
	Reduced N to effluent area	3.60	-$ 125	-6.7%	-6.7%	0.0%	0.0%	-1.4%	0.0%	$ 3,710	28.6	0.5	271.6	678,037,500	332
	Diverse pastures (i.e., plantain)	3.50	-$ 9	-3.3%	0.0%	0.0%	0.0%	0.0%	37.5%	$ 3,705	28.0	0.5	271.6	678,037,500	332
	Reduce soil P test to optimum	3.50	$ 218	0.0%	-15.0%	0.0%	0.0%	0.0%	75.0%	$ 3,759	28.0	0.5	271.6	678,037,500	332
	Variable rate fertiliser	3.25	$ 54	-5.0%	-10.0%	0.0%	0.0%	0.0%	75.0%	$ 3,773	27.6	0.5	271.6	678,037,500	332
	Reduced stocking rates	3.00	-$ 13	-3.3%	-6.7%	0.0%	0.0%	-6.6%	0.0%	$ 3,760	26.7	0.4	271.6	678,037,500	310
M2	Lined effluent ponds	3.00	-$ 20	-3.7%	-0.6%	0.0%	0.0%	0.0%	75.0%	$ 3,755	26.4	0.4	271.6	678,037,500	310
	Deferred and low rate application	2.80	-$ 5	-3.0%	-66.0%	0.0%	0.0%	0.0%	40.0%	$ 3,752	25.9	0.2	271.6	678,037,500	310
PLUC	Plantation forestry	2.25	-$ 2,772												
	Facilitated wetlands*	2.00	$ -	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	$ 3,752	25.9	0.2	271.6	678,037,500	310
	Reduced forage cropping	2.00	-$ 240	-6.7%	-20.0%	0.0%	0.0%	0.4%	0.0%	$ 3,512	24.2	0.2	271.6	678,037,500	311
M3	Use of low water soluble P fert	2.00	-$ 124	0.0%	-13.0%	0.0%	0.0%	0.0%	0.0%	$ 3,388	24.2	0.1	271.6	678,037,500	311
	Retention dams, bunds or sediment traps*	1.75	-$ 52	0.0%	-3.0%	-80.0%	-50.0%	0.0%	12.5%	$ 3,343	24.2	0.1	60.4	361,620,000	311
	Constructed wetlands*	1.75	-$ 2	0.0%	0.0%	-0.1%	-0.1%	0.0%	0.0%	$ 3,340	24.2	0.1	60.3	361,330,704	311
PLUC	Land retirement (permanent native forestry)	1.25	-$ 3,220												
	Stand off pads - no roof	1.25	-$ 308	-30.0%	0.0%	0.0%	0.0%	-3.0%	0.0%	$ 3,032	16.9	0.1	60.3	361,330,704	301
M4	Off-paddock structures - with roof	1.25	-$ 2,542	-2.3%	12.6%	0.0%	0.0%	13.4%	0.0%	$ 490	16.5	0.2	60.3	361,330,704	342
	Applying alum to pasture and crops 100%	1.00	-$ 105	0.0%	-20.0%	0.0%	0.0%	0.0%	0.0%	$ 385	16.5	0.1	60.3	361,330,704	342
	Applying alum to pasture and crops just to CSA	0.00	-$ 21	0.0%	-6.0%	0.0%	0.0%	0.0%	0.0%	$ 364	16.5	0.1	60.3	361,330,704	342

Appendix 39: Te Hoiere DH2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 2,373	30.0	4.4	3,177.3	4,100,000,000	250.9
Current										$ 2,373	21.6	2.1	1,419.3	2,235,648,000	249.8
M1	Stream fencing	4.0	-$25	-13%	-15%	-70%	-58%	0%	50%	$ 2,361	20.1	1.9	655.0	1,322,496,000	249.4
	Minimum tillage	3.6	$24	-3%	0%	0%	0%	0%	80%	$ 2,366	20.0	1.9	655.0	1,322,496,000	249.4
	Riparian planting (incl. forestry)	3.6	-$99	-30%	-30%	-61%	-58%	-1%	40%	$ 2,306	15.9	1.5	337.9	723,240,000	248.3
	Reduced N to effluent area	3.6	-$10	-3%	0%	0%	0%	0%	0%	$ 2,296	15.4	1.5	337.9	723,240,000	247.2
	Diverse pastures (i.e., plantain)	3.5	-$9	-3%	0%	0%	0%	0%	38%	$ 2,291	15.0	1.5	337.9	723,240,000	247.2
	Reduce soil P test to optimum	3.5	$95	0%	-15%	0%	0%	0%	75%	$ 2,315	15.0	1.5	337.92	723,240,000	247.2
	Variable rate fertiliser	3.25	$54	-5%	-10%	0%	0%	0%	75%	$ 2,328	14.8	1.4	337.92	723,240,000	247.2
M2	Reduced stocking rates	3.0	$114	-3%	0%	0%	0%	-8%	0%	$ 2,442	14.3	1.4	337.92	723,240,000	228.6
	Lined effluent ponds	3.0	-$15	-6%	0%	0%	0%	0%	75%	$ 2,439	14.1	1.4	337.92	723,240,000	228.6
	Deferred and low rate application	2.8	-$4	-3%	-66%	0%	0%	0%	40%	$ 2,437	13.9	0.7	337.92	723,240,000	228.6
PLUC	Plantation forestry	2.25	-$1,620												
M3	Reduced forage cropping	2.0	-$299	-10%	7%	0%	0%	-1%	0%	$ 2,138	12.5	0.7	337.92	723,240,000	226.4
	Space planted trees	2.0	-$103	0%	-20%	-70%	0%	0%	13%	$ 2,048	12.5	0.6	111.52	723,240,000	226.4
	Stand off pads - no roof	1.3	-$262	-30%	0%	0%	0%	-3%	0%	$ 1,786	8.7	0.6	111.52	723,240,000	219.6
	Off-paddock structures - with roof	1.3	-$1,892	-2%	13%	0%	0%	13%	0%	-$ 106	8.5	0.7	111.52	723,240,000	248.9
PLUC	Land retirement (permanent native forestry)	1.25	-$1,931												
M4	Applying alum to pasture and crops 100%	1	-$105	0%	-20%	0%	0%	0%	0%	-$ 211	8.5	0.5	111.52	723,240,000	248.9
	Applying alum to pasture and crops just to CSA	0	-$21	0%	-6%	0%	0%	0%	0%	-$ 232	8.5	0.5	111.52	723,240,000	248.9

Appendix 40: Te Hoiere SBH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 444	17.0	0.5	2,709.3	4,000,000,000	125.4
Current										$ 444	14.1	0.4	1,428.7	2,345,015,395	124.9
M1	Stream fencing	3.8	-$47	-13%	-15%	-70%	-58%	0%	44%	$ 418	13.0	0.4	622.2	1,326,969,789	124.7
	Diverse pastures (i.e., plantain)	3.8	-$9	-6%	0%	0%	0%	0%	44%	$ 413	12.6	0.4	622.2	1,326,969,789	124.7
	Riparian planting (incl. forestry)	3.3	-$115	-30%	-30%	-61%	-58%	-1%	32%	$ 334	9.7	0.3	301.1	683,456,012	124.0
M2	Facilitated wetlands*	2.7	$0	0%	0%	0%	0%	0%	28%	$ 334	9.7	0.3	301.1	683,456,012	124.0
M3	Use of low water soluble P fert	1.8	-$106	0%	-13%	0%	0%	0%	13%	$ 242	9.7	0.3	301.1	683,456,012	124.0
	Retention dams, bunds or sediment traps*	1.4	-$52	0%	-15%	-80%	-50%	0%	6%	$ 193	9.7	0.2	63.4	352,751,490	124.0
	Constructed wetlands*	1.4	-$9	0%	0%	0%	0%	0%	6%	$ 184	9.7	0.2	63.2	352,023,840	124.0
PLUC	Land retirement (permanent native forestry)	1.4	-$348												
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	$ 79	9.7	0.2	63.2	352,023,840	124.0
PLUC	Plantation forestry	0.7	$100												

Appendix 41: Te Hoiere SBH2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$ 314	20.0	3.9	2,835.0	4,000,000,000	139.1
Current										$ 314	17.0	3.2	1,708.2	2,585,380,000	138.8
M1	Stream fencing	3.5	-$39	-13%	-15%	-70%	-58%	0%	38%	$ 289	15.6	2.9	694.9	1,387,680,000	138.6
	Variable rate fertiliser	3.3	$54	0%	-1%	0%	0%	0%	67%	$ 308	15.6	2.9	694.9	1,387,680,000	138.6
	Diverse pastures (i.e., plantain)	3.3	-$9	-5%	0%	0%	0%	0%	33%	$ 302	15.0	2.9	694.9	1,387,680,000	138.6
	Riparian planting (incl. forestry)	3.2	-$82	-30%	-30%	-61%	-58%	0%	30%	$ 244	11.6	2.2	331.7	705,600,000	138.2
M2	Use of low water soluble P fert	2.7	-$159	0%	-13%	0%	0%	0%	33%	$ 138	11.6	2.0	331.7	705,600,000	138.2
PLUC	Plantation forestry	2.5	-$64												
M3	Space planted trees	2.0	-$103	0%	-20%	-70%	0%	0%	0%	$ 36	11.6	1.6	99.5	705,600,000	138.2
PLUC	Land retirement (permanent native forestry)	1.3	-$375												
M4	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	-$ 69	11.6	1.3	99.5	705,600,000	138.2

Appendix 42: Te Hoiere EF1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$378	2.5	0.2	1,247	400,000,000	0.0
Current										**$378**	**2.5**	**0.2**	**1,247**	400,000,000	**0.0**
M1	Riparian planting (incl. forestry)	3.31	-$ 6	-10%	-15%	-20%	0%	0%	36%	$374	2.4	0.1	1,247	400,000,000	0.0

Appendix 43: Te Hoiere EF2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$208	2.5	0.2	1,233.0	400,000,000	0.0
Current										**$208**	**2.5**	**0.2**	**1,233.0**	**400,000,000**	**0.0**
M1	Riparian planting (incl. forestry)	3.31	-$ 2	-10%	-15%	-20%	0%	0%	36%	$207	2.4	0.1	1,232.9	400,000,000	0.0

Appendix 44: Te Hoiere LH1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$ 295	24.1	2.1	2,255.2	4,000,000,000	125.4
Current										$ 295	24.1	2.1	2,265.5	4,016,649,227	125.4
M1	Stream fencing	3.8	-$30	-13%	-15%	-70%	-58%	0%	0%	$ 265	21.0	1.8	678.7	1,684,994,914	125.1
	Riparian planting (incl. forestry)	3.3	-$75	-30%	-30%	-61%	-58%	-1%	-1%	$ 190	14.7	1.2	263.9	705,600,000	124.5
M2	Facilitated wetlands*	2.7	$0	0%	0%	0%	0%	0%	0%	$ 190	14.7	1.2	263.9	705,600,000	124.5
M3	Constructed wetlands*	1.4	-$2	0%	0%	0%	0%	0%	0%	$ 187	14.7	1.2	263.6	705,211,920	124.5
PLUC	Land retirement (permanent native forestry)	1.4	-$304												
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	$ 82	14.7	1.0	263.6	705,211,920	124.5
PLUC	Plantation forestry	0.7	$144												

10.4.3 South Coastal Canterbury mitigation cost curves

Appendix 45: South Coastal Canterbury DI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$4,586	49.0	2.4	401.5	4,100,000,000	385
Current										**$4,586**	**31.8**	**0.9**	**200.2**	**2,304,593,356**	**372.2**
M1	Reduce N fertiliser use (below 190 kg N/ha)	3.7	-$233	-16%	0%	0%	0%	-4%	83%	$4,547	30.8	0.9	200.2	2,304,593,356	369.8
M1	Diverse pastures (i.e., plantain)	3.6	-$9	-2%	0%	0%	0%	0%	38%	$4,542	30.4	0.9	200.2	2,304,593,356	369.8
M1	Stream fencing	3.6	-$18	-13%	-15%	-70%	-58%	0%	42%	$4,531	28.0	0.8	84.8	1,276,390,167	369.3
M1	Riparian planting (incl. forestry)	3.5	-$80	-30%	-30%	-61%	-58%	-1%	37%	$4,480	22.0	0.6	42.6	680,885,525	368.0
M1	Variable rate fertiliser	3.5	$54	-5%	-10%	0%	0%	0%	75%	$4,494	21.7	0.6	42.6	680,885,525	368.0
M1	Deferred and low rate application	3.4	-$6	-3%	-66%	0%	0%	0%	71%	$4,492	21.5	0.4	42.6	680,885,525	368.0
M1	Lined effluent ponds	3.3	-$24	-6%	0%	0%	0%	0%	75%	$4,486	21.2	0.4	42.6	680,885,525	368.0
M1	Reduce soil P test to optimum	3.2	-$162	0%	-15%	0%	0%	0%	54%	$4,411	21.2	0.4	42.6	680,885,525	368.0
M2	Reduced stocking rates	2.8	-$131	-4%	0%	0%	0%	-8%	0%	$4,280	20.4	0.4	42.6	680,885,525	339.4
M2	Increased effluent area	2.7	-$145	0%	0%	0%	0%	-2%	0%	$4,135	20.4	0.4	42.6	680,885,525	331.8
M2	Facilitated wetlands*	2.3	$0	0%	0%	0%	0%	0%	19%	$4,135	20.4	0.4	42.6	680,885,525	331.8
M2	Variable rate irrigation	2.3	-$24	-1%	0%	0%	0%	0%	25%	$4,117	20.2	0.4	42.6	680,885,525	331.8
M2	Constructed wetlands*	2.2	-$24	0%	0%	-1%	-1%	0%	12%	$4,097	20.1	0.4	42.3	676,062,498	331.7
M2	Retention dams, bunds or sediment traps	2.0	-$52	0%	-3%	-80%	-50%	0%	12%	$4,050	20.1	0.4	9.3	358,727,040	331.7
PLUC	Plantation forestry	2.0	-$3,435												
PLUC	Land retirement (permanent native forestry)	1.8	-$3,693												
M4	Use of low water soluble P fert	1.8	-$159	0%	-13%	0%	0%	0%	8%	$3,904	20.1	0.3	9.3	358,727,040	331.7
M4	Stand off pads - no roof	1.4	-$419	-30%	0%	0%	0%	-3%	0%	$3,485	14.1	0.3	9.3	358,727,040	321.7
M4	Off-paddock structures - with roof	1.4	-$2,523	-2%	13%	0%	0%	13%	0%	$963	13.8	0.3	9.3	358,727,040	364.7
M4	Applying alum to pasture and crops 100%	1.2	-$105	0%	-20%	0%	0%	0%	0%	$858	13.8	0.3	9.3	358,727,040	364.7
M4	BD to spray irrigation	0.0	-$34	-45%	-63%	0%	0%	-1%	0%	$824	7.6	0.1	9.3	358,727,040	362.0
M4	Applying alum to pasture and crops just to CSA	0.0	-$21	0%	-6%	0%	0%	0%	0%	$803	7.6	0.1	9.3	358,727,040	362.0
M4	Reduced N to effluent area	0.0	-$29	-2%	0%	0%	0%	-1%	0%	$774	7.4	0.1	9.3	358,727,040	359.6

Appendix 46: South Coastal Canterbury DI2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$3,649	18.0	1.8	1107.9	4,100,000,000	315
Current										**$3,649**	**11.5**	**0.7**	**609.3**	**2,447,950,556**	**307**
M1	Reduce N fertiliser use (below 190 kg N/ha)	3.7	-$320	-11%	0%	0%	0%	-3%	83%	$3,595	11.3	0.7	609.3	2,447,950,556	305.2
	Diverse pastures (i.e., plantain)	3.6	-$9	-6%	0%	0%	0%	0%	38%	$3,590	10.9	0.7	609.3	2,447,950,556	305.2
	Stream fencing	3.6	-$14	-13%	-15%	-70%	-58%	0%	42%	$3,582	10.0	0.6	258.0	1,355,788,000	304.9
	Riparian planting (incl. forestry)	3.5	-$57	-30%	-30%	-61%	-58%	0%	37%	$3,545	7.9	0.5	129.6	723,240,000	304.1
	Variable rate fertiliser	3.5	$54	-5%	-10%	0%	0%	0%	75%	$3,559	7.8	0.5	129.6	723,240,000	304.1
	Deferred and low rate application	3.4	-$5	-3%	-66%	0%	0%	0%	71%	$3,558	7.7	0.3	129.6	723,240,000	304.1
	Lined effluent ponds	3.3	-$19	-12%	-1%	0%	0%	0%	75%	$3,553	7.4	0.3	129.6	723,240,000	304.1
	Reduce soil P test to optimum	3.2	-$95	0%	-15%	0%	0%	0%	54%	$3,509	7.4	0.3	129.6	723,240,000	304.1
M2	Reduced stocking rates	2.8	-$80	-6%	0%	0%	0%	-9%	0%	$3,429	7.0	0.3	129.6	723,240,000	277.6
	Increased effluent area	2.7	-$837	-6%	0%	0%	0%	-2%	0%	$2,592	6.6	0.3	129.6	723,240,000	273.4
	Variable rate irrigation	2.3	-$62	-1%	0%	0%	0%	0%	25%	$2,546	6.6	0.3	129.6	723,240,000	273.4
PLUC	Plantation forestry	2.0	-$2,995												
	Land retirement (permanent native forestry)	1.8	-$3,102												
M4	Use of low water soluble P fert	1.8	-$165	0%	-13%	0%	0%	0%	8%	$2,395	6.6	0.2	129.6	723,240,000	273.4
	Stand off pads - no roof	1.4	-$295	-30%	0%	0%	0%	-3%	0%	$2,100	4.6	0.2	129.6	723,240,000	265.1
	Off-paddock structures - with roof	1.4	-$1,998	-2%	13%	0%	0%	13%	0%	$101	4.5	0.3	129.6	723,240,000	300.5
	Applying alum to pasture and crops 100%	1.2	-$105	0%	-20%	0%	0%	0%	0%	-$4	4.5	0.2	129.6	723,240,000	300.5
	Reduced N to effluent area	0.0	-$61	-6%	0%	0%	0%	0%	0%	-$65	4.3	0.2	129.6	723,240,000	299.6
	Applying alum to pasture and crops just to CSA	0.0	-$21	0%	-6%	0%	0%	0%	0%	-$86	4.3	0.2	129.6	723,240,000	299.6

Appendix 47: South Coastal Canterbury DVL2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$1,761	11.0	0.5	1961.9	4,100,000,000	194
Current										**$1,761**	**7.5**	**0.1**	**934.9**	**2,172,333,750**	**189.6**
M1	Stream fencing	4.0	-$11	-13%	-15%	-70%	-58%	0%	50%	$1,755	7.0	0.1	431.5	1,285,042,500	189.4
	Riparian planting (incl. forestry)	3.8	-$50	-30%	-30%	-61%	-58%	0%	44%	$1,727	5.6	0.1	229.5	723,240,000	189.0
	Reduce N fertiliser use (below 190 kg N/ha)	3.7	-$56	0%	-20%	0%	0%	-2%	86%	$1,719	5.6	0.1	229.5	723,240,000	188.3
	Reduce soil P test to optimum	3.7	-$56	0%	-15%	0%	0%	0%	86%	$1,711	5.6	0.1	229.5	723,240,000	188.3
	Use of low water soluble P fert	3.7	-$112	0%	-13%	0%	0%	0%	83%	$1,693	5.6	0.1	229.5	723,240,000	188.3
	Minimum tillage	3.6	$13	0%	0%	0%	0%	0%	71%	$1,696	5.6	0.1	229.5	723,240,000	188.3
	Reduced stocking rates	3.4	$273	-9%	-20%	0%	0%	-12%	0%	$1,969	5.1	0.1	229.5	723,240,000	166.4
	Variable rate fertiliser	3.4	$54	-5%	-10%	0%	0%	0%	71%	$1,985	5.1	0.1	229.5	723,240,000	166.4
	Diverse pastures (i.e., plantain)	3.4	-$9	-9%	0%	0%	0%	0%	36%	$1,979	4.8	0.1	229.5	723,240,000	166.4
	Deferred and low rate application	3.3	-$3	-3%	-66%	0%	0%	0%	63%	$1,978	4.7	0.0	229.5	723,240,000	166.4
	Reduced N to effluent area	3.3	-$49	-9%	0%	0%	0%	-1%	0%	$1,929	4.3	0.0	229.5	723,240,000	165.2
M2	Lined effluent ponds	2.7	-$13	-14%	-1%	0%	0%	0%	57%	$1,929	4.0	0.0	229.5	723,240,000	165.2
PLUC	Plantation forestry	2.3	-$1,107												
M3	Reduced forage cropping	2.0	-$754	9%	0%	0%	0%	-1%	0%	$1,175	4.4	0.0	229.5	723,240,000	163.1
PLUC	Land retirement (permanent native forestry)	1.7	-$1,214												
M4	Stand off pads - no roof	1.3	-$226	-30%	0%	0%	0%	-3%	0%	-$265	3.1	0.0	229.5	723,240,000	158.2
	Off-paddock structures - with roof	1.3	-$1,792	-2%	13%	0%	0%	13%	0%	-$2,057	3.0	0.0	229.5	723,240,000	179.3
	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	-$2,162	3.0	0.0	229.5	723,240,000	179.3
	Applying alum to pasture and crops just to CSA	0.0	-$21	0%	-6%	0%	0%	0%	0%	-$2,183	3.0	0.0	229.5	723,240,000	179.3

Appendix 48: South Coastal Canterbury SBI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$1,134	13.0	0.4	782.1	4,000,000,000	125
Current										**$1,134**	**9.7**	**0.3**	**413.1**	**2,373,236,003**	**125.0**
M1	Stream fencing	3.7	-$33	-13%	-15%	-70%	-58%	0%	41%	$1,115	8.9	0.3	173.6	1,306,835,558	124.8
	Diverse pastures (i.e., plantain)	3.5	-$9	-8%	0%	0%	0%	0%	36%	$1,109	8.5	0.3	173.6	1,306,835,558	124.8
	Riparian planting (incl. forestry)	3.2	-$89	-30%	-30%	-61%	-58%	-1%	30%	$1,047	6.5	0.2	82.7	663,233,984	124.3
	Minimum tillage	3.2	$11	-15%	0%	0%	0%	0%	70%	$1,050	6.2	0.2	82.7	663,233,984	124.3
M2	Facilitated wetlands*	2.7	$0	0%	0%	0%	0%	0%	23%	$1,050	6.2	0.2	82.7	663,233,984	124.3
	Variable rate fertiliser	2.6	$54	0%	0%	0%	0%	0%	38%	$1,084	6.2	0.2	82.7	663,233,984	124.3
PLUC	Plantation forestry	2.1	-$726												
M3	Constructed wetlands*	2.1	-$23	0%	0%	-1%	-1%	0%	13%	$1,064	6.2	0.2	82.1	660,054,623	124.3
	Retention dams, bunds or sediment traps*	2.0	-$50	0%	-14%	-76%	-48%	0%	13%	$1,020	6.2	0.2	21.8	368,402,580	124.3
	Reduced forage cropping	2.0	-$23	0%	0%	0%	0%	2%	0%	$997	6.2	0.2	21.8	368,402,580	127.1
PLUC	Land retirement (permanent native forestry)	1.8	-$984												
M4	Use of low water soluble P fert	1.7	-$153	0%	-13%	0%	0%	0%	13%	$884	6.2	0.2	21.8	368,402,580	127.1
	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	$759	6.2	0.1	21.8	368,402,580	127.1
	Increased sheep : cattle ratio	0.9	$64	0%	0%	0%	0%	-3%	0%	$823	6.2	0.1	21.8	368,402,580	123.4

Appendix 49: South Coastal Canterbury SBVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$356	4.0	0.1	702.8	4,000,000,000	125
Current										**$356**	**3.5**	**0.1**	**387.9**	**2,913,679,592**	**124.8**
M1	Stream fencing	3.6	-$31	-13%	-15%	-70%	-58%	0%	38%	$336	3.2	0.1	157.8	1,563,891,922	124.6
	Diverse pastures (i.e., plantain)	3.4	-$9	0%	0%	0%	0%	0%	37%	$331	3.2	0.1	157.8	1,563,891,922	124.6
	Minimum tillage	3.4	$74	0%	0%	0%	0%	0%	75%	$349	3.2	0.1	157.8	1,563,891,922	124.7
	Facilitated wetlands*	3.1	$0	0%	0%	0%	0%	0%	27%	$349	3.2	0.1	157.8	1,563,891,922	124.7
	Riparian planting (incl. forestry)	3.1	-$107	-30%	-61%	-58%	-1%	-1%	28%	$272	2.4	0.0	79.0	1,556,947,985	124.1
M2	Variable rate fertiliser	2.6	$54	0%	0%	0%	0%	0%	44%	$303	2.4	0.0	79.0	1,556,947,985	124.1
	Catch crops for forage cropping	2.1	$121	0%	0%	0%	0%	0%	18%	$402	2.4	0.0	79.0	1,556,947,985	124.2
	Retention dams, bunds or sediment traps	2.1	-$52	0%	-15%	-80%	-50%	0%	13%	$357	2.4	0.0	17.7	834,079,278	124.2
	Constructed wetlands*	2.1	-$23	0%	0%	-1%	-1%	0%	17%	$337	2.4	0.0	17.6	830,252,907	124.2
PLUC	Plantation forestry	2.0	-$25												
	Land retirement (permanent native forestry)	1.9	-$283												
M4	Reduced forage cropping	1.9	$67	0%	0%	0%	0%	1%	0%	$424	2.4	0.0	17.6	830,252,907	125.4
	Use of low water soluble P fert	1.7	-$94	0%	-13%	0%	0%	0%	14%	$324	2.4	0.0	17.6	830,252,907	125.4
	Increased sheep : cattle ratio	1.3	-$90	0%	0%	0%	0%	0%	0%	$234	2.4	0.0	17.6	830,252,907	124.9

Appendix 50: South Coastal Canterbury SBVL2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$136	4.0	0.1	1230.8	4,000,000,000	59
Current										**$136**	**3.5**	**0.1**	**788.0**	**2,720,864,865**	**58.5**
M1	Stream fencing	3.3	-$37	-13%	-15%	-70%	-58%	0%	33%	$111	3.2	0.1	308.4	1,416,648,649	58.4
M1	Riparian planting (incl. forestry)	3.2	-$85	-30%	-30%	-61%	-58%	-1%	27%	$49	2.4	0.1	144.0	705,600,000	58.1
M1	Variable rate fertiliser	3.2	$54	0%	-1%	0%	0%	0%	67%	$67	2.4	0.1	144.0	705,600,000	58.1
M1	Diverse pastures (i.e., plantain)	3.2	-$9	0%	0%	0%	0%	0%	31%	$61	2.4	0.1	144.0	705,600,000	58.1
M2	Use of low water soluble P fert	2.2	-$88	0%	-13%	0%	0%	0%	20%	-$10	2.4	0.1	144.0	705,600,000	58.1
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	-$115	2.4	0.0	144.0	705,600,000	58.1
PLUC	Land retirement (permanent native forestry)	2.6	-$96												
PLUC	Plantation forestry	2.8	$11												

Appendix 51: South Coastal Canterbury SBVL3 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$71	4.0	0.2	758.0	4,000,000,000	15
Current										**$71**	**4.0**	**0.2**	**758.0**	**4,000,000,000**	**15.0**
M1	Variable rate fertiliser	3.2	$54	0%	0%	0%	0%	0%	67%	$89	4.0	0.2	758.0	4,000,000,000	15.0
M2	Use of low water soluble P fert	2.2	-$77	0%	-13%	0%	0%	0%	20%	$27	4.0	0.2	758.0	4,000,000,000	15.0
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	-$78	4.0	0.1	758.0	4,000,000,000	15.0

Appendix 52: South Coastal Canterbury DEVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin \$ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$1,049	4.0	0.4	362.5	600,000,000	139
Current										**$1,049**	**4.4**	**1.2**	**198.6**	**367,264,144**	**139.2**
	Stream fencing	3.6	-$57	-13%	-15%	-70%	-58%	0%	38%	$1,014	4.0	1.1	80.8	197,125,803	138.9
	Diverse pastures (i.e., plantain)	3.4	-$9	0%	0%	0%	0%	0%	37%	$1,009	4.0	1.1	80.8	197,125,803	138.9
M1	Minimum tillage	3.4	$11	0%	0%	0%	0%	0%	75%	$1,011	4.0	1.1	80.8	197,125,803	138.9
	Facilitated wetlands*	3.1	$0	0%	0%	0%	0%	0%	27%	$1,011	4.0	1.1	80.8	197,125,803	138.9
	Riparian planting (incl. forestry)	3.1	-$128	-30%	-30%	-61%	-58%	-1%	28%	$919	3.0	0.8	37.9	98,693,448	138.2
	Variable rate fertiliser	2.6	$54	0%	0%	0%	0%	0%	44%	$950	3.0	0.8	37.9	98,693,448	138.2
	Catch crops for forage cropping	2.1	$56	0%	0%	0%	0%	0%	18%	$995	3.0	0.8	37.9	98,693,448	138.2
M2	Retention dams, bunds or sediment traps	2.1	-$52	0%	-15%	-80%	-50%	0%	13%	$950	3.0	0.7	8.5	52,871,490	138.2
	Constructed wetlands*	2.1	-$24	0%	0%	-1%	-1%	0%	17%	$930	3.0	0.7	8.4	52,628,940	138.2
	Fence-line pacing prevention	2.1	-$158	0%	-14%	0%	0%	-1%	18%	$800	3.0	0.6	8.4	52,628,940	137.3
PLUC	Plantation forestry	2.0	-$718												
	Land retirement (permanent native forestry)	1.9	-$976												
	Reduced forage cropping	1.9	$60	0%	0%	0%	0%	0%	0%	$860	3.0	0.6	8.4	52,628,940	137.7
M4	Use of low water soluble P fert	1.7	$0	0%	-13%	0%	0%	0%	14%	$860	3.0	0.5	8.4	52,628,940	137.7
	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	$755	3.0	0.4	8.4	52,628,940	137.7

Appendix 53: South Coastal Canterbury DEVL2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin \$ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										-$16	5.0	0.2	600.4	600,000,000	165
Current										**-$16**	**4.5**	**0.2**	**367.8**	**393,858,333**	**164.8**
	Stream fencing	3.6	-$15	-13%	-15%	-70%	-58%	0%	38%	-$25	4.1	0.1	149.6	211,400,000	164.4
M1	Diverse pastures (i.e., plantain)	3.4	$63	0%	0%	0%	0%	0%	37%	$15	4.1	0.1	149.6	211,400,000	164.4
	Minimum tillage	3.4	$15	0%	0%	0%	0%	0%	75%	$19	4.1	0.1	149.6	211,400,000	164.5
	Riparian planting (incl. forestry)	3.1	-$58	-30%	-30%	-61%	-58%	-1%	28%	-$23	3.2	0.1	70.3	105,840,000	163.6
	Variable rate fertiliser	2.6	-$56	0%	-1%	0%	0%	0%	44%	-$54	3.2	0.1	70.3	105,840,000	163.6
M2	Catch crops for forage cropping	2.1	-$99	20%	0%	0%	0%	0%	18%	-$136	3.7	0.1	70.3	105,840,000	163.5
	Fence-line pacing prevention	2.1	$76	0%	-14%	0%	0%	-1%	18%	-$74	3.7	0.1	70.3	105,840,000	162.4
PLUC	Plantation forestry	2.0	-$265												
	Land retirement (permanent native forestry)	1.9	-$127												
	Reduced forage cropping	1.9	$60	0%	0%	0%	0%	1%	0%	-$14	3.7	0.1	70.3	105,840,000	163.5
M4	Use of low water soluble P fert	1.7	$184	0%	-13%	0%	0%	0%	14%	$143	3.7	0.1	70.3	105,840,000	163.5
	Applying alum to pasture and crops 100%	0.9	$96	0%	-20%	0%	0%	0%	0%	$240	3.7	0.1	70.3	105,840,000	163.5
	Alternative wallowing	0.6	$4	0%	-68%	0%	0%	0%	4%	$244	3.7	0.0	70.3	105,840,000	163.5

Appendix 54: South Coastal Canterbury AI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$3,091	20.0	0.3	322.7	200,000,000	27.3
Current										**$3,091**	**12.0**	**0.2**	**195.0**	**200,000,000**	**27.1**
M1	Minimum tillage	3.5	$185	-10%	0%	0%	0%	0%	79%	$3,130	11.7	0.2	195.0	200,000,000	27.1
	Riparian planting (incl. forestry)	3.1	-$58	-30%	-30%	-61%	0%	0%	24%	$3,086	8.8	0.2	88.9	200,000,000	27.0
M2	Zero tillage	2.9	-$1,546	-25%	0%	0%	0%	0%	58%	$2,435	7.7	0.2	88.9	200,000,000	27.0
	Facilitated wetlands*	2.8	$0	0%	0%	0%	0%	0%	22%	$2,435	7.7	0.2	88.9	200,000,000	27.0
	Reduce N fertiliser use (below 190 kg N/ha)	2.5	$33	-20%	0%	0%	0%	0%	59%	$2,449	7.0	0.2	88.9	200,000,000	27.0
	Retention dams, bunds or sediment traps	2.4	-$384	0%	-98%	-88%	0%	0%	22%	$2,150	7.0	0.0	13.3	200,000,000	27.0
	Constructed wetlands*	2.3	-$23	0%	0%	-1%	0%	0%	17%	$2,131	7.0	0.0	13.2	200,000,000	27.0
	Vegetated buffer strips (for arable cropping)	2.2	-$381	-49%	-51%	-82%	0%	-5%	15%	$1,806	3.8	0.0	2.7	200,000,000	25.7
PLUC	Plantation forestry	2.1	-$2,815												
	Land retirement (permanent native forestry)	1.8	-$3,073												
M4	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	$1,701	3.8	0.0	2.7	200,000,000	25.7

Appendix 55: South Coastal Canterbury AVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ ha^{-1} yr^{-1}	N loss kg N ha^{-1} yr^{-1}	P loss kg P ha^{-1} yr^{-1}	TSS loss t km^{-2} yr^{-1}	*E. coli* loss E. coli ha^{-1} yr^{-1}	CH_4 kg CH_4 ha^{-1} yr^{-1}
Unmitigated										$1,914	16.0	0.1	329.5	200,000,000	19.3
Current										**$1,914**	**10.4**	**0.0**	**170.8**	**200,000,000**	**19.1**
M1	Minimum tillage	3.5	$223	-13%	0%	0%	0%	0%	79%	$1,961	10.1	0.0	170.8	200,000,000	19.1
	Riparian planting (incl. forestry)	3.1	-$73	-30%	-30%	-61%	0%	-1%	24%	$1,906	7.6	0.0	77.8	200,000,000	19.0
M2	Zero tillage	2.9	-$38	-10%	-50%	-25%	0%	0%	58%	$1,889	7.3	0.0	68.3	200,000,000	19.0
	Facilitated wetlands*	2.8	$0	0%	0%	0%	0%	0%	22%	$1,889	7.3	0.0	68.3	200,000,000	19.0
	Reduce N fertiliser use (below 190 kg N/ha)	2.5	$32	-19%	0%	0%	0%	0%	59%	$1,903	6.6	0.0	68.3	200,000,000	19.0
	Retention dams, bunds or sediment traps*	2.4	-$379	0%	-97%	-87%	0%	0%	22%	$1,608	6.6	0.0	10.9	200,000,000	19.0
	Constructed wetlands*	2.3	-$23	0%	0%	-1%	0%	0%	17%	$1,589	6.6	0.0	10.8	200,000,000	19.0
	Vegetated buffer strips (for arable cropping)	2.2	-$322	-49%	-51%	-82%	0%	-5%	15%	$1,314	3.6	0.0	2.2	200,000,000	18.2
PLUC	Plantation forestry	2.1	-$1,469												
	Land retirement (permanent native forestry)	1.8	-$1,727												
M4	Applying alum to pasture and crops 100%	1.0	-$105	0%	-20%	0%	0%	0%	0%	$1,209	3.6	0.0	2.2	200,000,000	18.2

Appendix 56: South Coastal Canterbury FRI1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$21,928	6.5	0.1	313.9	1,600,000,000	0.0
Current										**$21,928**	**6.0**	**0.1**	**267.6**	**1,600,000,000**	**0.0**
M1	Facilitated wetlands*	0.0	$0	0%	0%	0%	0%	0%	22%	$21,928	6.0	0.1	267.6	1,600,000,000	0.0
	Riparian planting (incl. forestry)	0.0	-$286	-30%	-30%	-61%	0%	0%	24%	$21,711	4.5	0.1	122.3	1,600,000,000	0.0
M2	Constructed wetlands*	0.0	-$27	0%	0%	-1%	0%	0%	17%	$21,689	4.5	0.1	121.5	1,600,000,000	0.0
PLUC	Plantation forestry	0.0	-$21,483												
	Land retirement (permanent native forestry)	0.0	-$21,741												

Appendix 57: South Coastal Canterbury EF1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$188	2.5	0.2	303.4	400,000,000	0.0
Current										**$188**	**2.5**	**0.2**	**288.2**	**373,333,333**	**0.0**
M1	Riparian planting (incl. forestry)	3.31	-$ 3	-1%	-10%	-15%	-20%	0%	33%	$186	2.5	0.2	257.8	320,000,000	0.0

Appendix 58: South Coastal Canterbury EF2 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$4	2.5	0.2	193.5	400,000,000	0.0
Current										**$4**	**2.4**	**0.2**	**180.6**	**400,000,000**	**0.0**
M1	Riparian planting (incl. forestry)	3.31	-$ 0	-10%	-15%	-20%	0%	0%	33%	$4	2.3	0.2	154.8	400,000,000	0.0

Appendix 59: South Coastal Canterbury LVL1 mitigation cost curve

Bundle	Mitigation	Preference score	Δ EM	Δ N	Δ P	ΔTSS	Δ *E. coli*	Δ CH_4	Current % rate of implementation	Margin $ $ha^{-1} yr^{-1}$	N loss kg N $ha^{-1} yr^{-1}$	P loss kg P $ha^{-1} yr^{-1}$	TSS loss t $km^{-2} yr^{-1}$	*E. coli* loss E. coli $ha^{-1} yr^{-1}$	CH_4 kg CH_4 $ha^{-1} yr^{-1}$
Unmitigated										$172	7.4	0.1	388.5	4,000,000,000	59
Current										**$172**	**6.4**	**0.1**	**238.0**	**2,625,722,222**	**58**
M1	Stream fencing	3.6	-$28	-13%	-15%	-70%	-58%	0%	38%	$155	5.9	0.1	96.8	1,409,333,333	58
	Facilitated wetlands*	3.1	$0	0%	0%	0%	0%	0%	27%	$155	5.9	0.1	96.8	1,409,333,333	58
	Riparian planting (incl. forestry)	3.1	-$76	-30%	-30%	-61%	-58%	-1%	28%	$100	4.5	0.1	45.5	705,600,000	58
M2	Constructed wetlands*	2.1	$0	0%	0%	0%	0%	0%	17%	$100	4.5	0.1	45.5	705,600,000	58
PLUC	Plantation forestry	2.0	$0												
	Land retirement (permanent native forestry)	1.9	$15												
M4	Applying alum to pasture and crops 100%	0.9	-$105	0%	-20%	0%	0%	0%	0%	-$5	4.5	0.0	45.5	705,600,000	58

10.5 Case study validation

Appendix 60: Cashflow forecast for case study Farm 1 for scenario N30 with no pre-existing debt [feasible]

Farm 1		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574	60,574
SBVL1		15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574	15,574
Operating surplus		**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**	**76,148**
less																					
Interest	5%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax	28%	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322	-21,322
Normal asset replacement		-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934
Wages of management		-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641
Annual cash surplus		**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**	**19,252**
Opening debt		0	19,252	38,504	57,756	77,007	96,259	115,511	134,763	154,015	173,267	192,518	211,770	231,022	250,274	269,526	288,778	308,029	327,281	346,533	365,785
Closing debt		19,252	38,504	57,756	77,007	96,259	115,511	134,763	154,015	173,267	192,518	211,770	231,022	250,274	269,526	288,778	308,029	327,281	346,533	365,785	385,037
Interest cover																					

Appendix 61: Cashflow forecast for case study Farm 2 for scenario N30 with no pre-existing debt [partially feasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387
SBL2		81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627	81,627
SBVL2		37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
EF2		-185,860	-15,441	-15,441	-15,441	-162,969	-15,441	84,622	-15,441	-231,816	-15,441	-15,441	1,077,918	-15,441	-15,441	-15,441	-15,441	841,775	-15,441	-15,441	-15,441
Operating surplus		**-63,210**	**107,208**	**107,208**	**107,208**	**-40,320**	**107,208**	**207,272**	**107,208**	**-109,166**	**107,208**	**107,208**	**1,200,568**	**107,208**	**107,208**	**107,208**	**107,208**	**964,425**	**107,208**	**107,208**	**107,208**
less																					
Interest	5%	-	-6,185	-4,688	-4,022	-3,332	-8,540	-7,401	-3,231	-2,513	-11,121	-9,342	-8,625	-	-	-	-	-	-	-	-
Tax	28%	-	-10,588	-28,706	-28,892	-	-15,405	-55,964	-29,114	-	-	-23,037	-333,744	-30,018	-30,018	-30,018	-30,018	-270,039	-30,018	-30,018	-30,018
Normal asset replacement		-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520
Wages of management		-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976	-42,976
Annual cash surplus		**-123,706**	**29,940**	**13,319**	**13,798**	**-104,148**	**22,768**	**83,411**	**14,368**	**-172,174**	**35,591**	**14,334**	**797,703**	**16,694**	**16,694**	**16,694**	**16,694**	**633,890**	**16,694**	**16,694**	**16,694**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-123,706**	**29,940**	**13,319**	**13,798**	**-104,148**	**22,768**	**83,411**	**14,368**	**-172,174**	**35,591**	**14,334**	**797,703**	**16,694**	**16,694**	**16,694**	**16,694**	**633,890**	**16,694**	**16,694**	**16,694**
Opening debt		0	-123,706	-93,766	-80,448	-66,650	-170,798	-148,030	-64,619	-50,251	-222,425	-186,834	-172,500	625,203	641,897	658,591	675,285	691,979	1,325,869	1,342,564	1,359,258
Closing debt		-123,706	-93,766	-80,448	-66,650	-170,798	-148,030	-64,619	-50,251	-222,425	-186,834	-172,500	625,203	641,897	658,591	675,285	691,979	1,325,869	1,342,564	1,359,258	1,375,952
Interest cover			17.3	22.9	26.7	-12.1	12.6	28.0	33.2	-43.4	9.6	11.5	139.2								

Appendix 62: Cashflow forecast for case study Farm 2 for scenario N30 with no pre-existing debt and phased land use change [feasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387	3,387
SBL2		111,175	109,619	108,064	106,509	104,954	103,399	101,844	100,289	98,733	97,178	95,623	94,068	92,513	90,958	89,403	87,847	86,292	84,737	83,182	81,627
SBVL2		37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
EF2		-9,293	-10,065	-10,837	-11,609	-19,758	-20,530	-16,299	-17,071	-28,661	-29,434	-30,206	23,690	22,918	22,146	21,374	20,602	62,691	61,919	61,147	60,375
Operating surplus		**142,904**	**140,577**	**138,250**	**135,923**	**126,219**	**123,892**	**126,568**	**124,241**	**111,095**	**108,768**	**106,440**	**158,781**	**156,454**	**154,127**	**151,800**	**149,472**	**190,006**	**187,679**	**185,351**	**183,024**
less																					
Interest	5%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax	28%	-40,013	-39,362	-38,710	-38,058	-35,341	-34,690	-35,439	-34,787	-31,107	-30,455	-29,803	-44,459	-43,807	-43,155	-42,504	-41,852	-53,202	-52,550	-51,898	-51,247
Normal asset replacement		-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520	-17,520
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**41,348**	**39,672**	**37,997**	**36,321**	**29,335**	**27,659**	**29,586**	**27,910**	**18,445**	**16,769**	**15,094**	**52,779**	**51,104**	**49,428**	**47,752**	**46,077**	**75,261**	**73,585**	**71,910**	**70,234**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**41,348**	**39,672**	**37,997**	**36,321**	**29,335**	**27,659**	**29,586**	**27,910**	**18,445**	**16,769**	**15,094**	**52,779**	**51,104**	**49,428**	**47,752**	**46,077**	**75,261**	**73,585**	**71,910**	**70,234**
Opening debt		0	41,348	81,020	119,017	155,338	184,673	212,332	241,917	269,827	288,272	305,042	320,135	372,915	424,018	473,446	521,199	567,275	642,536	716,122	788,031
Closing debt		41,348	81,020	119,017	155,338	184,673	212,332	241,917	269,827	288,272	305,042	320,135	372,915	424,018	473,446	521,199	567,275	642,536	716,122	788,031	858,266
Interest cover																					

Appendix 63: Cashflow forecast for case study Farm 3 for scenario N30 with no pre-existing debt [unfeasible]

Farm 3		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBH1		8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273	8,273
SBH2		2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161	2,161
EF2		-21,568	-2,634	-2,634	-2,634	-27,798	-2,634	14,434	-2,634	-39,541	-2,634	-2,634	183,862	-2,634	-2,634	-2,634	-2,634	143,582	-2,634	-2,634	-2,634
FRI1		1,591	528	6,829	13,131	19,432	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733	25,733
Operating surplus		**-9,544**	**8,327**	**14,629**	**20,930**	**2,067**	**33,533**	**50,601**	**33,533**	**-3,374**	**33,533**	**33,533**	**220,028**	**33,533**	**33,533**	**33,533**	**33,533**	**179,749**	**33,533**	**33,533**	**33,533**
less																					
Interest	5%	-	-6,130	-6,895	-7,389	-7,776	-8,937	-8,846	-8,218	-8,182	-9,634	-9,487	-9,497	-2,792	-2,561	-2,321	-2,072	-1,814	-	-	-
Tax	28%	-	-	-108	-3,792	-	-5,288	-11,691	-7,088	-	-3,456	-6,733	-58,949	-8,607	-8,672	-8,739	-8,809	-49,822	-9,389	-9,389	-9,389
Normal asset replacement		-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051
Wages of management		-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448
Annual cash surplus		**-27,042**	**-15,302**	**-9,874**	**-7,749**	**-23,208**	**1,809**	**12,564**	**728**	**-29,055**	**2,944**	**-186**	**134,084**	**4,634**	**4,801**	**4,974**	**5,153**	**110,614**	**6,645**	**6,645**	**6,645**
less																					
Capital required to fund land use change		-95,560	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-122,603**	**-15,302**	**-9,874**	**-7,749**	**-23,208**	**1,809**	**12,564**	**728**	**-29,055**	**2,944**	**-186**	**134,084**	**4,634**	**4,801**	**4,974**	**5,153**	**110,614**	**6,645**	**6,645**	**6,645**
Opening debt		0	-122,603	-137,904	-147,778	-155,527	-178,735	-176,926	-164,362	-163,635	-192,690	-189,746	-189,932	-55,849	-51,214	-46,413	-41,440	-36,287	74,327	80,972	87,616
Closing debt		-122,603	-137,904	-147,778	-155,527	-178,735	-176,926	-164,362	-163,635	-192,690	-189,746	-189,932	-55,849	-51,214	-46,413	-41,440	-36,287	74,327	80,972	87,616	94,261
Interest cover			1.4	2.1	2.8	0.3	3.8	5.7	4.1	-0.4	3.5	3.5	23.2	12.0	13.1	14.4	16.2	99.1			

Appendix 64: Cashflow forecast for case study Farm 1 for scenario CNmax with no pre-existing debt [partially feasible]

Farm 1		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF1		-104,226	-13,554	-13,554	-13,554	-143,053	-13,554	74,280	-13,554	-203,486	-13,554	-13,554	946,187	-13,554	-13,554	-13,554	-13,554	738,903	-13,554	-13,554	-13,554
FRI1		-132,063	64,702	836,916	1,609,130	2,381,344	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557	3,153,557
Operating surplus		**-236,289**	**51,148**	**823,362**	**1,595,576**	**2,238,291**	**3,140,003**	**3,227,838**	**3,140,003**	**2,950,072**	**3,140,003**	**3,140,003**	**4,099,744**	**3,140,003**	**3,140,003**	**3,140,003**	**3,140,003**	**3,892,460**	**3,140,003**	**3,140,003**	**3,140,003**
less																					
Interest	5%	-	-599,126	-628,304	-620,329	-578,750	-520,786	-428,273	-329,267	-229,859	-133,710	-27,263	-	-	-	-	-	-	-	-	-
Tax	28%	-	-	-	-108,091	-464,671	-733,381	-783,878	-787,006	-761,659	-841,762	-871,567	-1,147,928	-879,201	-879,201	-879,201	-879,201	-1,089,889	-879,201	-879,201	-879,201
Normal asset replacement		-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934	-12,934
Wages of management		-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641	-22,641
Annual cash surplus		**-271,864**	**-583,553**	**159,483**	**831,581**	**1,159,294**	**1,850,261**	**1,980,112**	**1,988,155**	**1,922,978**	**2,128,956**	**2,205,598**	**2,916,241**	**2,225,227**	**2,225,227**	**2,225,227**	**2,225,227**	**2,766,996**	**2,225,227**	**2,225,227**	**2,225,227**
less																					
Capital required to fund land use change		-11,710,655	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-11,982,519**	**-583,553**	**159,483**	**831,581**	**1,159,294**	**1,850,261**	**1,980,112**	**1,988,155**	**1,922,978**	**2,128,956**	**2,205,598**	**2,916,241**	**2,225,227**	**2,225,227**	**2,225,227**	**2,225,227**	**2,766,996**	**2,225,227**	**2,225,227**	**2,225,227**
Opening debt		0	-11,982,519	-12,566,072	-12,406,588	-11,575,008	-10,415,714	-8,565,452	-6,585,340	-4,597,185	-2,674,208	-545,252	1,660,346	4,576,587	6,801,814	9,027,041	11,252,269	13,477,496	16,244,492	18,469,719	20,694,946
Closing debt		-11,982,519	-12,566,072	-12,406,588	-11,575,008	-10,415,714	-8,565,452	-6,585,340	-4,597,185	-2,674,208	-545,252	1,660,346	4,576,587	6,801,814	9,027,041	11,252,269	13,477,496	16,244,492	18,469,719	20,694,946	22,920,173
Interest cover			0.1	1.3	2.6	3.9	6.0	7.5	9.5	12.8	23.5	115.2									

Appendix 65: Cashflow forecast for case study Farm 2 for scenario CNmax with no pre-existing debt [unfeasible]

Farm 2		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRI1		-6,547	3,208	41,491	79,774	118,057	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340	156,340
EF		-862,444	-71,816	-71,816	-71,816	-757,953	-71,816	393,568	-71,816	-1,078,151	-71,816	-71,816	5,013,287	-71,816	-71,816	-71,816	-71,816	3,915,009	-71,816	-71,816	-71,816
Operating surplus		**-868,991**	**-68,608**	**-30,325**	**7,958**	**-639,896**	**84,525**	**549,909**	**84,525**	**-921,810**	**84,525**	**84,525**	**5,169,627**	**84,525**	**84,525**	**84,525**	**84,525**	**4,071,349**	**84,525**	**84,525**	**84,525**
less																					
Interest	5%	-	-74,679	-84,045	-91,964	-98,366	-137,480	-142,329	-124,151	-128,334	-183,042	-190,169	-197,652	-	-	-	-	-	-	-	-
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-583,450	-23,667	-23,667	-23,667	-23,667	-1,139,978	-23,667	-23,667	-23,667
Normal asset replacement		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wages of management		-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024	-44,024
Annual cash surplus		**-913,015**	**-187,311**	**-158,393**	**-128,030**	**-782,285**	**-96,979**	**363,556**	**-83,650**	**-1,094,168**	**-142,541**	**-149,668**	**4,344,500**	**16,834**	**16,834**	**16,834**	**16,834**	**2,887,348**	**16,834**	**16,834**	**16,834**
less																					
Capital required to fund land use change		-580,566	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-1,493,580**	**-187,311**	**-158,393**	**-128,030**	**-782,285**	**-96,979**	**363,556**	**-83,650**	**-1,094,168**	**-142,541**	**-149,668**	**4,344,500**	**16,834**	**16,834**	**16,834**	**16,834**	**2,887,348**	**16,834**	**16,834**	**16,834**
Opening debt		0	-1,493,580	-1,680,891	-1,839,284	-1,967,314	-2,749,600	-2,846,579	-2,483,022	-2,566,673	-3,660,840	-3,803,382	-3,953,050	391,450	408,284	425,118	441,952	458,786	3,346,134	3,362,968	3,379,802
Closing debt		-1,493,580	-1,680,891	-1,839,284	-1,967,314	-2,749,600	-2,846,579	-2,483,022	-2,566,673	-3,660,840	-3,803,382	-3,953,050	391,450	408,284	425,118	441,952	458,786	3,346,134	3,362,968	3,379,802	3,396,636
Interest cover			-0.9	-0.4	0.1	-6.5	0.6	3.9	0.7	-7.2	0.5	0.4	26.2								

Appendix 66: Cashflow forecast for case study Farm 3 for scenario CNmax with no pre-existing debt [unfeasible]

Farm 3		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBH1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBH2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF		-43,268	-12,586	-12,586	-12,586	-132,838	-12,586	68,976	-12,586	-188,955	-12,586	-12,586	878,620	-12,586	-12,586	-12,586	-12,586	686,138	-12,586	-12,586	-12,586
Operating surplus		**-43,268**	**-12,586**	**-12,586**	**-12,586**	**-132,838**	**-12,586**	**68,976**	**-12,586**	**-188,955**	**-12,586**	**-12,586**	**878,620**	**-12,586**	**-12,586**	**-12,586**	**-12,586**	**686,138**	**-12,586**	**-12,586**	**-12,586**
less																					
Interest	5%	-	-3,038	-4,694	-6,433	-8,259	-16,189	-18,503	-16,854	-19,201	-30,484	-33,512	-36,692	-	-1,183	-2,746	-4,388	-6,112	-	-	-
Tax	28%	-	-	-	-	-	-	-	-	-	-	-	-84,160	-	-	-	-	-173,982	-	-	-
Normal asset replacement		-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051	-5,051
Wages of management		-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448	-12,448
Annual cash surplus		**-60,766**	**-33,124**	**-34,780**	**-36,519**	**-158,596**	**-46,274**	**32,974**	**-46,939**	**-225,655**	**-60,569**	**-63,598**	**740,269**	**-30,085**	**-31,268**	**-32,832**	**-34,473**	**488,545**	**-30,085**	**-30,085**	**-30,085**
less																					
Capital required to fund land use change		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-60,766**	**-33,124**	**-34,780**	**-36,519**	**-158,596**	**-46,274**	**32,974**	**-46,939**	**-225,655**	**-60,569**	**-63,598**	**740,269**	**-30,085**	**-31,268**	**-32,832**	**-34,473**	**488,545**	**-30,085**	**-30,085**	**-30,085**
Opening debt		0	-60,766	-93,890	-128,670	-165,188	-323,784	-370,058	-337,084	-384,024	-609,678	-670,248	-733,845	6,424	-23,661	-54,930	-87,761	-122,234	366,311	336,226	306,141
Closing debt		-60,766	-93,890	-128,670	-165,188	-323,784	-370,058	-337,084	-384,024	-609,678	-670,248	-733,845	6,424	-23,661	-54,930	-87,761	-122,234	366,311	336,226	306,141	276,055
Interest cover			-4.1	-2.7	-2.0	-16.1	-0.8	3.7	-0.7	-9.8	-0.4	-0.4	23.9		-10.6	-4.6	-2.9	112.3			

Appendix 67: Cashflow forecast for case study Farm 4 for scenario CNmax with no pre-existing debt [feasible]

Farm 4		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue																					
SBI1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBL2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBVL1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRI		-15,459	7,574	97,969	188,364	278,759	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153	369,153
VEI1		753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293	753,293
EF2		-534,925	-70,078	-70,078	-70,078	-739,610	-70,078	384,044	-70,078	-1,052,059	-70,078	-70,078	4,891,962	-70,078	-70,078	-70,078	-70,078	3,820,263	-70,078	-70,078	-70,078
Operating surplus		**202,908**	**690,789**	**781,184**	**871,579**	**292,441**	**1,052,368**	**1,506,490**	**1,052,368**	**70,387**	**1,052,368**	**1,052,368**	**6,014,408**	**1,052,368**	**1,052,368**	**1,052,368**	**1,052,368**	**4,942,709**	**1,052,368**	**1,052,368**	**1,052,368**
less																					
Interest	5%	-	-64,231	-44,587	-20,706	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tax	28%	-56,814	-173,799	-199,110	-224,420	-	-149,834	-529,349	-275,041	-	-173	-275,041	-3,053,783	-275,041	-275,041	-275,041	-275,041	-2,453,632	-275,041	-275,041	-275,041
Normal asset replacement		-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494	-24,494
Wages of management		-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379	-35,379
Annual cash surplus		**86,220**	**392,885**	**477,613**	**566,578**	**232,567**	**842,661**	**917,267**	**717,453**	**10,514**	**992,321**	**717,453**	**2,900,750**	**717,453**	**717,453**	**717,453**	**717,453**	**2,429,203**	**717,453**	**717,453**	**717,453**
less																					
Capital required to fund land use change		-1,370,842	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Net cash change		**-1,284,622**	**392,885**	**477,613**	**566,578**	**232,567**	**842,661**	**917,267**	**717,453**	**10,514**	**992,321**	**717,453**	**2,900,750**	**717,453**	**717,453**	**717,453**	**717,453**	**2,429,203**	**717,453**	**717,453**	**717,453**
Opening debt		0	-1,284,622	-891,737	-414,123	152,455	385,022	1,227,683	2,144,950	2,862,403	2,872,916	3,865,237	4,582,691	7,483,441	8,200,894	8,918,347	9,635,801	10,353,254	12,782,457	13,499,910	14,217,363
Closing debt		-1,284,622	-891,737	-414,123	152,455	385,022	1,227,683	2,144,950	2,862,403	2,872,916	3,865,237	4,582,691	7,483,441	8,200,894	8,918,347	9,635,801	10,353,254	12,782,457	13,499,910	14,217,363	14,934,816
Interest cover			10.8	17.5	42.1																

Appendix 68: Cashflow forecast for case study Farm 5 for scenario CNmax with no pre-existing debt [unfeasible]

Farm 5		1	2	3	4	5	6	7	8	9	10
Net enterprise revenue											
AL1		0	0	0	0	0	0	0	0	0	0
EF2		-557,875	-65,595	-65,595	-65,595	-692,299	-65,595	359,477	-65,595	-984,760	-65,595
FRI1		0	0	0	0	0	0	0	0	0	0
Operating surplus		**-557,875**	**-65,595**	**-65,595**	**-65,595**	**-692,299**	**-65,595**	**359,477**	**-65,595**	**-984,760**	**-65,595**
less											
Interest	5%	-83,561	-119,181	-129,382	-139,950	-150,899	-184,803	-197,366	-195,079	-208,012	-254,501
Tax	28%	-	51,737-	54,594-	57,553-	236,095-	70,111-	-45,391	72,989-	333,976-	89,627-
Normal asset replacement		-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322
Wages of management		-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657
Annual cash surplus		**-712,414**	**-204,018**	**-211,362**	**-218,971**	**-678,081**	**-251,265**	**45,741**	**-258,664**	**-929,775**	**-301,448**
less											
Capital required to fund land use change		-									
Net cash change		**-712,414**	**-204,018**	**-211,362**	**-218,971**	**-678,081**	**-251,265**	**45,741**	**-258,664**	**-929,775**	**-301,448**
Opening debt		-1,671,210	-2,383,624	-2,587,642	-2,799,004	-3,017,976	-3,696,057	-3,947,322	-3,901,581	-4,160,245	-5,090,020
Closing debt		-2,383,624	-2,587,642	-2,799,004	-3,017,976	-3,696,057	-3,947,322	-3,901,581	-4,160,245	-5,090,020	-5,391,468
Interest cover		-6.7	-0.6	-0.5	-0.5	-4.6	-0.4	1.8	-0.3	-4.7	-0.3

Farm 5	11	12	13	14	15	16	17	18	19	20
Net enterprise revenue										
AL1	0	0	0	0	0	0	0	0	0	0
EF2	-65,595	4,579,032	-65,595	-65,595	-65,595	-65,595	3,575,888	-65,595	-65,595	-65,595
FRI1	0	0	0	0	0	0	0	0	0	0
Operating surplus	**-65,595**	**4,579,032**	**-65,595**	**-65,595**	**-65,595**	**-65,595**	**3,575,888**	**-65,595**	**-65,595**	**-65,595**
less										
Interest	-269,573	-285,188	-134,159	-144,899	-156,026	-167,553	-179,495	-60,774	-68,872	-77,262
Tax	93,847-	-1,202,276	55,931-	58,938-	62,054-	65,281-	-950,990	35,383-	37,651-	40,000-
Normal asset replacement	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322	-26,322
Wages of management	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657	-44,657
Annual cash surplus	**-312,300**	**3,020,588**	**-214,802**	**-222,535**	**-230,546**	**-238,845**	**2,374,424**	**-161,965**	**-167,795**	**-173,836**
less										
Capital required to fund land use change										
Net cash change	**-312,300**	**3,020,588**	**-214,802**	**-222,535**	**-230,546**	**-238,845**	**2,374,424**	**-161,965**	**-167,795**	**-173,836**
Opening debt	-5,391,468	-5,703,768	-2,683,180	-2,897,982	-3,120,516	-3,351,062	-3,589,908	-1,215,484	-1,377,448	-1,545,244
Closing debt	-5,703,768	-2,683,180	-2,897,982	-3,120,516	-3,351,062	-3,589,908	-1,215,484	-1,377,448	-1,545,244	-1,719,080
Interest cover	-0.2	16.1	-0.5	-0.5	-0.4	-0.4	19.9	-1.1	-1.0	-0.8