Healthy Rivers PLAN FOR CHANGE | Wai Ora HE RAUTAKI WHAKAPAIPAI

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Economic evaluation of scenarios for water-quality improvement in the Waikato and Waipa River catchments

Assessment of first set of scenarios
24 August 2015

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1. Introduction

1.1 Purpose

The Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai (HRWO) project will establish targets and limits for nutrients (nitrogen and phosphorus), sediment, and *E. coli* in water bodies across the Waikato and Waipa catchments.

As part of the process of establishing targets and limits, the Collaborative Stakeholder Group (CSG) has asked for a technical assessment of four initial scenarios. These initial scenarios are associated with a diverse set of goals for water-quality improvement (Table 1), and were purposely developed by the CSG to help them to explore a wide range of 'possible futures' and timeframes to achieve them.

The purpose of this report is to describe outputs from a predictive-modelling approach that aimed to identify the economic implications of altering land and point-source management to achieve the water-quality limits proposed for each of these scenarios. The modelling approach used sought to predict the economic implications of these scenarios at the farm, catchment, regional, and national scales.

The economic model utilised in this report represents a key contribution of the Technical Leaders Group (TLG) to the CSG's deliberations, given that it integrates diverse information generated from a broad array of technical work streams that the TLG has initiated and managed. Economic modelling is an important input to the CSG deliberation process, to describe 'plausible futures' and so support deliberations leading to policy-development decisions.

1.2 Background

The initial set of scenarios ('possible futures') developed by the CSG for evaluation are presented in Table 1 and can be summarised as follows:

- Scenario One: Substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This involves an improvement in water quality everywhere, even if it is already meeting the minimum acceptable state.

- Scenario Two: No further degradation in water quality, and improvements to at least minimum acceptable state.
- Scenario Three: Some general improvement in water quality for swimming, taking food, and healthy biodiversity, even though this may not reach the minimum acceptable state everywhere.
- Scenario Four: No further degradation in current water quality, in spite of projected extra contaminant loads (i.e. the nitrogen load-to-come) emerging from groundwater.

The four scenarios differ strongly in terms of the level of improvement required across a set of water-quality attributes and the sites at which these improvements must be observed. The water-quality attribute set agreed to by the CSG includes:

- Chlorophyll *a* (median and maximum),
- Total Nitrogen,
- Total Phosphorus,
- Nitrate (median and 95th percentile),
- *E. coli* (median and 95th percentile),
- Water clarity, and
- Ammonia.

The ammonia attribute has not been able to be accurately modelled in the available time, so is currently excluded from this analysis.

Following this introduction, Section 2 describes the model structure, while Section 3 presents the results of the catchment-level model and associated discussion. Section 4 then presents the predicted regional and national economic effects of the scenarios, while Section 5 concludes.

Table 1. The four water-quality scenarios proposed by the Collaborative Stakeholder Group during the CSG12 workshop, and accepted by the HRWO sub-committee.

Scenario description	Attributes			
	E. coli	**Clarity**	**Algae (Chlorophyll *a*)**	**Nutrients**
SCENARIO ONE: Substantial improvement in water quality for swimming, taking food, and healthy biodiversity				
Substantial improvement in water quality for swimming, taking food, and healthy biodiversity. This means: Swimmable in all seasons for microbes and clarity. Water quality supports ecological health. Some improvement in all parameters. [Represents CSG suggestion of *E. coli* to B, TP to minimum B, all others up one band – 'Restore']	Upper Waikato: Main stem remains A. Tributaries min B at 95% percentile (95%ile) Middle Waikato: Main stem A at Narrows at 95%ile; Horotiu and tributaries B Lower Waikato and Waipa: Main stem and tributaries B at 95%ile	Upper Waikato: Main stem A to Waipapa, tributaries go up 1 band Middle Waikato: Main stem B, tributaries go up 1 band Waipa: Upper stem B, lower stem C, tributaries go up 1 band Lower Waikato: C in main stem and tributaries	Upper Waikato: A sites improve. B sites to A, C sites to B. Middle Waikato: B for median, A for max. Lower Waikato: B for median and max; Huntly moves to B for med and A for max.	Total Phosphorus: Maintain where already A, raise to B for rest of river. Total Nitrogen: Improve where already A, all sites to Waipapa to A, rest of river to B. Ammonia and nitrate: Improve where already A, other sites go up 1 band.
SCENARIO TWO: No further degradation and improving sites to at least minimum acceptable standard for all attributes.				
No further degradation and improving to at least minimum acceptable standard for all attributes. This means: No degradation where currently A, B, or C band. Focus on lifting any D to C; lift *E. coli* to above maximum acceptable standard (MAS) for swimming throughout. ['Protect' + least 'restoring' to reach minimum acceptable standard for all attributes]	No further degradation at any site, and minimum of: Upper Waikato: Raise all tributaries to B at 95%ile. Middle Waikato: Raise Horotiu and all tributaries to B at 95%ile. Lower Waikato: Raise main stem and all tributaries to B at 95%ile.	No further degradation at any site, and minimum of C throughout: Upper Waikato: Main stem B, tributaries C Middle Waikato: Main stem and tributaries C Waipa: Maintain where currently B or C, and lift to C where currently D.	No further degradation at any site.	Total Phosphorus: Maintain where already an A, B, or C; lift Lower river to C. Total Nitrogen: No further degradation Nitrate N: No further degradation Ammonia: No further degradation

Scenario description	Attributes			
	E. coli	**Clarity**	**Algae (Chlorophyll *a*)**	**Nutrients**
	Waipa: Raise main stem and all tributaries to B at 95%ile.	Lower Waikato: Raise main stem and all tributaries to C		
SCENARIO THREE: Some general improvement in water quality for swimming, taking food, and healthy biodiversity.				
Some general improvement in water quality for swimming, taking food, and healthy biodiversity. This means: Some improvement across all attributes. Main stem suitable for swimming in Upper and Middle river, and in parts of Waipa but not Lower river. Lower, middle, and some Waipa river tributaries wadeable, but may not reach swimmable (B at 95%ile). [‘Protect’ + some ‘restoring’ but not fully swimmable]	Upper Waikato: Tributaries B at 95%ile Middle Waikato: Narrows stays at A 95%ile Horotiu gets to B at 95%ile Tributaries B at median but may not be B at 95%ile Lower Waikato: Tributaries min B at median. Main stem may not be B 95%ile. Waipa: Tributaries A at median, some are B at 95%ile.	No further degradation at any site, and minimum of: Upper Waikato: Main stem B, all tributaries C Middle Waikato: Main stem B, all tributaries C Waipa and Lower Waikato: Main stem and all tributaries C	Upper Waikato: B, with no further degradation of A sites Middle Waikato: B for median and maximum Lower Waikato: C but no degradation at Huntly (currently a B for maximum).	Total Phosphorus: Maintain where already an A or B Lift C sites in Upper and Middle to B and lift Lower river to C. Total Nitrogen: No further degradation; lift to a B for Middle river. Nitrate N: Lift C sites to a B. Ammonia: Lift median to a B.
SCENARIO FOUR: No further degradation in spite of lags.				
No further degradation, in spite of lags. Means: No drop in current water quality, in spite of projected extra nitrate load currently in groundwater. [‘Protect’ but not ‘restore’]	All sites: Current state maintained throughout with no further degradation.			

2. Catchment-level modelling methods

2.1 The economic modelling approach

This section describes the economic modelling approach used to evaluate the four scenarios. The model is an optimisation model–that is, it determines the least-cost combination of mitigation measures (land management, land-use changes, and point-source treatments) required to meet the water-quality attribute limits set for each scenario. An iterative process is used to identify how different mitigations could be implemented to minimise the cost associated with achieving a given limit (Gill et al., 1981). The term "optimisation" conveys how the iterative process seeks to *minimise* the cost of a change, and contrasts a simulation approach in which a model user evaluates different scenarios involving pre-defined management activities across the landscape of interest. This particular optimisation model uses a method known as mathematical programming (Bazaraa et al., 2006).

A computational economic model is essentially a collection of equations and decision variables that seek to describe some part of a complex reality. A decision variable in an optimisation model is a term that is identified by a model during its solution, while equations are pre-defined and outline the logic that the decision variables must obey. A key type of equation utilised in the form of mathematical modelling that is utilised in this study (mathematical programming) is a constraint. These constraints can define key relationships (i.e. a relational constraint), or can be used to restrict the level of certain decision variables (i.e. a limit). A key relationship used in the economic model applied here are limit constraints defining the bounds for given contaminants at different sites within the catchment. To describe a complex reality within a mathematical model, it is necessary to formulate various assumptions that permit practitioners to develop an understanding of the relationships between certain key levers. Without these assumptions, it is difficult to formulate such an understanding. The key assumptions underlying the economic model utilised here have now been peer-reviewed by leading national and international experts.

2.2 Model structure and optimisation

The model structure is loosely based on that of the Land Allocation and Management (LAM) catchment framework (Doole, 2012, 2015). The flexibility of this model is demonstrated in its broad utilisation across a number of nonpoint-pollution contexts, both nationally (Doole, 2013; Howard et al., 2013; Holland and Doole, 2014) and internationally (Beverly et al., 2013; Doole et al., 2013). Key benefits associated with the application of the LAM framework are (Doole, 2015):

1. Its flexible structure allows it to be broadly adapted to diverse circumstances (such as the diverse scenarios outlined in Table 1).
2. The complexity of the model can be altered, depending on the quality and quantity of resources available.
3. The model can be efficiently coded in popular nonlinear-optimisation software, such as the General Algebraic Modelling System (GAMS) (Brooke et al., 2014), that allows matrix generation.
4. The structure of the model allows the use of a broad range of calibration techniques.
5. Models of substantial size can be constructed (Doole, 2010).

The flexibility of the modelling structure has been particularly critical, as the model utilised in this study contains broadly-diverse relationships between land use, land management, contaminant loss, mitigation activity, pollutant attenuation, groundwater flows of nitrogen, and links between loads and concentrations.

Key mitigation costs included in the model are those associated with stream fencing, upgrading of effluent management on dairy farms, soil conservation, enhanced point-source treatment, transition costs associated with the replacement of one type of farming activity with another, and edge-of-field mitigations.[1] The efficacy of these mitigations and their costs has been gathered from a variety of literature sources, individual experts, and expert-panel workshops convened by the TLG.

Alongside these costs associated with mitigation, costs may also accrue through a decrease in farm profit associated with the de-intensification of a current land use or transition into a new land use. Changes to farm profit associated with different mitigation activities are computed using FARMAX for pastoral enterprises, partial budgeting for horticultural enterprises, and

[1] Examples of edge-of-field mitigations include bunds, sediment traps, and wetlands.

the Forest Investment Finder (FIF) for plantation forest. Inputs have been developed through interaction with technical experts within these sectors and industry organisations.

Figure 1 sets out the broad structure of the HRWO model. The LAM framework is characterised by delineation of the catchment into a number of partitions. The HRWO model involves:

1. Partitioning of the catchment into the four Freshwater Management Units (FMUs) agreed to by the CSG. These are Upper Waikato (Taupo Gates to Karapiro), Middle Waikato (Karapiro to Ngaruawahia), Lower Waikato (Ngaruawahia to Port Waikato), and Waipa. The area contained within the Shallow-Lakes FMU is included in the model, but is not studied independent of the others in this report.
2. Further partitioning of the area within each FMU into sub-catchments, many associated with their own monitoring site for a set of water-quality attributes.
3. Additional division of these 74 sub-catchments within the catchment into zones that represent farming systems of a consistent type (in terms of contaminant loss).

The information utilised in Step 3 was based initially on that generated by the Economic Impact Joint Venture (EIJV) program of work that preceded the HRWO process. Nonetheless, the information generated by the EIJV was mainly focused on the dynamics of nitrogen leaching. Thus, a key focus of subsequent work within the HRWO process has been the extension of the EIJV economic model to consider the loss and mitigation of phosphorus, sediment, and *E. coli*.

A key addition to the EIJV economic model has also been the integration of diverse hydrological/water quality models that relate contaminant losses within and across sub-catchments to pollutant concentrations at the various monitoring sites represented within the catchment. These models concern *E. coli* (Semadeni-Davies et al., 2015a), sediment (Yalden and Elliott, 2015), nitrogen (Semadeni-Davies et al., 2015b), and phosphorus (Semadeni-Davies et al., 2015b). The integration of these models into the economic model allows the depiction of explicit relationships between land management, point-source management, and concentrations of chlorophyll *a*, Total Nitrogen, Total Phosphorus, nitrate, *E. coli*, and black disc measurements at different sites across the catchment.

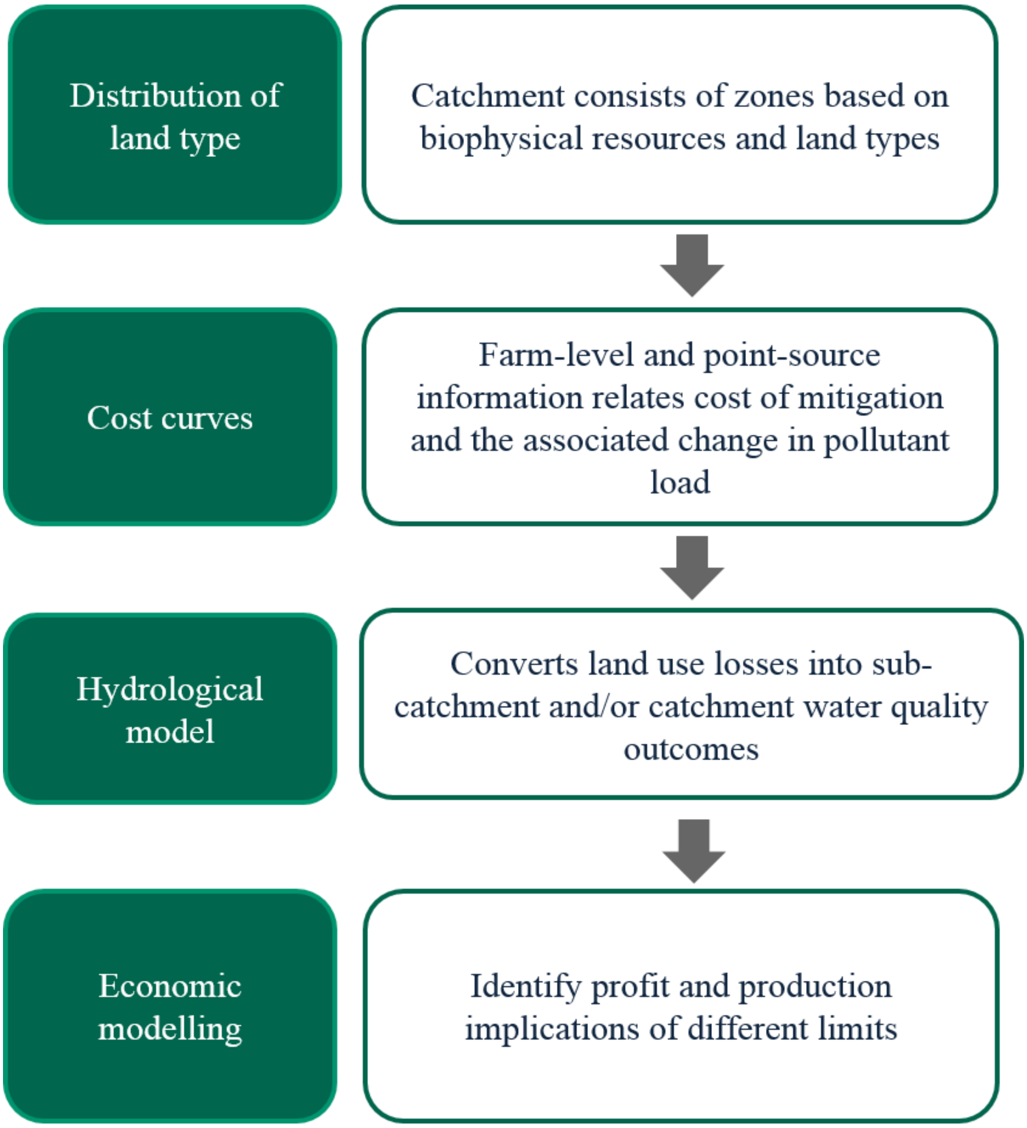
A key feature of these hydrological/water quality models are estimated fate matrices, which specify the flow and attenuation of contaminants between linked sites in the monitoring network. Various limits are evaluated in the scenarios through specifying the attribute concentrations that meet the scenario's desired band for median concentrations of chlorophyll-a, maximum concentrations of chlorophyll-a, Total Nitrogen concentration, Total Phosphorus concentration, median nitrate concentration, 95^{th} percentile nitrate concentration, median *E. coli* concentration, 95^{th} percentile *E. coli* concentration, and water clarity. The economic model then identifies the given set of mitigations, out of all of those sets that could be employed, required across the landscape to achieve these limits at least cost. Other objectives could be utilised to select the most-suitable management plan. However, using cost as a measure of the suitability of alternative management plans is commonplace (Daigneault et al., 2012; Doole, 2013) because of the central importance of societal cost when designing environmental policy (Hanley et al., 2007).

In keeping with standard practice (e.g. Hanley et al., 2007; Doole, 2010; Daigneault et al., 2012), the time path of adaptation is not included in the model, because:

1. The scarcity of data related to many relationships represented in the model is compounded when variation over time in key drivers of management behaviour (e.g. output price, input price, productivity, climate, innovation) is high and difficult to predict. An example is attempting to predict milk-price variation over the next few years, and how this influences mitigation costs for dairy farmers and related industries.
2. Dynamic models are difficult to develop and utilise because of their significant size and information demands (Doole and Pannell, 2008).
3. Output from intertemporal models is heavily biased by the starting and endpoint conditions defined during model formulation (Klein-Haneveld and Stegeman, 2005).

Overall, these issues provide a strong justification for the employment of a steady-state modelling framework. In terms of the process here, the CSG might choose to consider the scenarios they have developed as alternative outcomes along a timeline of change.

Figure 1. Basic conceptual structure of the catchment-level economic model applied in the study.

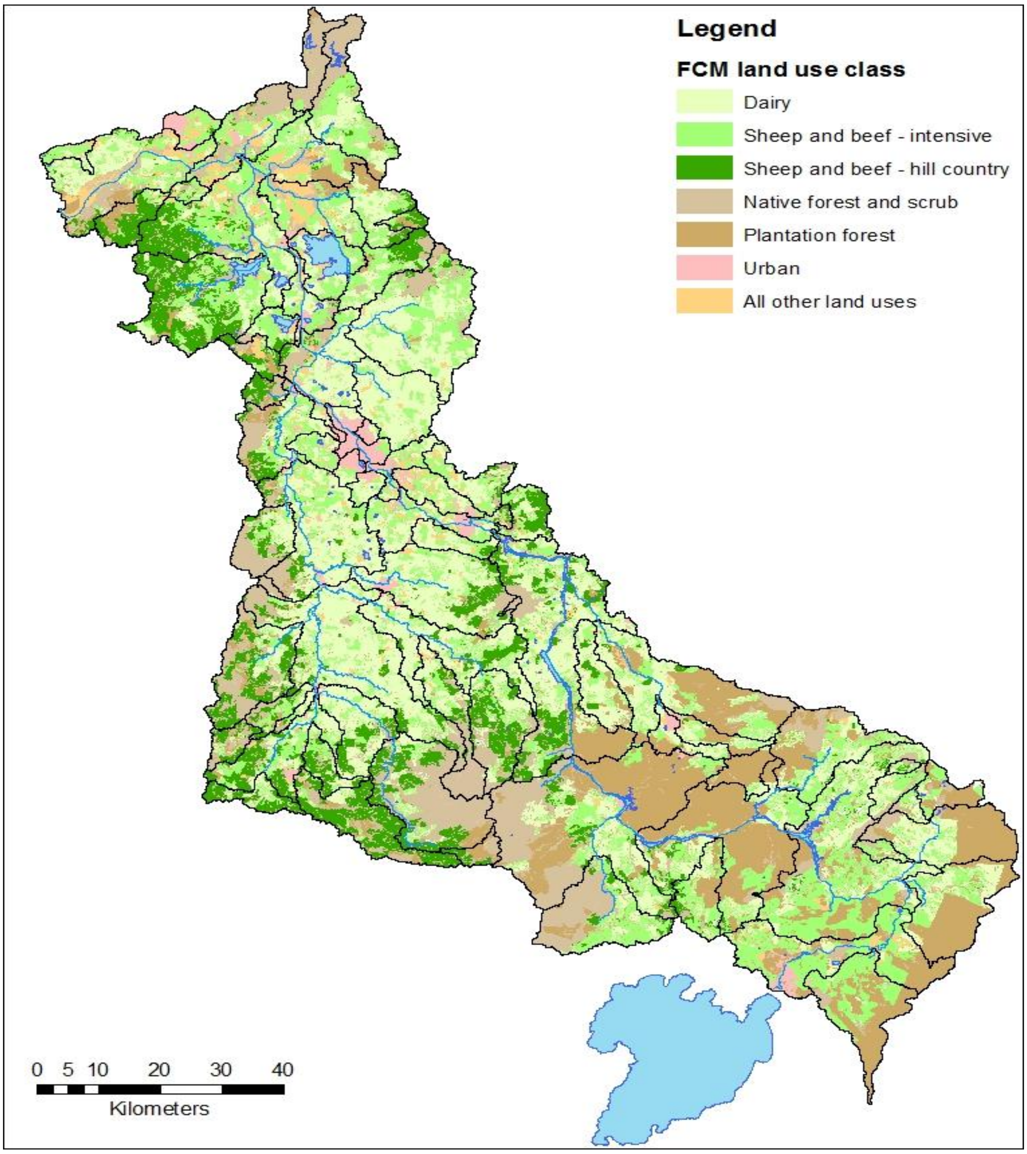


2.3 Application of the economic model

The chief land uses in the study region are presented in Figure 2. The high spatial diversity of land use highlights the difficulty of addressing the multiple-contaminant loads emanating from these areas. This is further emphasised when diversity in land management within individual sectors is considered (Doole, 2012).

The modelling application involves an analysis of 74 sub-catchments, which are further disaggregated into representative farms for dairy, dairy support, drystock, and horticulture sectors according to the characteristics of land and land management within these zones. Furthermore, 24 point sources are represented across the catchment, consisting of both industrial and municipal sources. Data on point source loadings was obtained from Vant (2014) and on costs of point source abatement from OPUS International Consultants (2013), modified following further consultation with the dischargers (Blair Keenan Waikato Regional Council). The economic and environmental characteristics of plantation forest across the entire catchment are estimated utilising information from Scion, expert opinion, and past studies.

Figure 2. Distribution of the primary land uses in the Waipa and Waikato River catchments. Horticulture and miscellaneous land use classes have been amalgamated for display, though the economic importance of the horticultural sector is explicitly recognised.



The number of representative farms contained within a catchment-level economic model can, in principle, range from a single farm representing the entire catchment to representing each specific farm individually (Doole and Pannell, 2012). Realistically, a shortage of data of a sufficient quality and quantity restricts our capacity to represent individual farms with any precision (Doole, 2012); this is particularly problematic in New Zealand due to confidentiality restrictions. Aggregation into representative farms is a pragmatic 'half-way house' that is likely to introduce some prediction error, in terms of estimating both contaminant losses and mitigation costs. However, larger errors can often accompany representations of individual farms, given a paucity of data available at that scale. Moreover, it removes the ability to study the movement of contaminants across the catchment, as the subsequent model is sufficiently large and unwieldy that the complexities involved with attenuation relationships and flow paths cannot be considered. Additional justifications are that the model becomes more difficult to interpret (Holland and Doole, 2014), while there is also the fact that mean trends remain the most-relevant anyway, since trends for farms on one side of the average offset the impact of those on the other (Doole, 2012). Issues of spatial aggregation and scale are common in natural-resource modelling approaches of this kind, and it is important to remain cognisant of its advantages and disadvantages when interpreting the outputs.

The model uses historical land-use patterns to constrain land-use changes to realistic levels. This approach was deemed appropriate in this application because it is straightforward to code, much easier to formulate and less prone to error than forcing calibration through the use of arbitrary calibration functions (Doole and Marsh, 2014), draws on regionally-specific data, and is the only land-use calibration method that has a rich theoretical justification (Onal and McCarl, 1991; Chen and Onal, 2012). Historic land-use patterns observed for a distinct region (i.e. sub-catchment) provide specific insight into the type of land-use change that can occur there. Indeed, these patterns provide spatial information regarding the implicit aggregate and biophysical factors that guide land-use change within this area. Using this historical information within the catchment model applied here allows the specification of a well-behaved aggregate model, despite lacking data for individual farms (Onal and McCarl, 1991; Chen and Onal, 2012). To use this approach, historic land use for each sub-catchment across 1972–2012 was drawn from the work of Hudson et al. (2015). The optimisation procedure then identified the best weighted average of these land-use patterns that attained the environmental limits set out by each scenario at least cost. Some economic models allow land use to change without constraint; this is done below to provide an alternative viewpoint, but also provides a highly-optimistic picture with regards to how quickly land-use change will occur in reality.

Sometimes, it is possible that environmental limits cannot be met. For example, model output presented below shows that this is particularly relevant to sites where 95^{th} percentile *E. coli* loadings are highest in the catchment. Normally, such violations will cause infeasibility of a mathematical-programming model, as there is no way that all limits can be met subject to the other relationships within the model remaining satisfied. To prevent such disruption to solution of the model, the limits defined within each scenario are formulated as soft constraints through the use of elastic programming (Gill et al., 2005).

Some mitigation practices involve the establishment of enduring assets; for example, the development of stand-off pads or riparian fences. The inclusion of their establishment costs as a lump sum would bias cost estimation. Therefore, according to standard practice (e.g. Howard et al., 2013), capital costs are converted to annual equivalent payments at an interest rate of 8% over a payback period of 25 years. Maintenance costs for these assets have also been considered. Forest profits have been annualised and it is important to recognise that, in reality, the returns associated with this activity will only be borne after harvest when trees are 28 years of age.

The model is used to evaluate five scenarios, the four scenarios outlined in Table 1 plus the baseline. The baseline is the current situation, with land use fixed at its current activity, mitigation use held at its current level, and the concentration of contaminants in the water being equivalent to their current magnitude. Within the model runs for scenarios 1–4, land-use change and mitigation use are left free, with their values determined by the model during its solution. As described above, land-use change is constrained to lie within the range observed over the last forty years in each sub-catchment in the main runs conducted with the model. Hereafter, this is referred to as the *constrained land-use change* scenario. However, model experiments have been performed in which land-use change is unconstrained. Some preliminary results of this work are also presented below, but ultimately it is up to the CSG to decide how much further attention is paid to this line of inquiry.

3. Results and Discussion

3.1 Output for the constrained land-use change scenario

Table 2 outlines differences in catchment-level profit across the five different scenarios. “Sector profit” identifies the amount of profit accruing to each industry as defined across each representative farm, while the “Costs” output outlines the cost of additional mitigation activity that is necessary to apply across the catchment to reach the water-quality goals associated with each scenario. Thus, the “Sector profit” fields primarily represent mitigation costs associated with de-intensification on existing farms, the use of stand-off pads on dairy farms, and land-use change. The values reported in Table 2 are the annual recurring levels of profit and cost associated with each scenario. Costs are represented as bracketed terms. For example, total annual profit in the dairy sector at the farm level is predicted to be $618m at current state, relative to $452m in scenario 1. Likewise, additional stream fencing will impose an ongoing annual cost of $8m in scenario 1. (This output for stream fencing represents one example of how capital costs have been annualised for mitigation that involves enduring assets.) The information is presented so that less-aspirational goals for water-quality improvement are realised as we move further to the right.

Table 2 does not consider the flow-on impacts associated with changes in catchment-level profit. For example, less money coming into a community because of reduced milk production can mean less income for services in the local town because farmers have less money to spend there. These impacts are not considered in Table 2; they are presented later in the report (Section 4) in the regional- and national-level analysis. Moreover, the social impacts of these changes are not considered. Rather, they are the focus of the integrated-assessment work that is ongoing.

Table 2 shows that the total catchment profit accruing to each scenario declines as we move from right to left; that is, as the limits placed on water quality become more stringent. Indeed, catchment total profit decreases from the current state by 51%, 35%, 25%, and 2% for scenarios 1, 2, 3, and 4, respectively.

Costs are distributed broadly across the sectors. Dairy production is by far the most-important agricultural activity within the region from an economic perspective, constituting around two-thirds of catchment profit. However, it bears significant costs as limits become more stringent. For example, dairy profit falls by 16% in scenario 3 and 27% in scenario 1. Drystock profit falls by around 15% as we move from scenario 2 to scenario 1, while the horticultural sector becomes highly unprofitable under the most-restrictive case (scenario 1).

Table 2. Catchment-level profit for each scenario with constrained land-use change. Bracketed terms constitute costs.

Variable	**Units**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**	**Current state**

Sector profit						
Dairy	$m	452.39	509.11	517.27	581.26	617.53
Drystock	$m	181.46	213.24	212.41	218.70	210.15
Horticulture	$m	(15.05)	28.26	19.88	28.79	28.21
Forest	$m	64.98	64.98	65.24	63.11	58.86
Land use transition	$m	21.32	21.27	20.98	17.38	0
Costs						
Stream fencing	$m	(8.31)	(9.75)	(6.64)	(0.12)	0
Effluent update	$m	(2.16)	(1.38)	(1.38)	0	0
Soil conservation	$m	(41.2)	(29.07)	(31.27)	0	0
Erosion plans (horticulture)	$m	(0.17)	(0.1)	(0.08)	0	0
Point source	$m	(137.77)	(137.77)	(46.39)	(1.34)	0
Edge-of-field	$m	(70.23)	(65.87)	(66.57)	(8.65)	0
Total profit	*$m*	*445.24*	*592.92*	*683.46*	*899.14*	*914.76*
Loss in profit	*$m*	*(469.52)*	*(321.84)*	*(231.3)*	*(15.62)*	-
Loss in profit	*%*	*-51*	*-35*	*-25*	*-2*	-

Overall, there is steady investment in mitigation activity as water-quality limits become more binding. Notable outcomes are significant investment in farm plans for sediment control, point-source mitigation, and the use of edge-of-field mitigations (e.g. bunds, sediment traps, and wetlands). The line item for land-use transition represents the explicit revenues and costs associated with the transition; these have been annualised so that they are comparable with the other values considered. Examples of revenues are the sale of processor shares and cows when dairy farms are converted to forest or drystock enterprises. An example of a cost is the construction of a woolshed when converting from dairy farming to drystock production. This line item for land-use transition does not consider the ongoing gain or loss in profit from either land-use involved in the transition, this is captured in the other sector-profit line items.

Profits from land-use transition are positive overall in each scenario in Table 2, denoting a net benefit from land conversion in each case.

Interestingly, there are a few cases where costs *decrease* moving from one scenario to one that is meant to be more restrictive. For example, stream fencing increases in cost from $8m to $10m going from scenario 1 to scenario 2. Such results are expected given that the severity of limits varies spatially across the catchment in many scenarios, mitigations have benefits for multiple contaminants, and the efficacy of mitigations varies across space.

Table 3 presents the land-use allocation associated with each scenario. Land-use change occurs on around 3–4% of total catchment area, with the loss of dairy land and gains in drystock and forestry land allocation being the main trends. The highest loss in dairy land is around 7%, while the highest loss in dairy profit (refer Table 2) is 27%. This demonstrates that model output is recognising a strong need to de-intensify production on dairy farms, alongside reducing the amount of land allocated to this enterprise itself. Afforestation of dairy land is highest in scenario 4, given the need to de-intensify production in dairy farming to address the load of nitrogen in groundwater arising from past intensification. Horticultural activity is highly unprofitable in scenario 1 (Table 2); yet, land-use change in this enterprise is modest (around 100 ha). This rigidity in land use is arising from constraints defined according to historical land-use patterns, and identifies that land-use patterns will likely have to change significantly from those observed historically if substantial losses in the primary sector are to be avoided. The distributional impacts of removing these land-use constraints is explored in Section 3.2.

Table 3. Catchment-level land-use allocation for each scenario with constrained land-use change. These values represent the level of one-off land-use transition and not annual expectations.

Variable	Units	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Current state
Dairy	Ha	286,774	286,833	287,524	291,634	308,008
Drystock	Ha	374,854	374,799	373,444	374,834	370,355
Horticulture	Ha	6,010	6,009	6,027	5,951	6,103
Forest	Ha	186,308	186,305	186,950	181,525	169,478

Total	*Ha*	*853,945*	*853,945*	*853,945*	*853,945*	*853,945*
Dairy to drystock	Ha	15,656	15,596	14,266	8,534	0
Dairy to forest	Ha	5,579	5,579	6,218	7,839	0
Drystock to forest	Ha	11,251	11,248	11,254	4,208	0
Horticulture to drystock	Ha	93	95	77	152	0
Total conversion	*Ha*	*32,579*	*32,518*	*31,815*	*20,733*	*0*
Change in land area	*%*	*4*	*4*	*4*	*2*	*0*

Table 4 outlines the change in production with each scenario. Dairy production decreases by up to a fifth (Table 4), imposing a high economic cost on farmers themselves (Table 2). Additionally, this has significant implications at the regional level (Section 4), given the central importance of dairy farming as a driver of secondary economic activity in the Waikato region. In contrast, drystock and timber outputs experience slight movements up or down, reflecting slight changes in land use and de-intensification. The most-significant impact is on horticultural crops that decrease by around 43% in the scenario 1 output in Table 4, aside from there being much less impact of limits on production in this sector in the other scenarios.

Table 4. Catchment-level production for each scenario with constrained land-use change.

Variable	**Units**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**	**Current state**
Milk solids	t	194,512	223,155	223,655	231,068	248,699
Wool	t	7,439	7,983	7,933	8,284	7,224
Mutton	t	16,381	18,204	18,058	18,724	15,194
Lamb	t	11,503	11,413	11,403	12,284	12,334
Beef	t	24,064	25,153	25,009	23,944	26,059
Bull beef	t	14,407	15,091	15,040	15,366	15,777
Hort. crops	t	142,310	245,674	225,058	240,766	251,452

S1 logs	M m^3	20	20	20	20	18
S2 logs	M m^3	54	54	54	52	49
S3 logs	M m^3	57	57	57	55	52
Pulp	M m^3	37	37	37	36	33
Waste	M m^3	3	3	3	2	2

Table 5 outlines the different extents to which mitigation practices are employed within the model across the scenarios. There is broad diversity in the level of implementation of each strategy, given differences in their relative cost-effectiveness and the comparative importance of the different water-quality attributes within each specific scenario. For example, replacement of existing 2-pond systems with systems for the land application of effluent is found to be a priority method across all scenarios. In contrast, the high cost of low-rate effluent application and its restricted suitability (this method is most pertinent for farms with poor-draining soils) limits its degree of utilisation.

The fencing of Accord streams on dairy land increases from 80% in the baseline to 84% in scenario 4 and then to around 92% in scenarios 1–3. In comparison, fencing of non-Accord streams on dairy land increases from 45% in the baseline to 50% in scenario 4 and then to around 60% in scenarios 1–3. The fencing of streams on drystock properties remains unchanged in scenario 4, but increases from 45% of potential in the baseline to around 90% of potential in scenarios 1–3. Here, it is important to recognise, however, that there are enormous practical challenges associated with achieving this at the farm-scale. The model recommends the use of buffers of 5m width on almost all streams protected by this additional riparian fencing. Farm plans play an important role for sediment mitigation, being applied on 14% and 27% of dairy and drystock land, respectively, in scenario 1. Also, improved management of phosphorus fertiliser plays a small role in all forms of agriculture and is typically a win-win solution, where both fertiliser costs and P losses are reduced without a loss in production. The more-stringent scenarios also require the use of wheel-track ripping and detention bunds for reducing sediment loss on around 15% of horticultural land. A large number of edge-of-field mitigations are incorporated in the model, each with their own suitability to a given landscape and different level of efficacy for removing diverse contaminants. The set of these mitigations considered include detention bunds, detention bunds and wetlands, sediment traps, small wetlands, and medium wetlands. Cost-effective mitigation requires significant investment in these edge-of-field mitigations. Indeed, contaminant loss from over half of the catchment is mitigated through the use of these structures across scenarios 1–3.

Table 5. Catchment-level mitigation use for each scenario with constrained land-use change. This table represents the additional mitigation use that has to occur above the current state.

Variable	**Units**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**
Replacement of 2-pond systems	%	96	96	96	80
Uptake of low-rate effluent application	%	15	8	8	0
Fencing of Accord streams in dairy	km	388	396	394	141
Fencing of non-Accord streams in dairy	km	257	259	256	88
Fencing of streams in drystock	km	2,432	2,865	1,922	0
5m buffers on Accord streams	km	388	394	392	140
5m buffers on non-Accord streams	km	257	257	255	88
5m buffers on drystock streams	km	2,432	2,847	1,921	0
Cows on stand-off during autumn/winter	%	83	86	71	8
Afforestation of dairy land	ha	5,579	5,579	6,218	7,839
Afforestation of drystock land	ha	11,251	11,248	11,254	4,208
Area covered by soil-conservation plans		139,499	100,218	108,405	0
Use of wheel track ripping in horticulture	ha	1,033	1,116	1,116	0
Use of decanting bunds in horticulture	ha	1,033	516	516	0
Improved P mgmt. on dairy farms	%	57	57	57	38
Improved P mgmt. on drystock farms	%	24	24	24	16
Improved P mgmt. on horticulture farms	%	28	28	28	22
Area serviced by detention bund	ha	92,431	89,821	102,706	12,214
Area serviced by bund+wetland	ha	72,099	69,056	83,204	9,253

Area serviced by sediment trap	ha	56,161	55,448	60,398	6,129
Area serviced by small wetland	ha	68,573	94,658	61,545	29,752
Area serviced by medium wetland	ha	228,178	199,099	211,327	19,083

Overall, Tables 2–5 demonstrate that scenarios 1–4 can be expected to require significant mitigation effort, with flow-on implications for catchment profit and production. However, an additional factor is that not all limits are met under each scenario, either. Indeed, as the scenarios become more stringent, the number of breaches in the limits for all contaminants generally increases (Table 6). (Here, a *breach* is defined as an indicator of water quality—such as the median level of chlorophyll *a*—not meeting the defined limit at a given site.) In the context of the model, a breached limit can be interpreted as the model being unable to find a management plan (i.e. a solution) that allows the limit at a given site to be satisfied, while allowing all other relationships in the model to be respected. Limits for clarity and 95th percentile measurements of *E. coli* are particularly difficult to satisfy across all scenarios. In contrast, limits for median *E. coli* are the only ones satisfied for a single contaminant across all sites in Scenario 1.

Table 6. Catchment-level number of breaches for each limit in each scenario, with constrained land-use change.

Indicator	Scen. 1	Scen. 2	Scen. 3	Scen. 4	No. of sites
Median Chlorophyll *a*	4	0	0	0	9
Maximum Chlorophyll *a*	5	0	0	0	9
Total Nitrogen	5	0	0	1	9
Total Phosphorus	3	0	0	0	9
Median nitrate	2	0	1	1	61
95th percentile nitrate	8	0	1	1	61
Median *E. coli*	0	0	1	0	61
95th percentile *E. coli*	37	37	29	0	61
Black disc (clarity)	11	7	7	0	58

The significant number of breaches identified across the simulated scenarios highlights that mitigation options defined within the baseline model are insufficient to achieve the desired attribute bands. It is observable from Table 5 that while these breaches of contaminant limits exist, maximum mitigation use is still not observed for some abatement strategies. This behaviour is observed for a number of reasons. These are:

1. The range across which some mitigations can be used is limited. For example, low-rate effluent application will never reach 100% in Table 5 because not all dairy farms are suitable (i.e. have poorly-drained soils).
2. The use of one mitigation to reduce one pollutant could drive breaches for another pollutant at the same site or a linked site downstream. For example, drystock conversion from dairy can reduce nitrogen loss by up to two-thirds, but substantially increase *E. coli* losses to water.
3. Levels of adoption in critical sub-catchments are essentially watered down when we consider their level of use over the whole catchment.
4. The number of mitigations considered for 95th percentile *E. coli* loads in the model are very low, given the lack of effective technologies that are available currently.
5. Highly elastic responses from the model are conditioned by the land-use constraints.

3.2 Output for the unconstrained land-use change scenario

The scenarios were evaluated again, but with land-use change unconstrained. Around 40–50% of the catchment experiences land-use change across all scenarios in this case (Table 7). There is broad de-intensification, as dairy land moves to drystock production and drystock land moves to plantation forest. Pastoral agriculture decreases from 680,000 ha in the baseline to 394,478 ha in scenario 1. Horticulture area declines by a quarter in scenarios 2–3, while it more than halves in scenario 1. Forest area increases to comprise nearly 60% of land use within the catchment across all scenarios.

Table 7. Catchment-level land-use allocation for each scenario with unconstrained land-use.

Variable	**Units**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**	**Current state**
Dairy	ha	70,513	71,471	122,200	222,068	308,008
Drystock	ha	323,965	285,382	259,139	135,948	370,355
Horticulture	ha	2,547	4,517	4,844	5,785	6,103
Forest	ha	456,920	492,575	467,761	490,144	169,478
Total	*ha*	853,945	853,945	853,945	853,945	*853,945*

Dairy to drystock	ha	144,926	118,538	91,815	11,756	0
Dairy to forest	ha	92,569	117,998	93,992	74,184	0
Drystock to forest	ha	194,873	205,099	204,291	246,482	0
Horticulture to drystock	ha	3,556	1,587	1,259	318	0
Total conversion	*ha*	435,924	443,222	391,357	332,740	*0*
Change in land area	*%*	51.05	51.90	45.83	38.97	*0*

Allowing unconstrained land-use change achieves a reduction in mitigation cost across all scenarios, compared to the constrained land-use change scenario. Indeed, catchment-level profit even increases in scenario 4 (by around 7%), as rationalisation of land-use more than offsets the losses associated with de-intensification to provide for nitrogen loads in groundwater. However, while profitable, this requires around 40% of land use to change from its current state (Table 7). These gains accrue to increased forestry income and benefits associated with the annualised value accruing to the sale of assets arising from the conversion of pastoral enterprises. Such increases belie a complex truth, however, in that such enormous change in land use will have significant economic and social impacts across sectors.

Table 8. Catchment-level profit for each scenario with unconstrained land-use change. Bracketed terms constitute costs.

Variable	**Units**	**Scen. 1**	**Scen. 2**	**Scen. 3**	**Scen. 4**	**Current state**
Sector profit						
Dairy	$m	118.18	131.22	261.57	507	617.53
Drystock	$m	136.02	200.83	190.4	136.03	210.15
Horticulture	$m	-1.69	22.23	24.26	29.35	28.21
Forest	$m	178.63	192.31	180.69	194.86	58.86
Land use transition	$m	209.22	223.17	186.53	110.93	0

Costs						
Stream fencing	$m	(6.7)	(7.44)	(3.55)	(0.01)	0
Effluent update	$m	(0.4)	(0.43)	(0.43)	0	0
Erosion plans	$m	(5.22)	(1.42)	(1.42)	0	0
Point source	$m	(137.77)	(129.65)	(40.56)	(2.51)	0
Edge-of-field	$m	(24.99)	(4.52)	(6.62)	(1.43)	0
Total profit	*$m*	*465.28*	*626.3*	*790.87*	*974.22*	*914.76*
Change	*$m*	*(449.48)*	*(288.46)*	*(123.89)*	*59.46*	-
Change	*%*	*-49*	*-31*	*-14*	*+7*	-

Table 9 shows that changes in land use have broad implications for catchment-wide production.

Table 9. Catchment-level production for each scenario with unconstrained land-use change.

Variable	Unit	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Current state
Milk solids	t	48,926	54,764	93,832	187,379	248,699
Wool	t	6,974	7,400	6,612	2,831	7,224
Mutton	t	17,008	19,955	17,688	7,532	15,194
Lamb	t	7,419	4,926	4,715	2,343	12,334
Beef	t	22,821	21,579	18,173	7,684	26,059
Bull beef	t	10,546	14,962	14,317	10,683	15,777
Hort. crops	t	69,290	181,430	193,095	229,328	251,452
S1 logs	M m^3	58	63	60	66	18
S2 logs	M m^3	137	148	140	148	49
S3 logs	M m^3	141	152	144	151	52
Pulp	M m^3	91	98	93	98	33
Waste	M m^3	6	7	7	7	2

3.3 Spatial impacts of the proposed scenarios

This section involves the presentation and discussion of various maps of the catchment that show how key results from the economic modelling vary across each sub-catchment and

FMU. All results reported in this section have been generated for the *constrained land-use change* option, but could be generated for the unconstrained land-use option if the CSG desires.

Figure 3 shows how total profit across each sub-catchment is impacted within each simulated scenario. Losses represent drops in baseline profit associated with the adoption of any mitigation (i.e. any component listed in the first column of Table 2). A number of key points are apparent. First, the breadth and size of losses increase as the scenarios become more stringent. Second, profit increases in scenario 4 in some locations, due to the rationalisation of land use. Last, there is a strong disparity in the size and distribution of impacts.

Figures 4–7 focus on the primary contaminant loads from land that drive the pollutant concentrations present in the water. Therefore, they provide a coarse summary of the degree of mitigation performed spatially for each contaminant.

Figure 4 highlights the change in nitrogen load reaching the monitoring site within each relevant sub-catchment, ignoring flows of nitrogen from upstream sites. Overall, it is notable that nitrogen loads decrease significantly as the scenarios become more stringent, and the degree to which this occurs is highly variable across space.

Figure 5 highlights the change in phosphorus load reaching the monitoring site within each relevant sub-catchment, ignoring flows of phosphorus from upstream sites. There is broad diversity in the degree to which phosphorus loads are reduced across the catchment, though the degree of reduction observed is generally increasing as limits become more stringent. Interestingly, the reductions observed are broadly distributed across space, even though limits placed directly on Total Phosphorus are only present on the main stem of the Waikato River.

Figures 6 and 7 show the change in sediment and microbial load, respectively, observed across each sub-catchment under each of the scenarios. Flows from upstream are ignored to improve ease of interpretation. The key factors again are how mitigation effort increases as more stringent limits are imposed, and the most cost-effective responses to limits are highly variable across space.

Figure 8 highlights where breaches for 95th percentile measurements of *E. coli* are observed under each of the simulated scenarios. It is apparent that breaches are numerous, broadly distributed, severe in magnitude, and their placement is reasonably consistent across scenarios 1–3.

Figure 9 shows where breaches for clarity measurements are observed in each scenario. These increase in number and severity as the limits placed on this attribute become more stringent.

Figures 10–12 identify where dairy to drystock (Figure 10), dairy to forest (Figure 11), and drystock to forest (Figure 12) conversion takes places within each scenario, under constrained land-use change. Even though there is a strong focus on the Upper Waikato, especially in scenario 4, change is broadly distributed across the entire catchment.

Figure 3. Change (%) in baseline profit within each sub-catchment for each scenario with constrained land-use change.

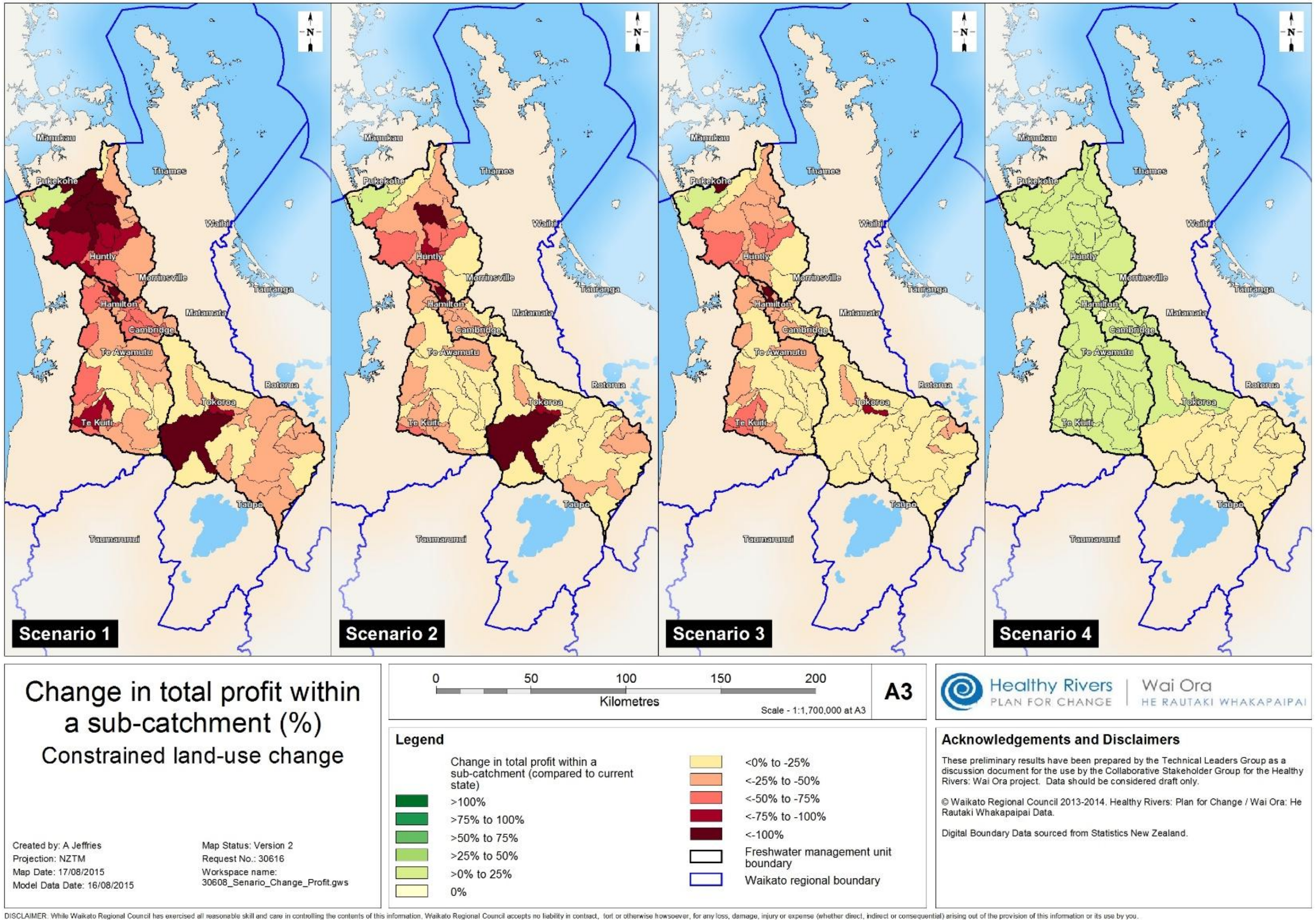


Figure 4. Change (%) in baseline nitrogen loads within each sub-catchment for each scenario with constrained land-use change.

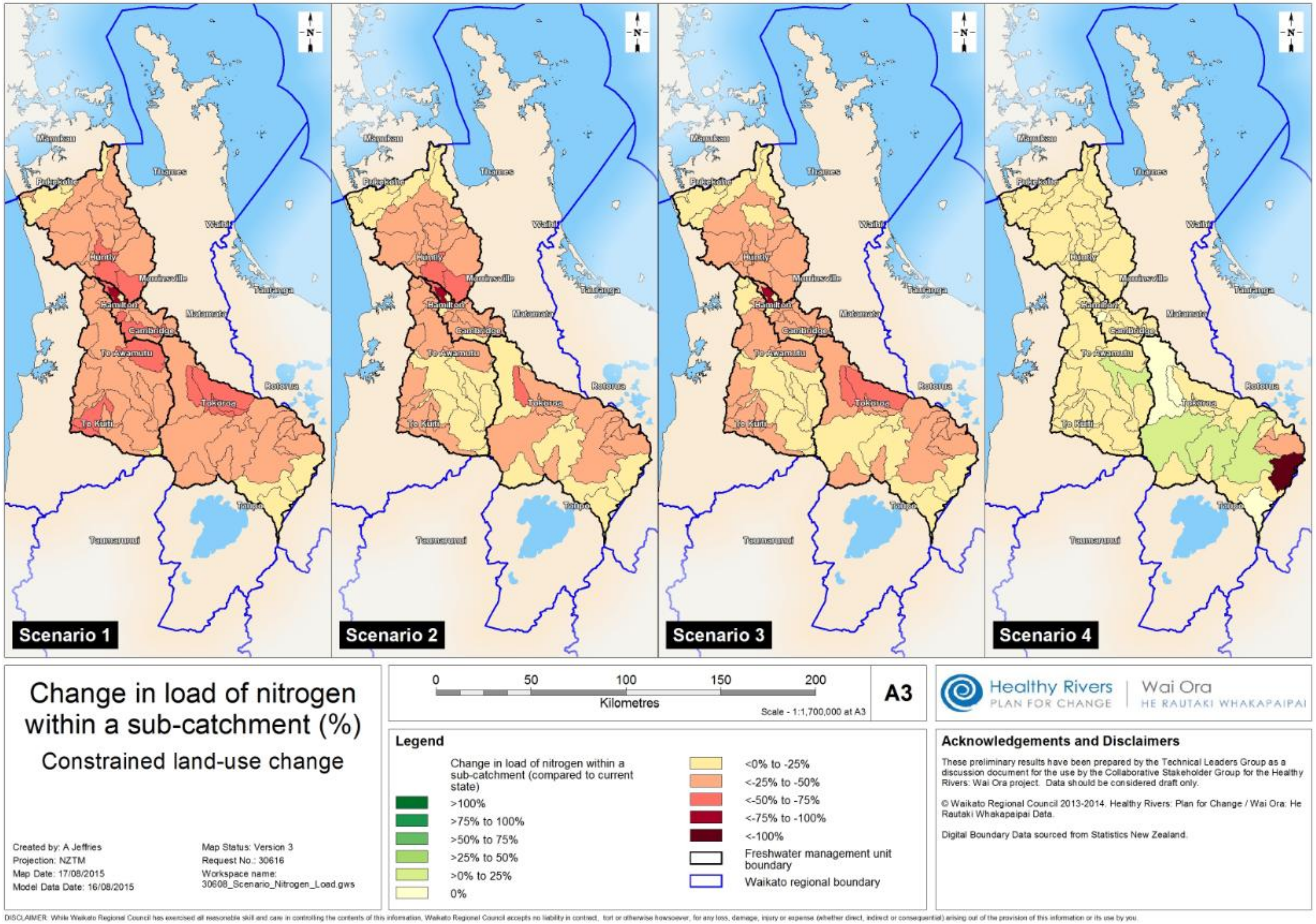


Figure 5. Change (%) in baseline phosphorus loads within each sub-catchment for each scenario with constrained land-use change.

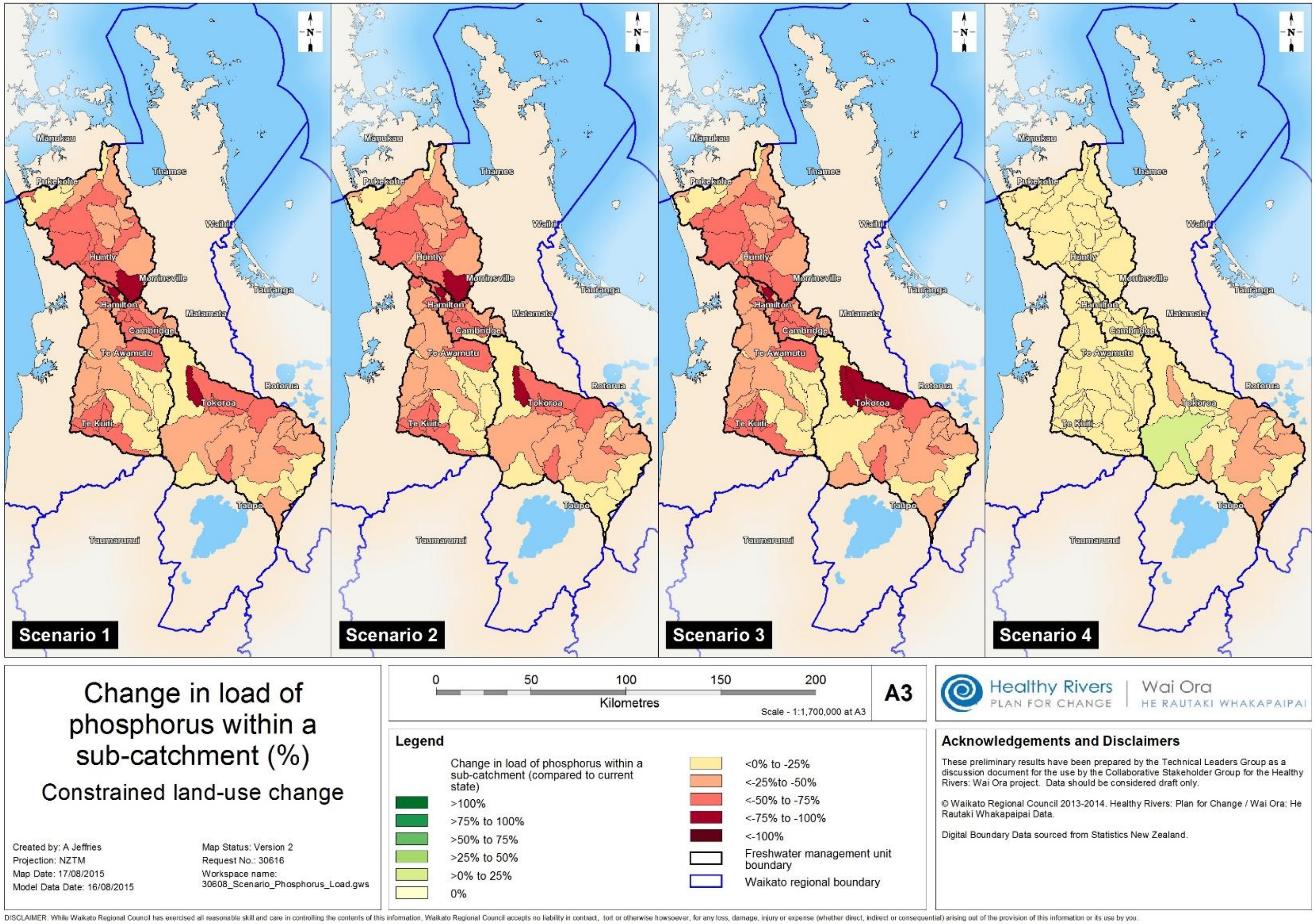


Figure 6. Change (%) in baseline sediment loads within each sub-catchment for each scenario with constrained land-use change.

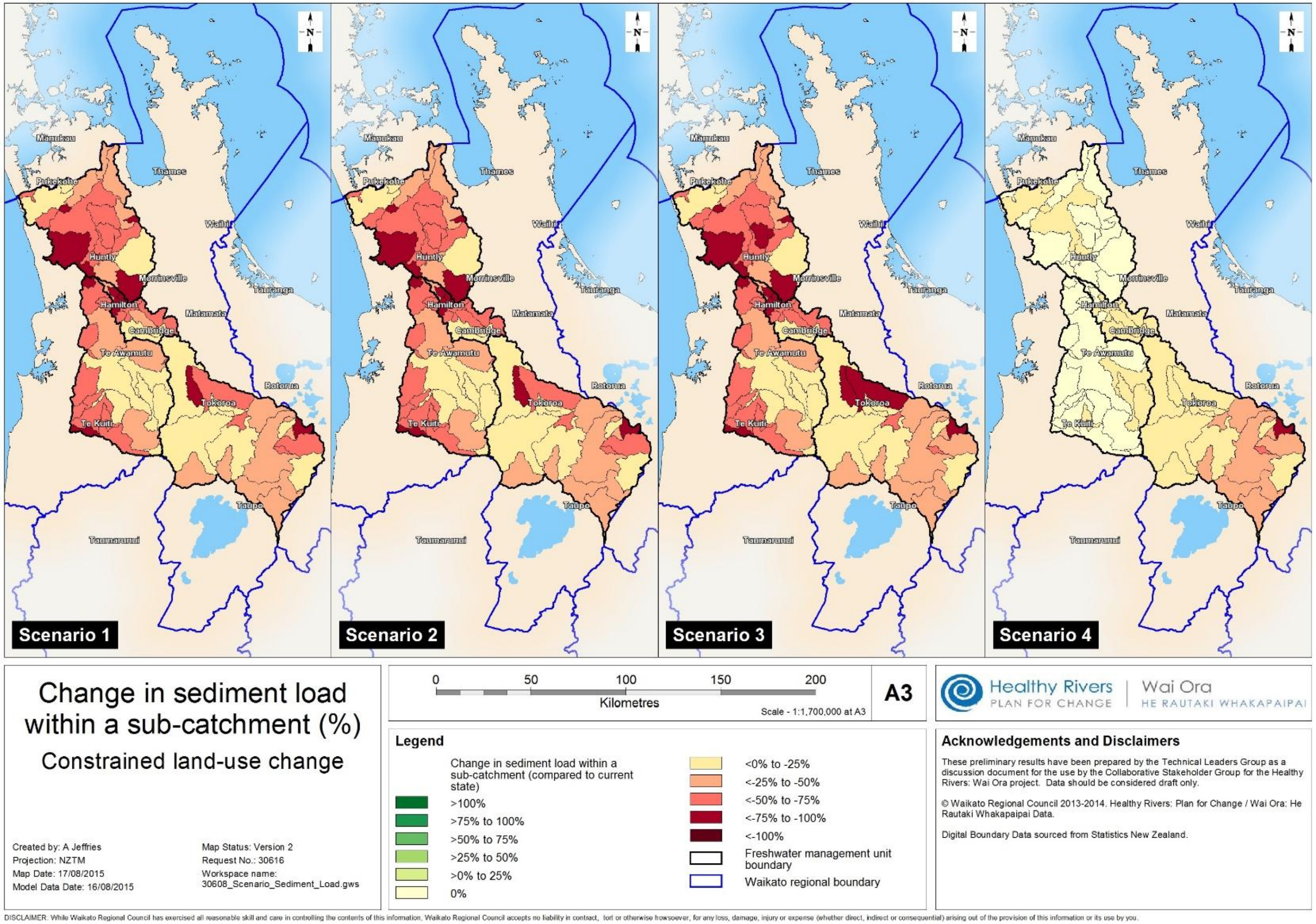


Figure 7. Change (%) in baseline *E. coli* loads within each sub-catchment for each scenario with constrained land-use change.

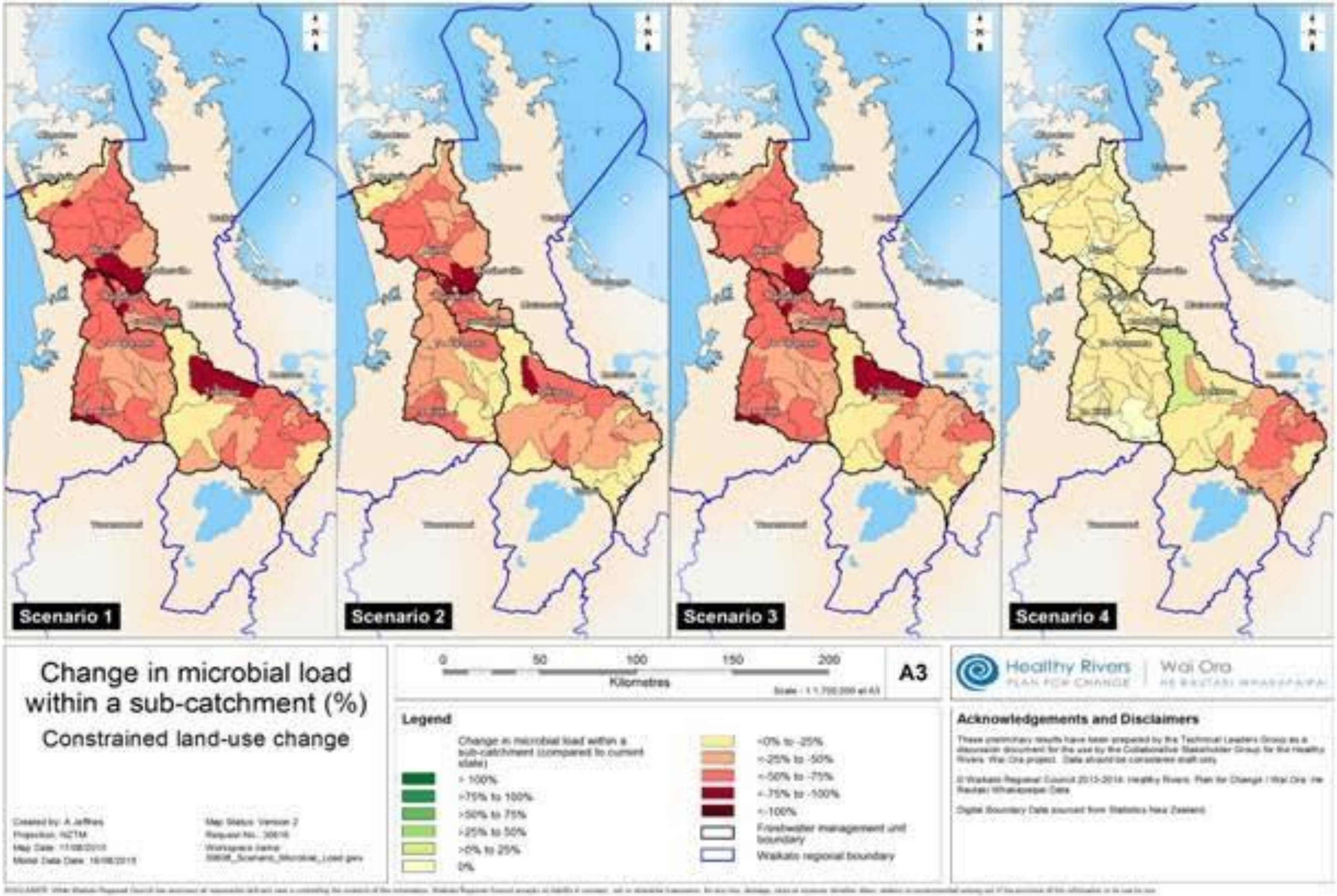


Figure 8. Degree that limits for 95th percentile levels of *E. coli* are breached for each scenario with constrained land-use change.

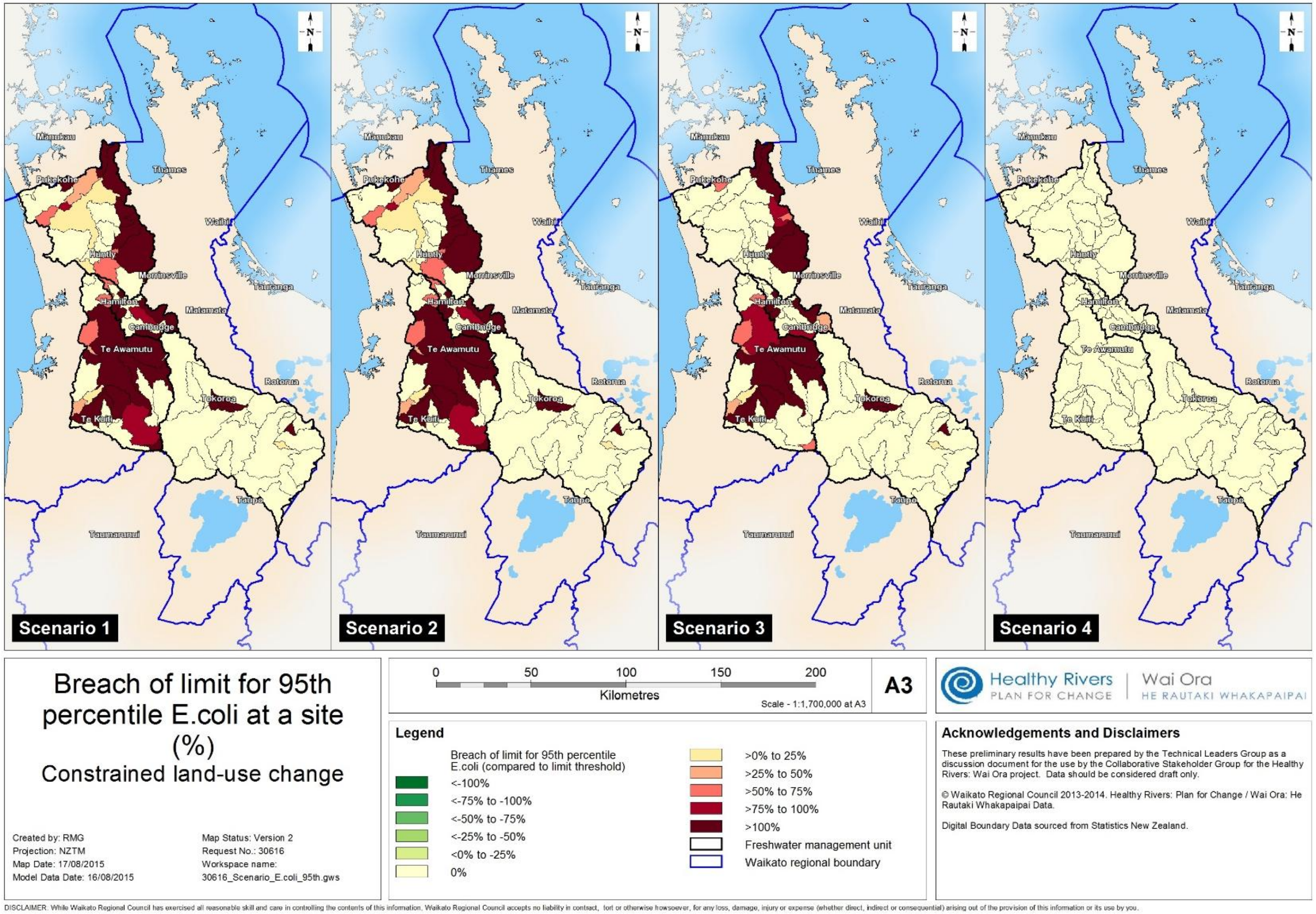


Figure 9. Degree that limits for clarity are breached for each scenario with constrained land-use change.

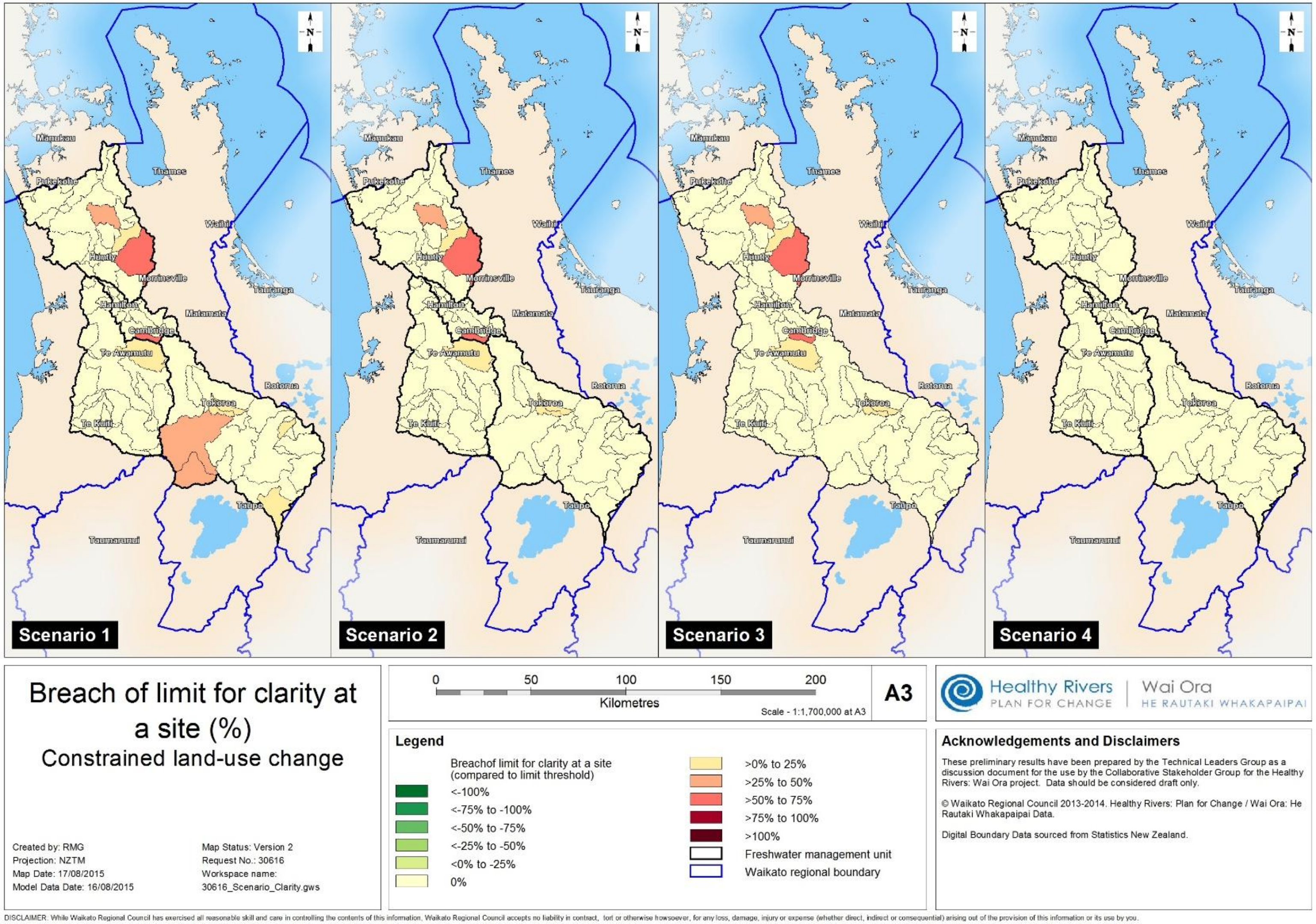


Figure 10. Location of dairy to drystock conversion for each scenario with constrained land-use change.

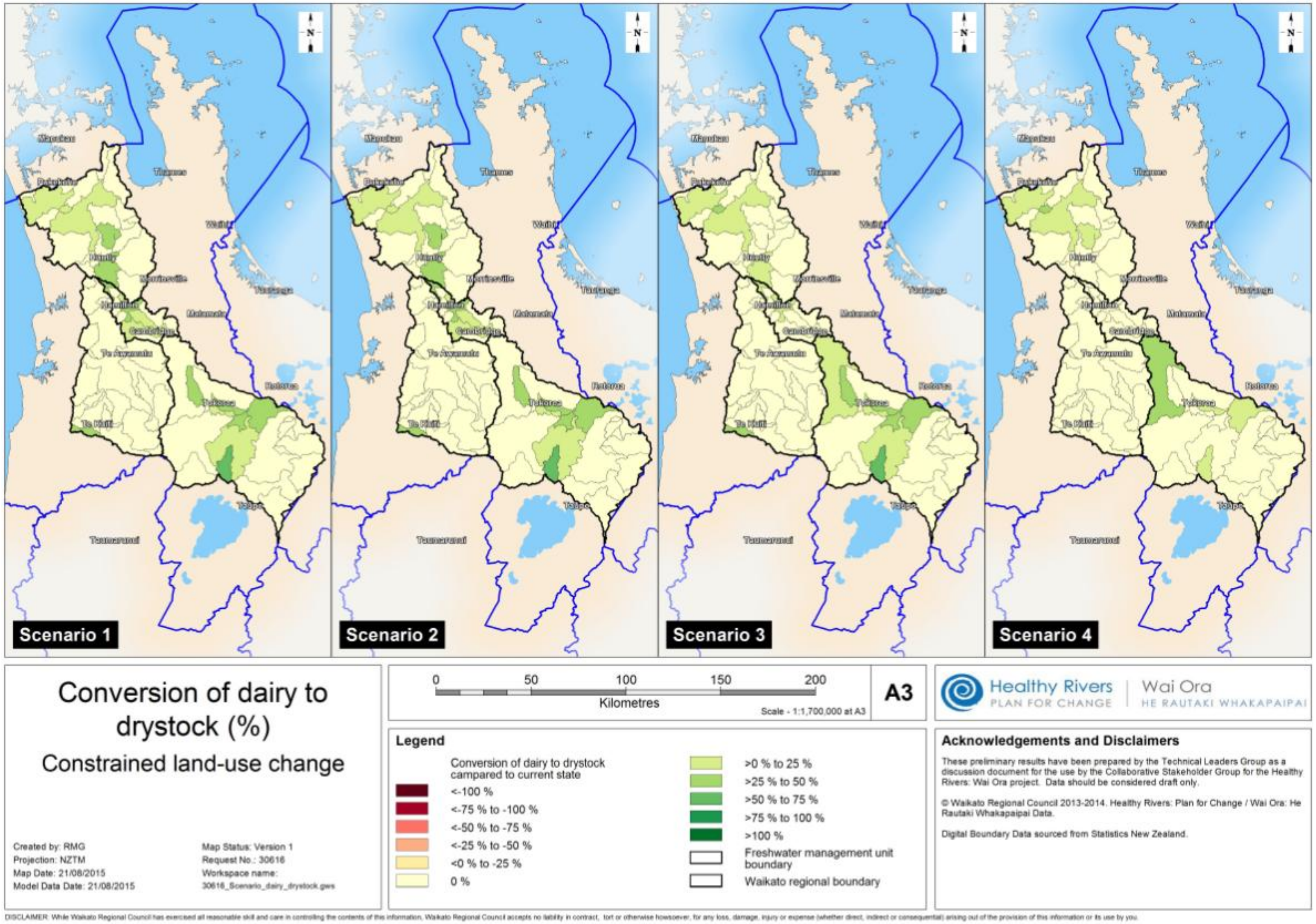


Figure 11. Location of dairy to forest conversion for each scenario with constrained land-use change.

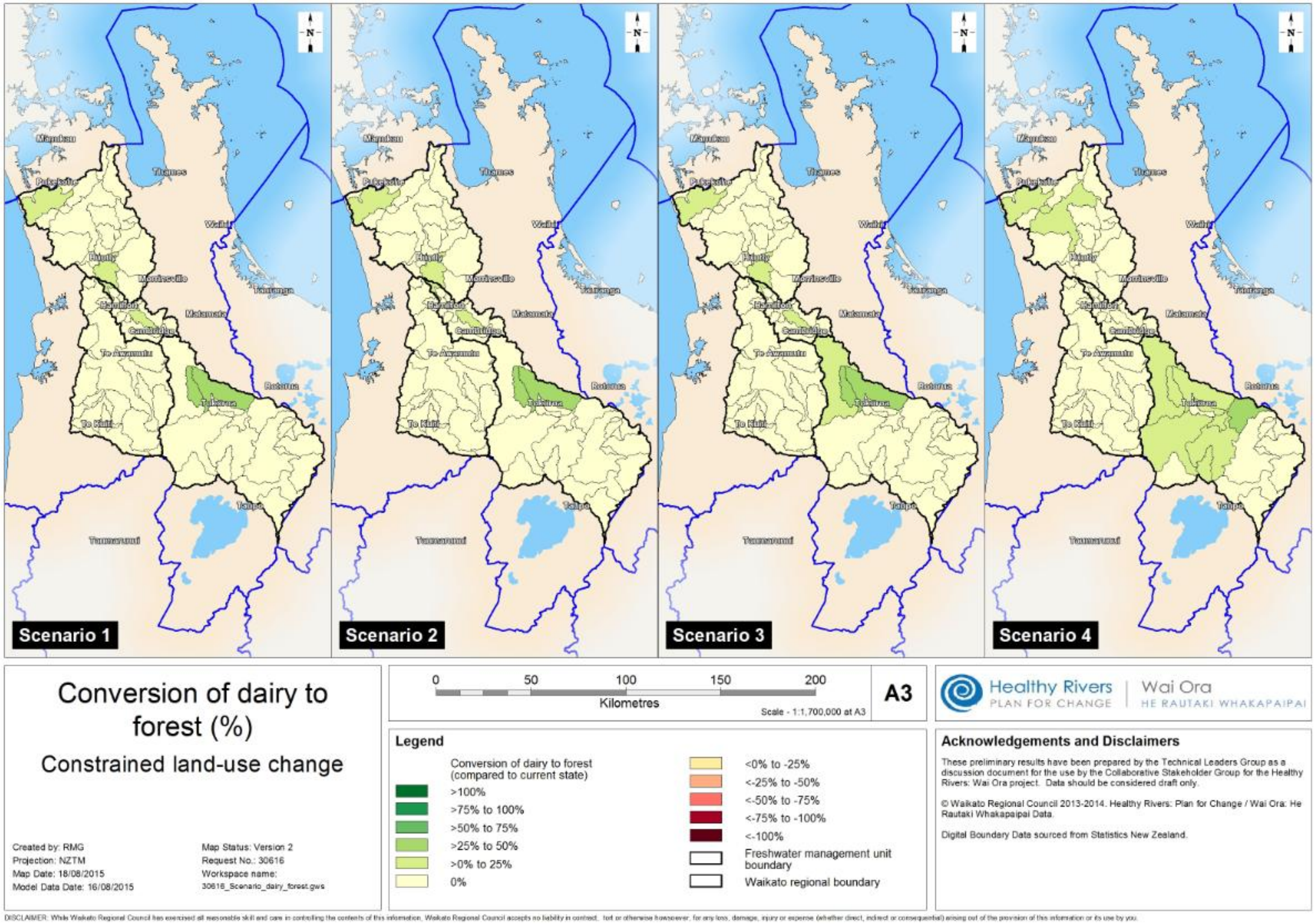
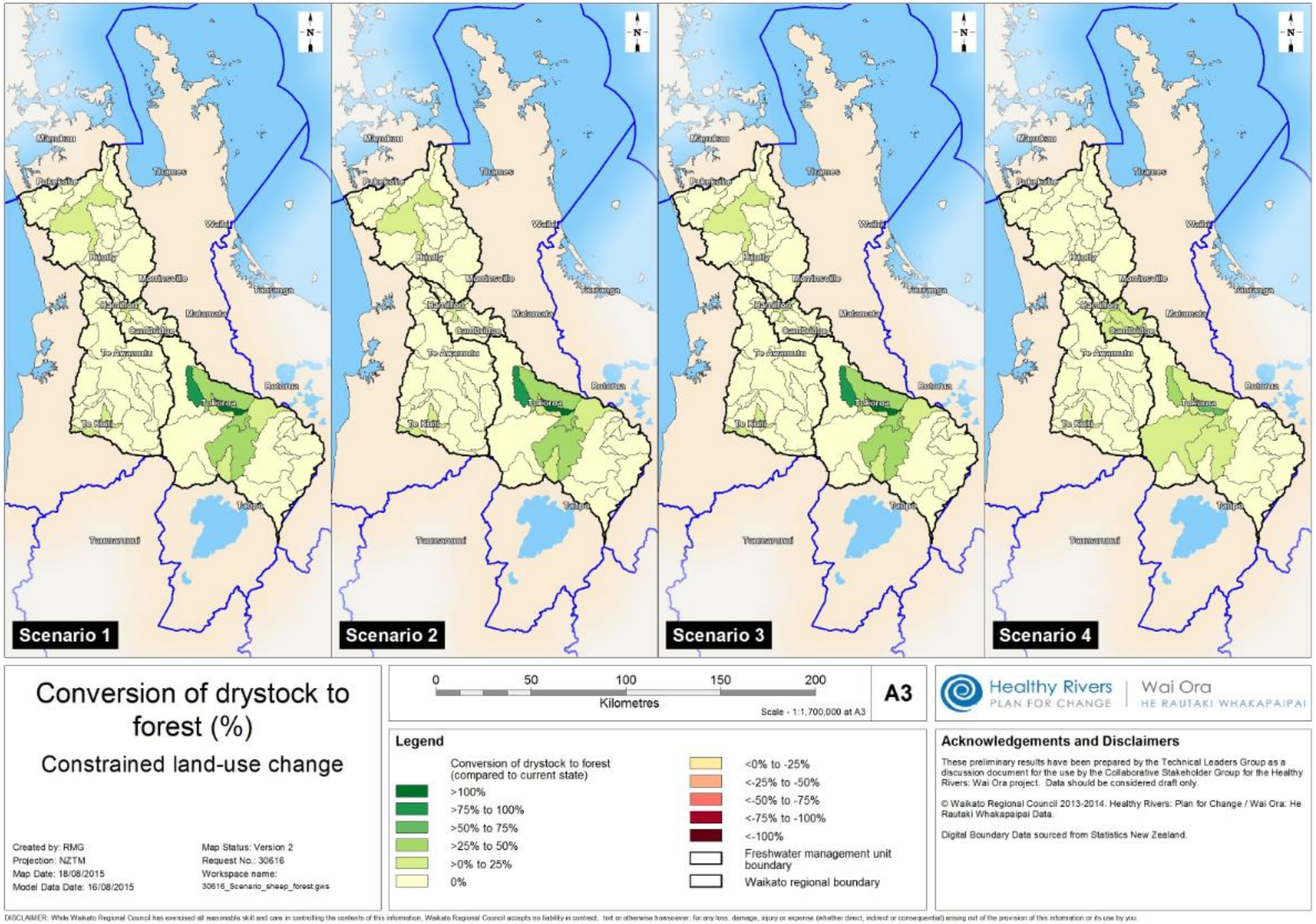


Figure 12. Location of drystock to forest conversion for each scenario with constrained land-use change.



4. Regional economic effects of the proposed scenarios

4.1 Justification of the input-output approach

Input-output (IO) models are the most widely-applied method for estimating the regional impacts of environmental policy, both in New Zealand and overseas. Moreover, they are one of the most popular economic methods applied globally (Miller and Blair, 2009), based on their clarity and descriptive capacity. These models study the flow of products, inputs, and sales between households and industries. Their primary advantage is that they describe the complex interdependency between different sectors within an economy, allowing the consideration of numerous flow-on relationships arising from a change in current economic activity. Accordingly, input-output models provide a means to estimate the regional impacts of a given policy mechanism, based on the idea that an initial decrease in net revenue entering into a regional economy—for example, in response to a change in milk production arising from reduced dairy-production intensity—will lead to a decline in subsequent spending in other industries within this economy, but the effect of these diminished contributions will dissipate over time due to the leakage of funds from the local economy (e.g. through expenditure outside of the region or through saving) (Mills, 1993). Such models have many benefits; namely, their ability to capture interrelationships between different sectors, low cost, and apparent simplicity, which helps to promote the clarity of their output. Moreover, the equilibrium structure of input-output models is consistent with the steady-state approach employed in the catchment-level model discussed above (Sections 2 and 3).

Nevertheless, these frameworks have some limitations, particularly associated with the inclusion of price impacts, budget constraints, and technical change. The application of input-output models is based on an explicit assumption that prices remain fixed, consistent with their equilibrium structure. However, an implication of this is that increased competition for scarce factors of production does not flow through to affect prices (Hughes, 2003). Also, the additional output associated with increased input use is assumed constant. These assumptions are highly stylised, but are justified in applied work based on their clarity, ease to deal with during computation, the inherent focus of these models on regional markets, and the complications associated with utilising more-detailed frameworks that do consider price feedbacks and varying returns to scale. Indeed, in relation to the last point, it is common that seeking to include price impacts through extending a model to become a computable general equilibrium framework or spatial decision support system will often lead to a downgrade in the amount of industry-level information that is included (Bess and Ambargis, 2013).

The decision to utilise an input-output analysis within the HRWO process is also partially justified by the existence of the Waikato Region Multi-Regional Input-Output Table, which was initially developed for the Waikato Regional Council Economic Futures Model (McDonald, 2010). The extension of a previous framework is more cost-effective than developing a framework from nothing, especially given that the existing framework has been applied previously and extension can take into account practices and principles that were learnt during its prior employment. This decision is also consistent with the time and budget constraints that face many limit-setting processes for water quality improvement in New Zealand, including the HRWO process. The adoption of an input-output model has also allowed the seamless integration of the regional economic model with the farm- and catchment-level models, such that the farm-, catchment-, and regional-level implications of alternative limits can be ascertained in an integrated way.

Although an IO model has been selected as the core analytical framework for the consideration of regional economic impacts of the scenarios in this study, alternative methodologies exist for assessing economic impacts; the most notable alternative is the use of Computable General Equilibrium (CGE) modelling. Key reasons for adopting an IO, rather than a CGE, framework for use in this study are:

1. *Disaggregation*: The IO approach readily produces results that are disaggregated by study regions (in this case, the different FMUs, Waikato region, and New Zealand) and economic sectors (altogether 107 economic sectors or 'industries' are reported in the model, though results are aggregated to 16 key sectors below), thus providing important information on the distribution of economic impacts.
2. *Paucity of data*: Creation of a multi-regional CGE model that reports down to the level of each FMU would necessitate the construction of a Social Accounting Matrix (SAM) for the local area. There is a lack of information pertaining to interregional investment flows upon which to complete this task.
3. *Full analysis of 'circular flow of income'*: Although based on IO, a concerted attempt is made in this study to take full consideration of the 'circular flow of income' within

an economy, much like an analysis based on a SAM or CGE. Both 'backward' and 'forward' linkages are considered. Backward-linkage effects are those experienced by suppliers, or in other words, organisations situated up the supply chain. This includes, for example, the loss in demand for products of fertiliser manufacturers as a result of a reduction in farming intensity. Forward-linkage effects, by contrast, are experienced by those who purchase goods or are situated down the supply chain. This includes the loss in dairy-product manufacturing necessitated by a fall in the supply of raw milk from farms. Thus, it is an example of an extensive application of IO for the purposes of economic impact assessment.

4. *Timeframe and budget*: It has been feasible to couple an IO-based model to the selected catchment-level model, so as to produce a picture of district, regional, and national economic impacts, while keeping within the timeframe and budget of the project. In contrast, linking a CGE model to the catchment-level model is a major piece of work and is beyond the scope of this project. To date, this type of work has not been undertaken within New Zealand for the analysis of water-quality limits.

4.2 Introduction to Input-Output analysis

It is helpful to provide readers, particularly those not familiar with input-output analysis, with a brief introduction to the IO framework. (Further information is provided in Miller and Blair (2009).) This introduction is provided below. The remaining sections of the methodology describe the way the different scenarios are incorporated into an IO framework, including the major assumptions that are applied.

At the core of any IO analysis is a set of data that measures, for a given year, the flows of money or goods among various sectors or industrial groups within an economy. These flows are recorded in a matrix or 'IO table' by arrays that summarise the purchases made by each industry (its inputs) and the sales of each industry (its outputs) from and to all other industries. By using the information contained within such a matrix, IO practitioners calculate mathematical relationships for the economy in question. These relationships describe the interactions between industries—specifically, the way in which each industry's production requirements depend on the supply of goods and services from other industries. With this information it is possible to calculate, given a proposed alteration to a selected industry (a scenario), all of the necessary changes in production that are likely to occur throughout supporting industries within the wider economy. For example, if one of the changes anticipated for one FMU were to be a loss in the amount of dairy farming, the IO model would calculate all of the losses in output that would also occur in industries supporting dairy farming (e.g. fertiliser production, fencing contractors, farm machinery suppliers), as well as the industries that, in turn, support these industries.

As with all modelling approaches, IO analysis relies on certain assumptions for its operation. Among the most important is the assumption that the input structures of industries (i.e. the mix of commodities or industry outputs used in producing output for a specific industry) are fixed. In the real world, however, these 'technical coefficients' will change over time as a result of new technologies, relative price shifts causing substitutions, and the introduction of new industries. For this reason, IO analysis is generally regarded as most suitable for short-run analysis, where economic systems are unlikely to change greatly from the initial snapshot of data used to generate the base IO tables. This further justifies the selection of this method for the regional-level economic analysis, given that the catchment-level model presented above also represents a snapshot of reality that is based heavily on current prices, technologies, management practices, and knowledge of biophysical relationships. This also justifies the use of constrained land-use changes, at least to some extent, given that economic analysis is best equipped for studying marginal changes.

4.3 Overview of impacts assessed

The study of economy-wide economic impacts commenced with identifying six key categories of likely economic effects associated with the proposed options for water-quality improvement:

Changes to farming systems: backward linkage supply chain impacts. Attribute limits can encourage changes in land-management practices for farms within each FMU. Examples might include removing summer crops and replacing these with supplements and lowering fertiliser use. These measures result in changes to the purchasing patterns of farms, creating flow-on impacts through economic supply-chain linkages.

Changes to farming systems: forward linkage supply chain impacts. The changes in farming practices will also result in reductions to the overall output of farms. With less output (e.g.

milk, wool, meat) produced per hectare, the supply to downstream processors (dairy manufacturers, meat processors, textile manufacturers, etc.) will be reduced, ultimately leading to a reduction in sales by these industries.

Conversion between land uses: backward supply chain impacts. In addition to changes in land management, the proposed scenarios will also likely result in changes in land use across the FMUs. This will create additional impacts for industries that would otherwise be involved in supplying goods and services to the existing farms. Businesses that are responsible for providing direct inputs to the forestry sector (e.g. pruning contractors, accountants etc) will be positively impacted by conversion of land to forestry. Businesses involved indirectly in forestry supply chains (e.g. firms selling supplies to contractors) will also be positively impacted.

Conversion between land uses: forward linkage supply chain impacts. Similar to the forward-linkage effects resulting from changes in farming systems, the conversion of land from one use to another will result in changes to the supply of key products to downstream processors (for example, more timber to processors, but less raw milk to dairy product manufacturing if dairy land is replaced by forest production).

Changes in incomes for land owners. For each of the scenarios evaluated, there will be changes in income for landowners in the form of wages/salaries and profits. This will cause changes in the expenditure patterns of these land owners; hence, creating impacts through the rest of the economy.

Outlays and revenues associated with land conversion. The conversion of land into different uses is associated with a set of discrete capital investments and other economic transfers. For land owners, these can be both outlays (e.g. construction of woolsheds, planting costs) and revenues (e.g. sale of Fonterra shares, sale of dairy herds). The income and expenditure patterns of land owners will have flow-on implications through the district, regional, and national economies.

Changes for wood and paper processing. Baseline FMU wood- and paper-processing input mixes were replaced with superior data provided directly by Scion. This ensured that the latest available information on processing methods, unique to each FMU, was appropriately incorporated.

4.4 Overview of output from regional economic modelling

The impact of each of the four scenarios is ascertained, relative to the current state described for the catchment in Section 3. All runs described involve the constrained land-use change option. Table 10 summarises the total changes in Value Added associated with each scenario across each FMU, the rest of the Waikato region, and the national economy. Value added is a standard measure of economic activity, similar to regional GDP but excluding production taxes. Indeed, these measures are seldom different by more than 1%. The loss of Value Added as a percentage of total Value Added for each spatial unit, is also presented. Altogether an annual Value Added loss of $229 million is estimated for New Zealand under scenario 4, increasing to a maximum of $1.17 billion per year under scenario 1 (Table 10). The Value Added impacts for scenario 2 and scenario 3 lie within these two extremes. To place these results in context, for 2014 total annual industry Value Added is estimated at around $210 billion for New Zealand, with $18.8 billion originating from the Waikato region (Statistics New Zealand, 2015). Thus, at least in terms of Value Added, the scenario 4 impact equates to approximately 0.1% of the economy at the national level, and 0.5% at the regional level. Under scenario 1, these figures increase to 0.6% and 3.3% of the national and regional economy, respectively.

Table 10. Reduction in Value Added ($m) across each FMU, the rest of the Waikato Region, and the rest of New Zealand (annual figures, change relative to current state).

Spatial unit	**Change in Value Added ($m)**				**Loss of Value Added (%)**			
	Sc. 1	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**
Lower Waikato FMU	-152	-82	-80	-6	-7.6	-4.1	-4	-0.3
Waipa FMU	-140	-69	-72	-3	-7.7	-3.8	-3.9	-0.1
Mid-Waikato FMU	-123	-51	-49	-17	-1.5	-0.6	-0.6	-0.2
Upper Waikato FMU	-103	-69	-72	-42	-6.4	-4.3	-4.5	-2.6
Rest of Waikato	-104	-38	-37	-30	-2.1	-0.8	-0.8	-0.6
Rest of New Zealand	-552	-179	-186	-131	-0.3	-0.1	-0.1	-0.1
Total New Zealand	-1,174	-487	-496	-229	-0.6	-0.2	-0.2	-0.1

The following discussion focuses on information presented across 16 aggregated sectors in the regional economy, despite the fact that 107 individual industries are represented in the IO model itself.

Tables 11–14 present the changes in Value Added, employment, and international exports across each of the aggregated industries for each FMU, relative to the current situation (the baseline described in the catchment-level model). Table 15 presents these changes for the Waikato region as a whole, while Table 16 presents the predicted impacts for the national economy.

All employment results are measured by using Modified Employee Counts (MECs). Statistics New Zealand typically reports employment data according to the Employee Count (EC) measure. ECs are a head count of all salary and wage earners for a reference period. This includes most employees, but does not capture all working proprietors—individuals who pay themselves a salary or wage. The modified employment count or MEC measure is based on ECs, but includes an adjustment to incorporate an estimate of the number of working proprietors.

Within the Lower Waikato FMU (Table 11), the impacts are confined largely to the agricultural industries under all scenarios. Employment impacts for sheep, beef, and grain range from a gain of 40 MECs under scenario 4, to a loss of around 90 MECs under scenario 1. Dairy farming impacts range from a loss of some 120 MECs under scenario 4, to around 480 MECs under scenario 1. The loss in jobs for other primary industries (which includes horticulture) ranges from some 20 MECs in scenario 2, to 340 MECs in scenario 1. Under scenario 1, there is also a relatively substantial impact for the ‘other services’ sector. This reflects changes in spending on a large group of services resulting particularly from reductions in household income. As meat and dairy product manufacturing are not significant sectors within this FMU, the model does not calculate very substantial impacts for these sectors in the Lower Waikato, when compared to the impacts calculated for other FMUs.

For the Waipa FMU (Table 12), impacts on pastoral activities are significantly greater under scenario 1 than the other scenarios. For example, around 100 and 500 jobs are lost on dairy and drystock farms, respectively, within this FMU in scenario 1 alone. Negative effects on

Value Added and employment are mainly observed in drystock and dairy sectors, together with the processing industries linked to these enterprises.

For the mid-Waikato FMU (Karapiro to Ngaruawahia) (Table 13), the impacts on dairy-product manufacturing are much more significant than in the Lower Waikato FMU. Interestingly, although the Value Added change in dairy-product manufacturing is greater than that experienced within dairy farming itself (e.g. within scenario 2, $15m per year, compared to $11m), the employment impact is greater for dairy farming than dairy-product manufacturing (e.g. 76 MECs compared to 50 MECs under scenario 2). This reflects relatively low employment intensities of production within dairy-product manufacturing. The greatest employment impacts within the mid-Waikato FMU actually occur within the two service sectors ‘retail and wholesale trade’ and other services. This illustrates the important role of service activities within this FMU in supporting pastoral activities within not just the local FMU, but the entire Waikato region.

In the Upper Waikato FMU (Lake Karapiro to Taupo Gates) (Table 14), the impacts on dairy farming are very significant under all scenarios. The calculated annual Value Added lost for that sector ranges from $45m in scenario 4 to $77m in scenario 1. This FMU also experiences the greatest increase in forestry, although afforestation benefits remain relatively modest (remembering that this is the constrained land-use change option).

The distribution of impacts within the Waikato region varies significantly across FMUs and between the scenarios. Under scenario 1, just under one-quarter of the total regional Value Added impact occurs within the Lower Waikato FMU (Ngaruawahia to Port Waikato), compared to only 6% of the impact under scenario 4. By contrast, the rest of the Waikato region (i.e. that part of the region not within the study FMUs) accounts for 17% of the total Value Added impact under scenario 1, but 30% of the impact under scenario 4. Consistently, the mid-Waikato FMU (Karapiro to Ngaruawahia) experiences a lower impact than the other parts of the Waikato when measured as a share of total Value Added. This reflects the location of major urban centres within this FMU, and a more diverse economy that is relatively less impacted by changes within the agricultural sector.

Notice that for each of the scenarios evaluated, an additional loss of Value Added/employment is experienced for the dairy cattle farming and sheep, beef, and grain industries within the rest of the Waikato region, beyond that which is explained by impacts within the FMUs themselves. This is derived by the input-output model simply due to supply-chain interconnections. Currently, there are relatively strong interlinkages between farmers within the region, with a proportion of the output from dairy/drystock farms being supplied particularly to other farmers within the study FMUs. Thus, when output from farmers within a study FMU is reduced, this causes a reduction in demand for the output of farmers in the rest of the Waikato region. In the real world, some of the loss of demand experienced by farmers in the rest of the region could probably be compensated by providing additional supply to the export, rather than local, markets. In this way, the model is likely to slightly overstate the impacts on Waikato farmers outside of the FMUs themselves.

The construction sector within the Waikato region (Table 15) experiences some positive impacts under the scenarios, especially businesses within the lower and mid-Waikato and Waipa FMUs. This reflects, in particular, very substantial costs (particularly under scenarios 1 and 2) on upgrading point-source discharge regimes creating additional demand for construction activities. Additionally, construction activities are stimulated by earthworks necessary to establish wetlands within dairy farms, earth bunds on horticultural farms (particularly in the Lower Waikato), and various other activities necessary to upgrade farms or alter land use.

The farm-systems modelling, which is the major data input to this analysis of FMU, regional, and national impacts, establishes a range of one-off land improvement costs necessary to help reduce contaminant losses from farms. This includes fencing and planting of riparian buffers, establishment of wetlands, and wheel track ripping and establishment of earth bunds on horticulture farms. As no funding regime has been proposed for these land-improvement costs, the modelling has made a working assumption that these fall on landowners. Indeed, the allocation of mitigation costs is a separate issue that will ultimately be determined by which policy actions are taken. Note that although all of these costs are included in the model and impact on levels of demand for goods and services, it is only expenditures that occur within the current account (i.e. not capital-related expenditures) that appear directly in the Value Added calculations of the respective farms.

At the scale of the New Zealand economy (Table 16), impacts on service industries are particularly pronounced. Service industries tend to be highly interconnected within an economy, and thus are impacted through a myriad of supply-chain interconnections when there is a change in the system. Also, many of the service industries are particularly affected by reductions in spending necessary to finance the contaminant-reduction interventions.

In this study, the analysis of export impacts at the national level (Table 16) is based on changes in the supply of key agricultural commodities and the impacts on production of associated export commodities (mainly raw milk and dairy products; logs and wood and paper products; sheep, cattle, and meat products; and wool and textiles). Exports from the dairy-product manufacturing industry are most-significantly impacted under each of the scenarios, ranging from a loss of $173 million per year under scenario 4, to $537 million per year under scenario 1 (Table 16). The loss in meat and meat-product exports equates to just 6% of the loss in value of dairy-product exports under scenario 4, but this increases to 36% under scenario 1. Under scenarios 2–4, there is some increase in sheep production from within some FMUs, which in respect to meat-product manufacturing and exports, helps to partially offset the loss in cattle production from farms. However, under scenario 1 sheep production falls to below that of scenarios 2 and 3, reflecting more restrictive limits being placed on water quality attributes.

Table 11. Regional economic impacts in the Lower Waikato (Ngaruawahia to Port Waikato) FMU with constrained land-use change.

Industry	**Value added ($m)**				**Employment (MECs)**				**International exports ($m)**			
	Sc. 1	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**
Sheep, beef, and grain	-40	-30	-30	2	-89	43	30	40	-1	0	0	0
Dairy farming	-63	-43	-33	-5	-482	-250	-198	-118	-1	0	0	0
Forestry	1	1	1	0	2	2	2	2	0	0	0	0
Other primary	-28	0	-8	-1	-344	-23	-157	-52	0	0	0	0
Agriculture and forestry support	-1	0	0	0	-15	-2	-1	-6	0	0	0	0
Meat and meat product manufacturing	-1	0	0	0	-10	-1	-1	0	-4	-1	0	0
Dairy product manufacturing	0	0	0	0	-2	-1	-1	-1	-2	-1	-1	-1
Wood and paper manufacturing	0	0	0	0	3	3	3	2	0	0	0	0
Other manufacturing	0	0	0	0	-2	0	0	-1	0	0	0	0
Utilities	-4	-1	-2	-1	-3	-1	-1	-1	0	0	0	0
Construction	2	2	2	0	44	41	38	1	0	0	0	0
Wholesale and retail trade	-1	0	0	0	-18	-9	-8	-2	0	0	0	0
Transport	-1	0	0	0	-6	-2	-2	-1	0	0	0	0
Professional/administrative services	0	0	0	0	0	3	1	-1	0	0	0	0
Local and central government	0	0	0	0	-2	-1	-1	0	0	0	0	0
Other services	-15	-9	-8	0	-120	-67	-63	-3	0	0	0	0
Total change relative to current state	-151	-80	-78	-5	-1044	-265	-359	-141	-8	-2	-1	-1

Table 12. Regional economic impacts in the Waipa River FMU with constrained land-use change.

Industry	Value added ($m)				Employment (MECs)				International exports ($m)			
	Sc. 1	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**
Sheep, beef, and grain	-25	-16	-19	2	-114	-6	-6	24	-1	0	0	0
Dairy farming	-69	-39	-39	0	-447	-33	-33	0	-1	0	0	0
Forestry	0	0	0	0	0	0	0	0	0	0	0	0
Other primary	-6	0	0	0	-109	6	7	-1	0	0	0	0
Agriculture and forestry support	-2	0	0	0	-36	6	5	-9	0	0	0	0
Meat and meat product manufacturing	-6	-1	-1	0	-56	-7	-6	-2	-20	-2	-2	-1
Dairy product manufacturing	-12	-4	-4	-3	-41	-15	-14	-10	-55	-20	-19	-13
Wood and paper manufacturing	0	0	0	0	0	0	0	0	0	0	0	0
Other manufacturing	0	0	0	0	-4	-1	-1	-1	0	0	0	0
Utilities	0	0	0	0	-2	-1	-1	-1	0	0	0	0
Construction	2	2	2	0	39	30	38	-1	0	0	0	0
Wholesale and retail trade	-2	-1	-1	0	-46	-25	-25	-2	0	0	0	0
Transport	-1	0	0	0	-8	-3	-3	-2	0	0	0	0
Professional/administrative services	0	0	0	0	2	6	2	-3	0	0	0	0
Local and central government	-1	0	0	0	-16	-9	-9	-1	0	0	0	0
Other services	-17	-10	-10	0	-153	-86	-89	-2	0	0	0	0
Total change relative to current state	-139	-69	-72	-1	-991	-138	-135	-11	-77	-22	-21	-14

Table 13. Regional economic impacts in the mid-Waikato (Karapiro to Ngaruawahia) FMU with constrained land-use change.

Industry	Value added ($m)				Employment (MECs)				International exports ($m)			
	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4
Sheep, beef, and grain	-4	-2	-2	0	-16	13	7	4	0	0	0	0
Dairy farming	-18	-11	-9	0	-174	-76	-38	-3	0	0	0	0
Forestry	0	0	0	0	0	0	0	0	0	0	0	0
Other primary	-5	0	0	0	-93	1	-2	-33	0	0	0	0
Agriculture and forestry support	-2	0	0	-1	-42	-5	-5	-14	0	0	0	0
Meat and meat product manufacturing	-8	-1	-1	0	-77	-11	-10	-3	-26	-4	-3	-1
Dairy product manufacturing	-33	-15	-14	-9	-113	-50	-46	-32	-145	-64	-59	-41
Wood and paper manufacturing	0	0	0	0	2	2	2	2	0	0	0	0
Other manufacturing	-2	0	0	-1	-28	-3	2	-10	0	0	0	0
Utilities	0	1	1	0	-2	1	0	-2	0	0	0	0
Construction	1	2	2	0	19	26	34	0	0	0	0	0
Wholesale and retail trade	-8	-4	-4	-1	-175	-93	-86	-17	0	0	0	0
Transport	-2	-1	-1	-1	-28	-9	-10	-6	0	0	0	0
Professional/administrative services	3	6	2	-1	23	83	28	-22	0	0	0	0
Local and central government	-4	-2	-2	0	-38	-23	-22	-2	0	0	0	0
Other services	-41	-24	-23	-3	-490	-283	-275	-31	0	0	0	0
Total change relative to current state	-123	-51	-51	-17	-1232	-427	-421	-169	-171	-68	-62	-42

Table 14. Regional economic impacts in the Upper Waikato (Karapiro to Taupo Gates) FMU with constrained land-use change.

Industry	**Value added ($m)**				**Employment (MECs)**				**International exports ($m)**			
	Sc. 1	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**
Sheep, beef, and grain	-22	-11	-10	-1	-167	-59	-53	31	-1	0	0	0
Dairy farming	-77	-66	-68	-45	-797	-673	-722	-602	-1	-1	-1	-1
Forestry	8	8	9	6	77	77	80	54	2	2	3	2
Other primary	-4	0	0	0	-43	-1	-10	-11	0	0	0	0
Agriculture and forestry support	-2	-1	-1	-1	-33	-15	-20	-21	0	0	0	0
Meat and meat product manufacturing	-1	0	0	0	-5	-1	-1	0	-2	-1	-1	0
Dairy product manufacturing	-6	-4	-4	-3	-20	-12	-12	-9	-27	-16	-16	-13
Wood and paper manufacturing	10	10	10	7	53	53	55	37	5	5	5	4
Other manufacturing	0	0	0	0	-3	-1	2	0	0	0	0	0
Utilities	5	6	0	0	12	13	0	0	0	0	0	0
Construction	-2	-3	1	1	-37	-40	26	13	0	0	0	0
Wholesale and retail trade	-1	-1	-1	0	-34	-23	-19	-10	0	0	0	0
Transport	-1	0	0	0	-6	-2	-2	-2	0	0	0	0
Professional/administrative services	1	2	0	0	25	27	5	2	0	0	0	0
Local and central government	0	0	0	0	-3	-2	-2	-1	0	0	0	0
Other services	-12	-8	-8	-5	-119	-81	-84	-44	0	0	0	0
Total change relative to current state	-104	-68	-72	-41	-1100	-740	-757	-563	-24	-11	-10	-8

Table 15. Total economic impacts in the Waikato Region with constrained land-use change.

Industry	Value added ($m)				Employment (MECs)				International exports ($m)			
	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 1	Sc. 2	Sc. 3	Sc. 4
Sheep, beef, and grain	-96	-60	-62	2	-471	-19	-31	87	-3	0	0	1
Dairy farming	-265	-174	-164	-63	-2,257	-1,166	-1,122	-844	-3	-2	-1	-1
Forestry	9	9	9	6	78	78	82	55	3	3	3	2
Other primary	-42	3	-5	-2	-582	-1	-143	-97	0	0	0	0
Agriculture and forestry support	-8	-1	-2	-3	-155	-23	-30	-63	0	0	0	0
Meat and meat product manufacturing	-31	-5	-5	-2	-255	-40	-37	-12	-98	-16	-14	-5
Dairy product manufacturing	-82	-38	-36	-26	-276	-126	-121	-87	-367	-168	-161	-117
Wood and paper manufacturing	10	10	11	7	61	61	63	43	6	6	6	4
Other manufacturing	-4	-1	0	-1	-50	-10	1	-15	0	0	0	0
Utilities	0	5	-1	-2	2	13	-2	-4	0	0	0	0
Construction	1	1	8	1	40	36	142	16	0	0	0	0
Wholesale and retail trade	-15	-8	-7	-2	-340	-188	-172	-42	0	0	0	0
Transport	-6	-2	-2	-1	-65	-21	-23	-15	0	0	0	0
Professional/administrative services	5	10	3	-1	58	138	36	-28	0	0	0	0
Local and central government	-5	-3	-3	0	-68	-40	-40	-6	0	0	0	0
Other services	-94	-56	-55	-10	-992	-581	-575	-100	0	0	0	0
Total loss relative to baseline	-623	-310	-311	-97	-5,272	-1,889	-1,972	-1,112	-462	-177	-167	-116

Table 16. Total economic impacts across New Zealand with constrained land-use change.

Industry	Value added ($m)				Employment (MECs)				International exports ($m)			
	Sc. 1	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**
Sheep, beef, and grain	-151	-70	-71	-4	-1,292	-163	-168	-6	-3	0	0	1
Dairy farming	-368	-217	-205	-97	-3,146	-1,534	-1,479	-1,136	-3	-2	-1	-1
Forestry	7	8	9	5	70	75	79	52	3	3	3	2
Other primary	-50	4	-4	-4	-833	-52	-192	-140	0	0	0	0
Agriculture and forestry support	-31	-7	-8	-11	-600	-142	-162	-210	0	0	0	0
Meat and meat product manufacturing	-70	-12	-11	-4	-709	-123	-114	-39	-191	-33	-30	-10
Dairy product manufacturing	-126	-58	-56	-41	-474	-219	-211	-153	-537	-247	-238	-173
Wood and paper manufacturing	10	12	13	9	61	79	83	57	6	7	7	5
Other manufacturing	-39	-12	-9	-10	-356	-113	-75	-90	-1	0	0	0
Utilities	-14	1	-6	-5	-25	4	-11	-11	0	0	0	0
Construction	-7	-3	8	0	-86	-32	132	2	0	0	0	0
Wholesale and retail trade	-55	-24	-21	-10	-980	-465	-421	-164	0	0	0	0
Transport	-38	-13	-13	-9	-437	-145	-151	-102	0	0	0	0
Professional/administrative services	-22	15	-8	-13	-407	169	-136	-198	0	0	0	0
Local and central government	-19	-11	-11	-2	-218	-124	-125	-27	0	0	0	0
Other services	-203	-102	-102	-33	-1,940	-1,009	-1,014	-283	0	0	0	0
Total loss relative to baseline	-1,176	-489	-495	-229	-11,372	-3,794	-3,965	-2,448	-726	-272	-259	-176

5. Conclusions

Healthy Rivers: Plan for Change/Wai Ora He Rautaki Whakapaipai will establish targets and limits for nutrients (nitrogen and phosphorus), sediment, and *E. coli* in water bodies across the Waikato and Waipa River catchments. As part of this process, the Community Stakeholder Group (CSG) have identified an initial set of scenarios for water-quality improvement across these catchments that they wish to explore. This report addresses the extent of change required to achieve each scenario, given the current (baseline) situation as the starting point.

An economic model—considering the farm-, catchment-, regional-, and national-level economic implications of water-quality limits—is utilised to investigate and predict these changes. This model represents a key contribution of the Technical Leaders Group (TLG) to the Healthy Rivers/Wai Ora process, given that it integrates diverse information generated from a broad array of work streams initiated and managed by this committee. The model is applied to evaluate the current (baseline) scenario and the four alternative scenarios proposed by the CSG, in the context of various assumptions regarding how land-use change is best represented in models of this kind.

A number of key findings are evident in model output:

1. Three of the four scenarios (scenarios 1–3) impose a significant cost on the region, in terms of monetary outcomes, lost primary production, and jobs. Scenarios 1, 2, and 3 are estimated to cost the regional economy around $623 million; $310 million; and $311 million each year, respectively.
2. Model output identifies that scenarios 1, 2, and 3 reduce catchment-level profit annually by around 51%, 35%, and 25%, respectively.
3. These scenarios require the utilisation of a wide range of mitigation activities apart from land-use change; yet, within each scenario, at least one of the limits proposed by the CSG is breached.
4. Regional employment in key industries is also significantly affected, especially dairy-processing activity, and these negative impacts are distributed broadly across the Waikato. For example, there is a predicted loss of 2,000 jobs in this region in scenarios 2–3 and 5,000 jobs in scenario 1.

5. When expanded to the national level, scenarios 1, 2, and 3 cost the economy around $1,174 million; $487 million; and $496 million each year, respectively.
6. There is also a total national loss of around 11,372; 3,794; and 3,965 jobs associated with scenarios 1, 2, and 3, respectively.

Overall, this economic analysis emphasises that significant changes in land management and land use are required to achieve the water-quality objectives set out by the four scenarios developed by the CSG. These changes are likely to impose notable economic costs that vary spatially across the Freshwater Management Units defined within the HRWO process and the greater Waikato region itself.

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