AQUALINC RESEARCH LIMITED

Assessment of Farm Mitigation Options and Land Use Change on Catchment Nutrient Contaminant Loads in the Southland Region

Prepared for Southland Regional Council

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AQUALINC RESEARCH LIMITED

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EXECUTIVE SUMMARY

Intensification of agricultural land use, particularly the conversion of land use from traditional sheep and beef to dairy farming and ongoing production increases on existing dairy farms, continues to drive increasing loads of nutrients discharged to Southland's aquatic environments. Management of the effects of agricultural land use intensification on water quality in Southland will require careful consideration of two general approaches: on-farm mitigation measures, and control of land use intensification. This study investigated how nutrient loads in eight large Southland catchments would be changed by on-farm mitigation measures, and the extent to which on-farm mitigation measures could offset the effects of land use change and increasing production on dairy farms on catchment water quality.

A recent economic impact study by central government (MFE, 2013) provided estimates of the loss of nitrogen and phosphorus from every farm in the region (kg/hectare/year). The study distinguished farms on the basis of enterprise type (Dairy, Sheep & Beef or Forestry), and also accounted for other factors that influence nutrient loss rates, including land use intensity, land use capability, and drainage type. Nutrient loss estimates were based on the OVERSEER® farm nutrient budgeting model. OVERSEER® was also used to estimate how loss rates would change under three levels of on-farm mitigation measures. The mitigation levels represented bundles of measures that have different implications for nutrient loss rates and on-farm costs. Mitigation level 1 (M1) represented the most easily implemented measures, and Mitigation level 3 (M3) represented the most expensive, but effective measures.

A spatial analysis to determine the catchment agricultural loads of nitrogen and phosphorus (tonnes per year) was made by summing the farm losses within eight large catchments that comprise the majority of the Southland region. The eight catchments included the areas draining to four large estuaries: Waiau River Estuary, Jacobs River Estuary, New River Estuary, and Toetoes Harbour. These were large catchments which comprised the Waiau River, Aparima River, Oreti River, and Mataura River catchments, respectively. The other four catchments included areas draining to four additional estuaries: Bluff Harbour, Lake Brunton, Haldane Estuary, and Waikawa Harbour.

The current agricultural loads of nitrogen and phosphorus in the eight study catchments totalled approximately 16,100 and 374 tonnes/year, respectively, and these were distributed across the eight catchments in proportion to the number of farms. Loads from dairy farms comprised a disproportionately large proportion of the load in most of the catchments in comparison to the farm area. This reflects the higher loss rates of nitrogen and phosphorus from this enterprise type. Agricultural loads of nitrogen were reduced by between 18 and 32% when all farms adopted M1. M3 made more substantial reductions in all catchments with reduction in nitrogen loads from 29-37% and phosphorus loads from 40-80%. When only dairy farms adopted the mitigations, the reductions of the agricultural loads were significantly lower. Adoption of M1 by only dairy farms reduced catchment agricultural loads of nitrogen by between 1 and 6%, and of phosphorus by between 4 and 29%. Adoption of M3 by only dairy farms reduced catchment agricultural loads of nitrogen by between 2 and 18%, and of phosphorus by between 5 and 32%.

The load reductions under the mitigation measures were represented as 'additional capacity' (i.e. capacity for new contaminant load while at least maintaining current nutrient loads). Two types of additional capacity were calculated. First, the load reduction estimates were

expressed as equivalent land areas (and numbers of farms) converted from sheep & beef to dairy farming. The estimated areas and numbers of farms represent how much land use conversion would be required to 'use' the benefits of implementing the mitigations (in effect to have increased dairy farming while maintaining the current catchment loads). Second, the load reductions were converted to the number of years that nitrogen losses can increase at a compounding rate of 2% per year. This figure was based on work by Monaghan and De Klein (2014), who showed that this was the average increase in production per hectare in five regionally representative catchments in which land use is dominated by dairy farming (including the Bog Burn in Southland). The study by Monaghan and De Klein also showed nitrogen losses increased at a rate of 2% per year over the past decade.

The additional capacity created by applying M1 on all farms was equivalent to conversion of a total area of 137,572 hectares of sheep & beef farms, or 584 individual farms, across the eight catchments. Additional capacity created assuming that M1 was applied only on dairy farms was considerably less, and represented conversion of a maximum of 24,000 hectares, or 100 farms. The additional capacity created by applying M3 on all farms was equivalent to conversion of 293,000 hectares, or 1,200 farms. Additional capacity created assuming that M3 was applied only on dairy farms was equivalent to conversion of 108,000 hectares, or 460 farms.

In most catchments, the additional capacity created by applying M1 on all existing farms was equivalent to between 5 and 8 years of production increase on existing dairy farms at a compounding rate of 2% per year. Additional capacity created by applying M1 on only dairy farms was equivalent to only 1 to 3 years of productivity increases on existing dairy farms. When all farms were assumed to adopt M3, additional capacity was generally equivalent to 9 years of production increases on dairy farms. Additional capacity created by M3 on dairy farms only was equivalent to only 2 to 5 years of productivity increases.

The key findings of this study are that mitigation measures on farms could result in reductions in nutrient loads discharged in Southland. However, these reductions could be eroded in the future due to ongoing conversion of sheep & beef to dairy farms and production increases on dairy farms. The study indicates that adoption of M1 and M3 on dairy farms would only provide for an additional capacity that is equivalent to 25,000 and 108,000 hectares of conversion, which are equivalent to 104 or 460 averaged sized sheep & beef farms, respectively. Based on historical rates of conversion, the benefits of M1 could be eroded by farm conversions alone in a few years. In addition, based on past production increases on dairy farms, it seems likely that future production increases alone could use up the additional capacity created under all the mitigation scenarios in approximately a decade or less.

The largest reductions in nutrient loads can be achieved when both sheep & beef and dairy farms adopt mitigation measures. This is because sheep & beef remains the dominant land use by area in the Southland region, but losses from dairy farmers are greater per hectare. Overall, the contributions from both land uses are significant. However, given the higher per hectare losses, it follows that mitigation on dairy farms provides a greater per hectare benefit for water quality.

It is concluded that under the status quo of ongoing conversions and increasing production on dairy farms, water quality will not be maintained (or improved by 10% as required under the current Plan[1]) in the long term even if very stringent mitigation requirements (i.e. M3 on all farms) were to be adopted. Setting limits for catchment nutrient loads and then managing discharges to meet these limits appears to be the most appropriate method for ensuring that the goal of maintaining and improving water quality in Southland will be achieved.

[1] Objective 4 of the Water Plan specifies a “10% improvement” in levels of nitrate, phosphorus, clarity and microbiological contaminants between 2010 and 2020 in lowland, hill and spring-fed water bodies.

1 INTRODUCTION

Southland Regional Council (SRC) has a long-term project for the management of water and land in the Southland region called *Water and Land 2020 & Beyond* (WAL2020). The project responds to water quality changes and increasing pressure on ecosystem health that is currently being experienced in parts of the region. It addresses these issues in three key work streams; Focus Activities, Interim Measures, and then Catchment Limits. Among the significant environmental issues are increases in the loads of nutrients (nitrogen and phosphorus) discharged into aquatic environments. High levels of nutrients are of concern because they lead to eutrophication of rivers and estuaries. In addition, high levels of one type of nutrient (i.e. nitrate) are toxic. Nitrate can contaminate groundwater that is used by humans for drinking, and surface waters where it has ecological health implications. The major contributor to nutrient discharges in Southland has been shown to be from diffuse sources associated with agricultural land use (Aqualinc, 2014).

Intensification of agricultural land use, particularly land use conversion from traditional sheep & beef to dairy farming and increasing production on existing dairy farms, continues to drive increasing loads of nutrients discharged to Southland's aquatic environments. Nutrient discharges are generally considerably higher (approximately three times, see Section 2.1) from dairy, compared to sheep & beef farms. In addition, recent work by Monaghan and De Klein (2014) indicates that an average increase in milk production of 2% per annum occurred on 50 surveyed dairy farms in five case study catchments throughout New Zealand, over the period from 2001 to 2009. Monaghan and De Klein also found that these productivity increases were associated with similar percentage increases in nitrogen leaching.

A key goal of the WAL2020 project is to enable sustainable land use, while maintaining and improving water quality and water quantity across the catchments within the Southland region. In addition, objective 4 of the Regional Water Plan (RWP) also sets an improvement target of 10%[2] in various water quality measures, including nutrients. This improvement target is to be achieved in the 10-year period from when the RWP became operative (i.e. in 2010). The WAL2020 project is also SRC's response to recent government policies, particularly the *National Policy Statement – Freshwater Management 2012* (NPS-FM). The NPS-FM requires that regional councils establish objectives, set limits and establish methods (including rules) to avoid over-allocation. In particular, the NPS-FM recognises the need to manage land, water and coastal environments in an integrated way, and to establish limits to effectively manage the cumulative effects of land use on water quality.

Management of the effects of agricultural land use intensification on water quality in Southland will require careful consideration of two general approaches: on-farm mitigation measures, and managing land use intensification. Both of these approaches will impact on a wide range of community values, including social, cultural, economic and environmental. The implications of setting freshwater objectives and limits were recently the subject of a joint venture economic impact study by central government departments, including the Ministry for the Environment (MfE), the Ministry of

[2] Objective 4 of the RWP specifies a "10% improvement" in levels of nitrate, phosphorus, clarity and microbiological contaminants between 2010 and 2020 in lowland, hill and spring-fed water bodies.

Primary Industries (MPI), and the Department of Conservation (DOC) (MFE, 2013). The purpose of the economic impact study was primarily to inform government on the potential impacts of amending the NPS-FW to include a National Objectives Framework (NOF) (MFE, 2013). The study results concluded that expansion of dairy farming could occur, and the tested NOF 'bottom lines' would continue to be met without undertaking additional mitigation both now and in 2037. However, the study also showed that although 'bottom lines' would continue to be met, water quality would decline. Declines in water quality would be inconsistent with the goal of WAL2020, the Regional Plan and also the NPS-FW, which requires that overall water quality in a region is maintained.

The purpose of the present study was to use the data that was generated from the economic impact study by central government to further understand nutrient contaminant loads in the Southland region. In particular, this study has investigated how nutrient loads in eight large Southland catchments could be changed by on-farm mitigation measures, and the extent to which on-farm mitigation measures could off-set the effects of land use change and increase production on dairy farms on catchment water quality.

2 DATA

2.1 Agricultural Source Loads

In this report, 'source load' is defined as the total annual mass of contaminant generated at the source (e.g. from land under a specific land use, or from a point source such as a sewage treatment station discharge). As part of the recent economic impact study by central government (MFE, 2013), detailed modelling of source loads from all agricultural land (including forestry) in Southland was carried out by NZIER (2013). The NZIER study provides estimates of the source loads of nitrogen and phosphorus from every farm in the region, as well as estimates of how these loads would change under various on-farm mitigation measures. These source loads were estimated for the 'current' land use based on land use data obtained in 2012.

The NZIER (2013) study identified the location of all 3290 farms within the region, and then categorised them based on four factors:

- Enterprise type (Dairy, Sheep & Beef, or Forestry)
- Land use intensity level (High, Medium or Low)
- Land use capability (LUC) category (A=1-2, B=3-4, and C=5+)
- Drainage type (well drained (WD) or poorly drained (PD))

Representative farm types were defined based on all potential combinations of the four factors (see Figure 1). Each farm in the region was then assigned to a farm type based on analysis of spatial data (NZIER, 2013). Not all the potential combinations occur in Southland. For example, dairy farming did not occur in LUC category C.

Estimates of total annual loads of nitrogen and phosphorus leached from each farm were made by AgResearch Ltd (NZIER, 2013). The farm nutrient budgeting model, OVERSEER®, was used to simulate leaching rates for the current (2012) farm practice and three levels of mitigation (see Figure 1).

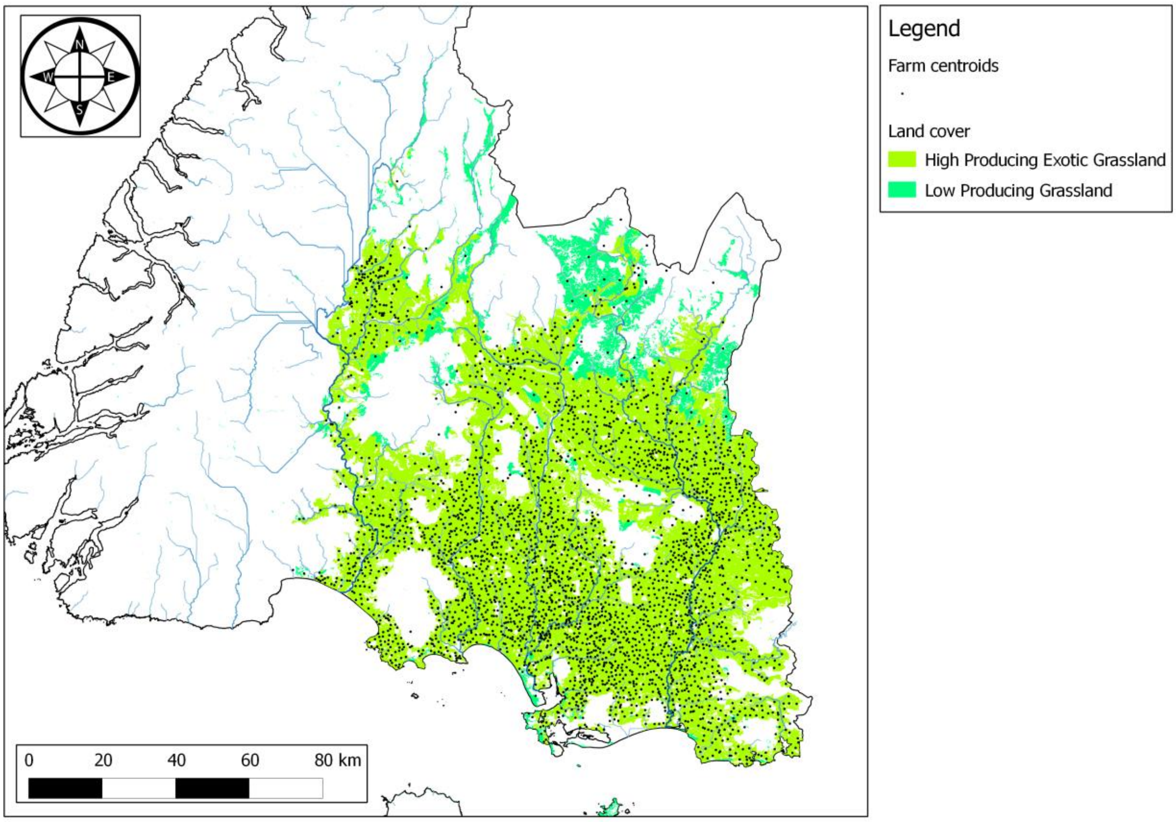

Figure 1: The location of the Southland farms that were included in the study. The map indicates the centroids of all 3290 farms within the region, as well as the area of pasture land cover as defined by MfE's New Zealand Land Cover Database.

The practice of 'wintering-off' refers to dairy cows spending the winter months away from the main farm (the milking platform) on a separate farm that provides dairy support in addition to other pastoral agriculture (mainly sheep and beef). Wintering-off commonly occurs on forage paddocks where kale, swedes, or other forage crops have been grown. For a number of reasons, nitrogen leaching from winter forage paddocks can be high, relative to normal pasture, so wintering-off has a disproportionate effect (by area) on nitrogen losses. Because the OVERSEER® model represents a single farm, wintering-off was not represented in the estimates of farm source loads of nitrogen and phosphorus (NZIER, 2013). To account for the impact of wintering-off, the NZIER study estimated nitrogen losses associated with wintering-off and added these to the loads estimated using OVERSEER®. The wintering-off nitrogen leaching estimates took into account the land area required to winter off the dairy herd and the estimated nitrogen losses from winter forage crop grazing. This allowed the total regional load of nitrogen leached due to wintering-off to be estimated. The NZIER study then assumed that the total regional load of nitrogen due to wintering-off was distributed over sheep & beef farms. The total load was distributed to sheep & beef farms that had LUC categories of A and B, and allowance was made for differences in stocking rates associated with these land classes. In addition, the distribution was stratified by 'water management zones', which were defined by subdividing the Southland region into lowlands, hill country, and inland basins. It was assumed that wintering would occur on dairy support farms that were in the same 'water management zone' as the dairy farm.

In the present study, we used the approach of NZIER (2013) to account for wintering occurring on sheep & beef farms. We used the same estimates of the regional load of nitrogen leached due to wintering-off and the same assumptions about stocking rates associated with LUC categories A and B. Contrary to the approach of NZIER, we did not stratify the distribution of wintering-off by water management zone, and simply distributed the wintering-off over all sheep & beef farms in the region. This was because the need to winter off is often driven by climate and soil conditions. Farmers try to restrict wintering on heavier soils (which dominate the lowland Southland plains) to preserve their productive capacity for growing grass. Thus, the inland basins and hill country areas of Southland, where soils are lighter and rainfall is lower, are likely to receive wintering cows from the 'lowland zone'. We consider our un-stratified distribution of wintering-off over all sheep & beef farms is likely to be more robust than the assumptions about wintering made by NZIER. However, we acknowledge that this is also a simplification of the reality that is necessary, because there is currently a lack of data about wintering-off practices.

2.2 Non-agricultural Source Loads

Catchment source loads also include loads from non-agricultural areas including scrub, tussock and native forest. We needed to account for these non-agricultural sources of nitrogen and phosphorus to understand the relative contribution of agricultural loads to water quality.

We used source loads derived from the calibration of the SPARROW (Spatially Referenced Regressions On Watershed) component of the CLUES model (Palliser & Elliott, 2013). The SPARROW model includes a source load term for different land use/cover categories, and further modifies this with a land to water delivery term, which includes consideration of rainfall (delivery increases with increasing rainfall). The model was recently calibrated for the Southland region as part of the economic impact study (Palliser & Elliott, 2013). The calibrated nitrogen source load for scrub and native vegetation was 4.6 kg/ha/yr, and the coefficient for the delivery term was 3.6 per meter of annual rainfall. The effect of the delivery term on the source load is spatially variable due to the spatial variation in rainfall. However, the variability of the delivery term over the catchments of interest is not large (~0.73 to 0.88, based on annual rainfall variation from 1 to 1.5 m). We therefore adopted an approximate uniform nitrogen source load over all catchments for non-farms areas of 3.4 kg/ha/yr. Similar source load estimates are available from the SPARROW model for phosphorus, but these are more spatially variable due to the inclusion of a spatially variable erosion term. We did not therefore attempt to estimate source loads of phosphorus for the non-farm areas in this simple analysis; but this could be possible in the future.

2.3 Realised Load Estimates

We attempted to verify our estimates of nutrient source loads by comparing them with estimates of 'realised loads' derived from water quality data. It is important to distinguish source loads from the realised loads. These two variables are both loads that can be calculated for a catchment, which are expressed using the same units (kg or tonnes/year). However, the realised load refers to loads exported from a catchment, and implicitly includes attenuation of the source load within the stream network (e.g. Elliott & Sorrell, 2002). The source load refers to the load delivered to the stream network and, therefore, does not include any attenuation.

We estimated realised loads for the study catchments using models of realised total nitrogen loads developed by Aqualinc (2014). The model was derived using water quality and flow data observed at 73 State of Environment (SoE) monitoring sites in the Southland region. The observed nitrogen loads at the 73 SOE sites were used to fit a regression model that used catchment characteristics as predictors, such as area, topography, land cover and climate (see Aqualinc (2014) for details).

The regression models were used to predict the realised loads for the study catchments. We compared the estimated realised loads with the estimated source loads. We expected the realised loads to be less than the source loads due to attenuation and anticipated that attenuation would be in the range of 30% to 50%. We assumed that estimates of attenuation in this range was evidence that our load estimates were reasonable.

2.4 Mitigations

Farmers can modify farming activities to produce lower levels of nitrogen and phosphorus leaching. The NZIER (2013) study used the OVERSEER® model to estimate nitrogen and phosphorus leaching rates for each farm type under three levels of mitigation. Each level of mitigation has different implications for discharges and on-farm costs. The three levels were modelled as cumulative; that is, Mitigation level 2 (M2) includes Mitigation level 1 (M1), and Mitigation level 3 (M3) includes M1 and M2. A very brief description of the practices adopted under the three levels of mitigation is provided in Table 1. For more details, see NZIER (2013).

There was no mitigation applied to wintering-off because of the manner in which it was handled by the NZIER (2013) study. This is likely to result in an underestimate of the extent to which mitigation could reduce loads of nitrogen in particular.

Table 1: Mitigation measures assumed to apply under the three levels of mitigation.The measures at each level differ between enterprise type (i.e. sheep & beef and dairy farms). The three levels are cumulative; i.e. M2 includes M1, and M3 includes M1 and M2.

Mitigation level	Name	Sheep & Beef	Dairy
Mitigation level 1	M1	• Optimised nutrient inputs • Low solubility P • Wetlands	• Stock exclusion from streams • Improved nutrient management • Improved farm dairy effluent (FDE) management
Mitigation level 2	M2	• Stock exclusion from streams • Reduced stocking rates, improved productivity	• Wetlands • Improved FDE management • Reduced stocking rates, improved per animal productivity.
Mitigation level 3	M3	• Grass buffer strips • Feed pad for beef cattle	• Restricted grazing strategies • Grass buffer strips • Improved FDE management

2.5 Nutrient Leaching Rates Under Differing Mitigation Measures

The leaching rates estimated using OVERSEER® for each of the farm types are shown in Figure 2. Farm leaching rates were highest for dairy farms, followed by sheep & beef and forestry. The range of estimated leaching rates was highest for dairy farming, indicating that this enterprise type had the highest potential to reduce loads. Forestry had no capacity to mitigate leaching rates.

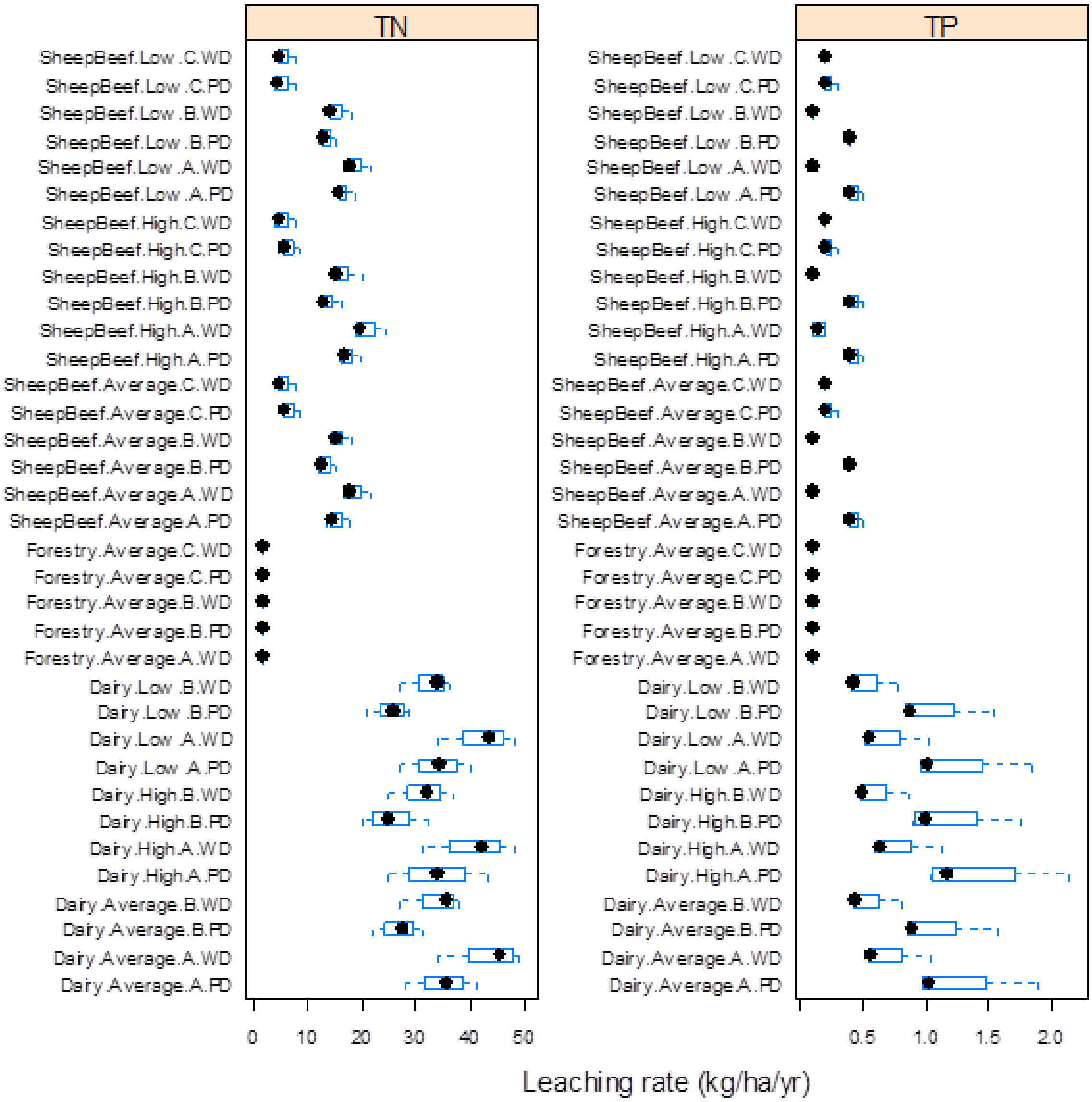

Figure 2: Range of leaching rates for all representative farm types estimated using the OVERSEER® model. (Source: NZIER, 2013) The range includes the current estimated leaching rate and the reduced leaching rates under the three mitigation bundles. Only farm types that actually occurred are shown in the plot (e.g. dairy farming did not occur in LUC category C).

3 ASSESSMENT

3.1 Catchments and Farms

We performed a spatial analysis of source and realised loads of nitrogen and phosphorus in the Southland region broken down into eight catchments. The eight catchments included the areas draining to four estuaries: Waiau River Estuary, Jacobs River Estuary, New River Estuary, and Toetoes Harbour. These were large catchments which comprised the Waiau River, Aparima River, Oreti River, and Mataura River catchments, respectively (Figure 3 and Table 2). The other four catchments included areas draining to four additional estuaries: Bluff Harbour, Lake Brunton, Haldane Estuary, and Waikawa Harbour (Figure 3 and Table 2). The study did not include two estuaries (Waimatuku Estuary and Waituna Lagoon), because the spatial resolution of the farm data was insufficient for these small catchments to be well represented.

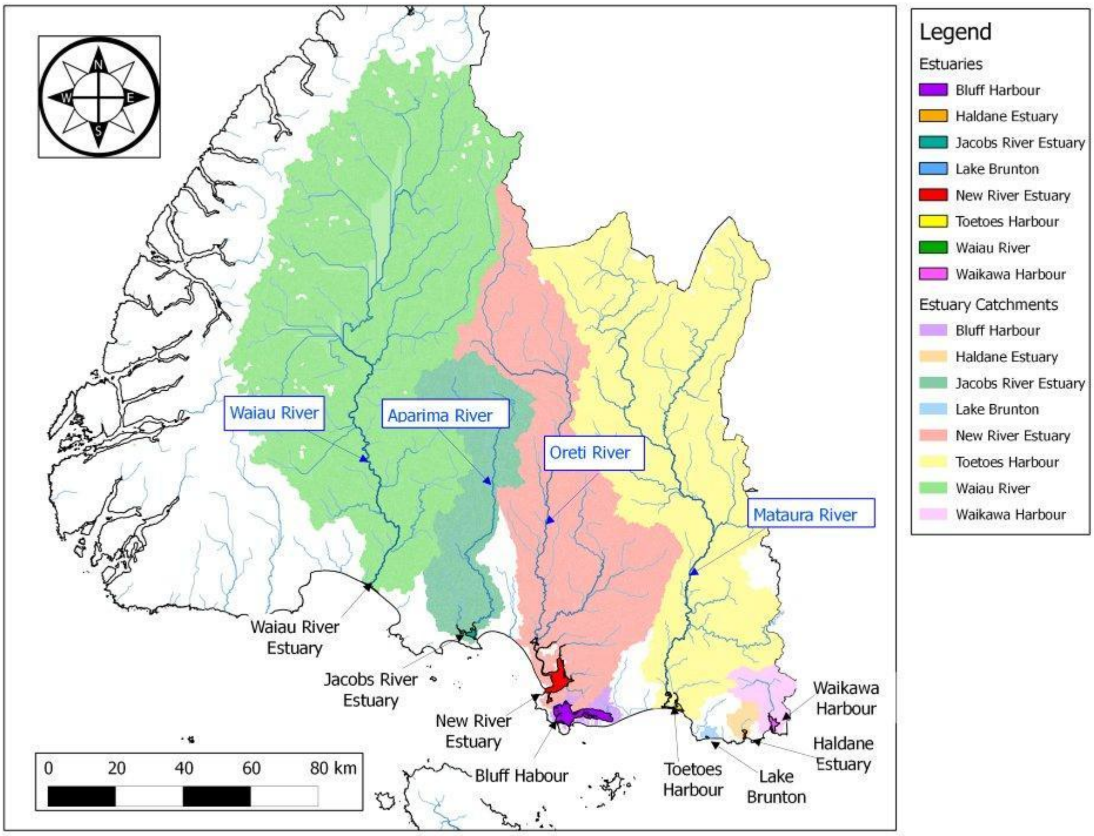

Figure 3: The eight catchments that were used as the basis of the spatial analysis in this study.

We used data from NZIER within a Geographic Information System (GIS) to associate each farm with one of the study catchments. We made this association by locating the centroid of each farm within one study catchment. There is some error associated with this as the boundaries of some farms crossed catchment boundaries. We assumed that the aggregate of these errors would be small because of the large scale of the analysis. Approximately 11% of the farm centroids were not within any of the eight study catchments; for example, farms within the catchments of Waimatuku Estuary and Waituna Lagoon. These farms were excluded from the analysis, which means that the totals of the catchment nutrient loads presented in this study do not represent (i.e. underestimate) the total regional nutrient loads. Different enterprise types made up varying proportions of the study catchments, and agricultural land use made up varying amounts of the total area of the eight study catchments (Table 2).

Table 2: Total number of farms by enterprise type, total catchment area, and farm area in each catchment.

Catchment	Total number of farms	Dairy	Forestry	Sheep & beef	Catchment area (ha)	Farm area (ha)
Waiau_River	347	33	3	311	827,299	190,900
Jacobs_River_Estuary	345	102	10	233	156,474	104,700
New_River_Estuary	1125	271	33	821	409,334	248,658
Bluff_Harbour	10	1	2	7	6793	1617
Toetoes_Harbour	1035	237	14	784	560,322	453,879
Lake_Brunton	5	-	-	5	1455	1353
Haldane_Estuary	7	-	-	7	6758	2082
Waikawa_Harbour	39	2	1	36	23,605	14,145

3.2 Catchment Nutrient Loads

We estimated current (2012) agricultural source loads of nitrogen and phosphorus by summing the farm source loads provided by NZIER (2013) within each catchment by enterprise type and practice (i.e. assuming no mitigation or one of the three mitigation scenarios). We made two sets of assumptions regarding the adoption of the three mitigation scenarios: either the mitigations were adopted by all enterprise types (i.e. dairy and sheep & beef), or the mitigations were adopted only by dairy farms. We also estimated the total nitrogen source load for each catchment by multiplying the non-farm areas (Table 2) by the estimated non-agricultural source load (3.4 kg/ha/yr), and adding this to the estimated agricultural nitrogen source load.

We evaluated the potential overall water quality improvement by comparing current catchment nitrogen loads to the estimated loads if farms adopt the mitigations. This represents an indicator for assessing the RWP Objective 4 (to improve water quality by 10%[3]). We consider the indicator based on nitrogen load is relevant for several reasons. Firstly, many water quality issues in Southland are primarily due to high nitrogen (or nitrate), including eutrophication of estuaries and rivers, and contamination of groundwater (Aqualinc, 2014). Secondly, all contaminants are highly correlated at the regional scale (Aqualinc, 2014), and therefore nitrogen can be considered a proxy for other contaminants. Finally, loads and concentrations are generally correlated, and reductions in loads are generally assumed to be associated with equivalent reductions in concentrations (Palliser & Elliott, 2013). The overall water quality improvement was calculated as:

$$\frac{(\text{Total catchment nitrogen source load} - \text{Total catchment nitrogen source load under mitigation}) \times 100\%}{\text{Total catchment nitrogen source load}}$$

[3] Objective 4 of the Water Plan specifies a "10% improvement" in levels of nitrate, phosphorus, clarity and microbiological contaminants between 2010 and 2020 in lowland, hill and spring-fed water bodies.

3.3 Analysis of Additional Capacity Created by Mitigations

The economic impact study by central government concluded that growth in agricultural production can be achieved while maintaining or improving overall water quality (MFE, 2013). However, because growth in agricultural production (particularly dairy production) will increase agricultural source loads (particularly nutrient loads), future growth, while maintaining or improving water quality, can only occur if mitigation measures are used to make ‘additional capacity’ (i.e. capacity for new contaminant load). The reductions in contaminant loads estimated for each of the eight study catchments were converted into two types of additional capacity estimates. First, we converted the load reduction estimates into equivalent land areas (and numbers of farms) being converted from sheep & beef to dairy farming. The estimated areas and numbers of farms represent how much land use conversion would be required to ‘use’ the benefits of implementing the mitigations (in effect, to have increased dairy farming while maintaining the current nutrient loads). Second, we converted the load reductions to a number of years of increasing production on existing dairy farms. We assumed that productivity increases occur at a compounding rate of 2% per year based on the findings of Monaghan and De Klein (2014). We also assumed that there is a commensurate increase (i.e. 2%) in the leached nitrogen associated with the increased productivity, again based on the work of Monaghan and De Klein.

The exact area of land use change required to use a given additional capacity (i.e. load reduction) depends on the characteristics of the farm (i.e. the farm type) on which the change occurs. Our analysis is non-specific about where the land use change occurs in the catchments. We therefore used the difference in the mean leaching rates for dairying and sheep & beef over all farm types to represent the difference in loads between land uses.

4 RESULTS

4.1 Catchment Nutrient Loads

4.1.1 Current Loads

The current agricultural source loads of nitrogen and phosphorus in the eight study catchments were approximately 16,100 and 370 tonnes/year and these were distributed across the eight catchments in proportion to the number of farms (Table 3). Wintering-off (i.e. wintering of dairy cows off the diary platform) contributed 7% of the total nitrogen load across the eight catchments. The estimated total nitrogen source load (i.e. including contributions from non-agricultural land) across all eight catchments was approximately 19,400 tonnes/year. The estimated realised loads (i.e. the loads that were estimated based on water quality monitoring data) were derived by Aqualinc (2014), and were always less than the source loads, except for Waikawa Harbour. This resulted in estimated average attenuation coefficients (the amount by which the source load is reduced in the environment) of around 30% (Table 3). Catchment attenuation rates from 30 to 50% are consistent with reported values reported by other studies in New Zealand (e.g. Palliser & Elliott, 2013), indicating that the analysis is reasonable from a mass balance perspective.

Table 3: Estimated loads of nitrogen and phosphorus in the eight study catchments. The total catchment source load of nitrogen represents the farm loads plus the non-farm source loads. The estimated realised loads were derived from catchment load models (Aqualinc, 2014). The estimated attenuation is the difference between the source and realised loads divided by the source load.

Catchment	Current catchment agricultural source loads (t/year)		Total catchment source nitrogen load (t/yr)	Estimated realised nitrogen loads (t/yr)	Estimated attenuation (%)
	Nitrogen	Phosphorus			
Bluff_Harbour	19	1	36	29	20
Haldane_Estuary	23	0	39	26	33
Jacobs_River_Estuary	1958	53	2133	1300	39
Lake_Brunton	20	0	20	14	30
New_River_Estuary	4969	139	5513	3718	33
Toetoes_Harbour	6256	142	6617	4392	34
Waiau_River	2714	35	4970	1864	62
Waikawa_Harbour	144	4	176	180	-2
Total/average	16,102	374	19, 404	11,524	31 (average)

Although sheep & beef farms were the dominant source of nitrogen and phosphorus load in most of the catchments (Table 4), loads from dairy farms comprised a disproportionately large proportion in comparison to their farm area (Table 2). This reflects the higher leaching rates of nitrogen and phosphorus from this enterprise type (Figure 2). Nitrogen loads associated with wintering-off of dairy cows accounted for 7% of the total nitrogen load from the eight study catchments.

Table 4: Relative contribution (%) to current agricultural source loads of nitrogen and phosphorus by enterprise type. Note that the contribution of wintering-off of dairy cows to nitrogen load is a component of the sheep & beef contribution.

Catchment	Nitrogen			Phosphorus		
	Dairy	Forestry	Sheep & Beef	Dairy	Forestry	Sheep & Beef
Bluff_Harbour	42	2	56	61	3	36
Haldane_Estuary	-	-	100	-	-	100
Jacobs_River_Estuary	50	1	49	64	2	34
Lake_Brunton	-	-	100	-	-	100
New_River_Estuary	52	0	48	67	1	32
Toetoes_Harbour	30	0	70	40	0	60
Waiau_River	10	0	89	19	1	80
Waikawa_Harbour	6	0	93	11	0	89

4.1.2 Changes to Agricultural Source Loads Under Mitigation Scenarios

Agricultural source loads of nitrogen were reduced from current loads by between 18 and 32% when all farms adopted M1 (Table 5). Agricultural loads of phosphorus were reduced by between 0 and 31% when all farms adopted M1. M2 made very minor differences in the reduction of nitrogen and phosphorus loads compared to M1. M3 made more substantial nitrogen and phosphorus load reductions in all catchments. Reductions of the agricultural source loads of nitrogen ranged from 29 to 37%, and reductions in phosphorus loads were in the order of 40 to 80%.

The overall water quality improvements (as indicated by reduction in total catchment nitrogen source loads) were always less than the reduction in the agricultural nitrogen load, because farms only make up a proportion of the catchments. Adoption of M1 by all farms produced a reduction in total catchment nitrogen source loads of more than 11% for all catchments. Adoption of M2 had a minor effect on the total catchment nitrogen source loads compared to M1, but adoption of M3 further reduced loads by more than 20% for most catchments.

Table 5: Reductions in the agricultural source loads (% of current load) for nitrogen and phosphorus in each catchment under the three levels of mitigation and assuming all farm types adopt mitigations.

Catchment	M1			M2			M3		
	Nitrogen	Phosphorus	Overall[1]	N	P	Overall[1]	N	P	Overall[1]
Bluff_Harbour	22	25	11	22	14	11	32	57	17
Haldane_Estuary	32	0	19	32	0	19	37	80	22
Jacobs_River_Estuary	18	31	16	19	34	17	30	39	27
Lake_Brunton	25	0	25	25	0	25	28	38	28
New_River_Estuary	18	31	16	19	35	17	30	42	27
Toetoes_Harbour	24	19	22	24	21	23	33	55	31
Waiau_River	25	11	14	25	10	14	29	39	16
Waikawa_Harbour	29	9	23	28	6	23	33	52	27

[1] The overall column indicates the reduction of the total catchment nitrogen source load of nitrogen (agriculture and non-agricultural loads). This is assumed to represent the overall improvement to water quality.

Table 6 shows that when only dairy farms adopted the mitigations, the reductions of the current source loads were significantly lower than those when all farms were assumed to apply the mitigations. Adoption of M1 by dairy farms produced a reduction of agricultural source loads of nitrogen of between 1 and 6% for catchments in which dairy farms were present. Adoption of M3 by dairy farms further reduced agricultural source loads of nitrogen to between 2 and 18% for catchments in which dairy farms were present. Adoption of M1 by only dairy farms reduced agricultural source loads of phosphorus by between 4 and 29% for catchments in which dairy farms were present. Adoption of M3 by dairy farms further reduced agricultural source loads of phosphorus between 5 and 32%.

Table 6: Reductions in the agricultural source loads (% of current load) for nitrogen and phosphorus in each catchment under the three levels of mitigation assuming only dairy farms adopt the mitigations.

Catchment	M1			M2			M3		
	Nitrogen	Phosphorus	Overall[1]	N	P	Overall[1]	N	P	Overall[1]
Bluff_Harbour	4	26	2	4	29	2	12	29	6
Haldane_Estuary	0	0	0	0	0	0	0	0	0
Jacobs_River_Estuary	6	28	5	8	31	6	18	31	15
Lake_Brunton	0	0	0	0	0	0	0	0	0
New_River_Estuary	6	29	5	8	32	7	18	32	15
Toetoes_Harbour	3	17	3	4	19	4	10	18	9
Waiau_River	1	9	0	1	9	1	4	9	2
Waikawa_Harbour	1	4	1	1	5	1	2	5	2

[1] The overall column indicates the reduction of the total catchment nitrogen source load of nitrogen (agriculture and non-agricultural loads). This is assumed to represent the overall improvement to water quality.

4.2 Additional Capacity

4.2.1 Additional Capacity Represented as Equivalent Land Use Change

The additional capacity when expressed as areas of land conversion from sheep & beef to dairy farming that are consistent with the load reductions under M1 is shown in Table 7. The areas of land conversion are also shown in Table 7 as the equivalent number of dairy farms based on the current average dairy farm area in the region (237 ha).

The calculations of additional capacity under M1 were based on mean loss rates for nitrogen and phosphorus of 10.1 kg/ha/yr and 0.2 kg/ha/yr, respectively, for sheep & beef farms, and 35.1 kg/ha/yr and 0.8 kg/ha/yr, respectively, for dairy farms. More additional capacity was created for phosphorus than nitrogen in some catchments. For example, in the Jacobs River Estuary catchment the load reductions were equivalent to converting 13,760 ha of sheep & beef to dairy farms (or 58 average sized sheep &

beef farms) for nitrogen, but 30,299 ha (or 129 average sized sheep and beef farms) for phosphorus (Table 7). If it is assumed that the usable additional capacity is that of the limiting nutrient, the additional capacity created by applying M1 on all farms would be equivalent to the conversion of a total area of 137,572 ha or 584 existing sheep & beef farms across all the eight catchments (Table 7). No additional capacity is created in the Haldane and Lake Brunton catchments, and the equivalent of 58, 149 and 214 farms would be created in Jacobs River Estuary, New River Estuary, and Toetoes Harbour, respectively (Table 7). It is noted that these calculations include the nitrogen losses associated with wintering-off of cows from existing dairy farms on sheep & beef farms. However, wintering-off losses have not been included in the calculation of additional capacity (i.e. the additional dairy farms that are equivalent to the reductions in source loads). This means that the additional capacity shown in Table 7 is overestimated (i.e. if wintering were included, the conversion areas and numbers of farms would be slightly less than shown).

Additional capacity created assuming that M1 is applied only to dairy farms was considerably less than for mitigations on all farms (Table 7). The limiting nutrient in this case was always nitrogen, and additional capacity created represented a maximum of 24,426 ha or 104 farms converting from sheep & beef to dairy farms.

Table 7: Additional capacity created (i.e. load reductions) in each catchment by adopting M1 expressed as conversion of area (ha) of sheep &beef to dairy farms, and as conversion of a number of average sized sheep & beef farms. Results are shown for the assumption that all farms adopt M1 and only dairy farms adopt M1.

Catchment	M1 All Farms				M1 Dairy only			
	Nitrogen (ha)	Phosphorus (ha)	Nitrogen (farms)	Phosphorus (farms)	Nitrogen (ha)	Phosphorus (ha)	Nitrogen (farms)	Phosphorus (farms)
Bluff_Harbour	166	314	1	1	32	314	0	1
Haldane_Estuary	298	0	1	0	0	0	0	0
Jacobs_River_Estuary	13,760	30,299	58	129	4,382	27,061	19	115
Lake_Brunton	198	0	1	0	0	0	0	0
New_River_Estuary	35,177	80,452	149	342	11,584	73,832	49	314
Toetoes_Harbour	59,548	50,475	253	214	7,432	45,814	32	195
Waiau_River	26,768	6,936	114	29	960	54,58	4	23
Waikawa_Harbour	1,659	764	7	3	36	362	0	3
Total	137,572	169,240	584	718	24,426	152,841	104	650

The calculations of additional capacity under M3 were based on mean loss rates for nitrogen and phosphorus of 9.7 kg/ha/yr and 0.2 kg/ha/yr (respectively) for sheep & beef farms, and 26.8 kg/ha/yr and 0.7 kg/ha/yr (respectively) for dairy farms. If it is assumed that the usable additional capacity is that of the limiting nutrient, the additional capacity created by applying M3 on all farms would be equivalent to a total area of 292,758 ha or the conversion of 1242 existing sheep & beef farms across all the eight catchments (Table 8).

Additional capacity created assuming that M3 is adopted only on dairy farms was considerably less than for adopting M3 on all farms (Table 8). The limiting nutrient in this case was always nitrogen, and additional capacity created represented a maximum of dairy conversion of 27% and 28% of the existing sheep & beef farm areas in the Jacobs River Estuary and New River Estuary catchments (respectively), and only 9% and 2% for the Toetoes Harbour and Waiau River catchments (respectively).

Table 8: Additional capacity created (i.e. load reductions) in each catchment by adopting M3 expressed as conversion of area (hectares) of sheep and beef to dairy farms and as conversion of a number of average sized sheep and beef farms. Results are shown for the assumption that all farms adopt level 3 mitigations and only dairy farms adopt level 3 mitigations.

Catchment	M3 All Farms				M3 Dairy only			
	Nitrogen (ha)	Phosphorus (ha)	Nitrogen (farms)	Phosphorus (farms)	Nitrogen (ha)	Phosphorus (ha)	Nitrogen (farms)	Phosphorus (farms)
Bluff_Harbour	350	697	1	3	126	335	1	1
Haldane_Estuary	492	492	2	2	0	0	0	0
Jacobs_River_Estuary	34,162	37,283	145	158	18,816	28,876	80	123
Lake_Brunton	323	113	1	0	0	0	0	0
New_River_Estuary	88,369	10,4213	375	443	49,553	78,155	210	332
Toetoes_Harbour	120,313	13,9326	511	592	34,665	46,467	147	197
Waiau_River	45,944	23,967	195	102	5,048	5,200	21	22
Waikawa_Harbour	2,805	4,049	12	17	158	385	1	2
Total	292,758	310,140	1,242	1,317	108,366	159,419	460	667

4.2.2 Additional Capacity Represented as Years of Production Increases

Additional capacity created by adopting M1 on all existing farms was equivalent to between 5 and 21 years of production increase (at a compounding rate of 2%) on existing dairy farms (Table 9). It is noted that this analysis assumes that losses increase on dairy platforms but that the wintering-off losses do not increase. In this analysis, the Waikawa Catchment is an outlier at 21 years, which arises because there are only two dairy farms in the catchment but 36 sheep & beef farms (Table 2). Therefore, under the M1 scenario, in which all farms mitigate, there would be considerable additional capacity created in the Waikawa Catchment that is only slowly 'used up' by the two dairy farms. The remaining catchments had additional capacity, representing only 5 to 8 years of production increases on dairy farms. Additional capacity created by adopting M1 on dairy farms only was equivalent to only 1 to 3 years of productivity increases (Table 9). This is due to the considerably smaller load reduction under this scenario (Table 6).

When all farms were assumed to adopt M3, additional capacity was generally equivalent to 9 years of production increases on dairy farms (Table 9). The major exception to this was Waikawa Catchment at 22 years for reasons discussed above. Additional capacity created by adopting M3 on dairy farms only was equivalent to only 2 to 5 years of production increases (Table 9).

Table 9: Additional capacity created by mitigation measures expressed as years of production increase (at a compounding rate of 2%) on existing dairy farms. The Haldane Estuary and Lake Brunton catchments do not have values because there are no dairy farms assigned to these catchments.

Catchment	M1 All Farms (yr)	M1 Dairy only (yr)	M3 All Farms (yr)	M3 Dairy only (yr)
Bluff_Harbour	8	3	9	5
Haldane_Estuary	-	-	-	-
Jacobs_River_Estuary	5	2	7	5
Lake_Brunton	-	-	-	-
New_River_Estuary	5	3	7	5
Toetoes_Harbour	8	2	9	5
Waiau_River	8	1	9	2
Waikawa_Harbour	21	3	22	6

5 CONCLUSIONS

5.1 Key Findings

This study indicates that mitigation measures on farms could result in reductions in nutrient loads discharged in Southland. However, these reductions could be eroded in the future due to ongoing conversion of sheep & beef to dairy farms and production increases on dairy farms. The study also indicates that adoption of M1 and M3 on dairy farms only would only provide for an additional capacity that is equivalent to 25,000 and 108,000ha of conversion, which are equivalent to 104 and 460 averaged sized sheep & beef farms, respectively. Based on historical rates of conversion, the benefits of M1 could be eroded by farm conversions alone in a few years. In addition, based on past production increases on dairy farms, it seems likely that future production increases alone could use up the additional capacity created under all the mitigation scenarios in approximately a decade or less.

The largest reductions in nutrient loads can be achieved when both sheep & beef and dairy farms adopt mitigation measures. This is because sheep & beef remains the dominant land use by area in the Southland region, but losses from dairy farmers are greater per hectare. Overall, the contributions from both land uses are significant. However, given the higher per hectare losses, it follows that mitigation on dairy farms provides a greater per hectare benefit for water quality.

We conclude that under the status quo of ongoing conversions and increasing production on dairy farms, water quality will not be maintained (or improved by 10%) in the long term, even if very stringent mitigation requirements (i.e. M3 on all farms) were to be adopted. Setting limits for catchment nutrient loads, and then managing discharges to meet these limits, appears to be the most appropriate method for ensuring that the goal of maintaining and improving water quality across the catchments within the Southland region will be achieved.

5.2 Assumptions

This analysis is regional and high level in scope, and a number of assumptions and simplifications have been made to make the calculations manageable. We have assumed that the OVERSEER® modelling, carried out as part of the central government economic impact study (NZIER, 2013), provides a reasonable representation of the agricultural nutrient source loads. These load estimates were derived from a simple classification of farm types, and the use of relatively coarse GIS data to assign for the individual farms to types. A more accurate picture of nutrient source loads would require detailed data farm scale data collection and modelling.

The mitigation options that were considered by this study were those that could be evaluated using OVERSEER®. The bundling of various individual mitigation options into the specific options used by this study (i.e. M1, M2 and M3) were pragmatic decisions made by experts as part of the recent economic impact study by central government (MFE, 2013). Similar reductions (or better) may be achievable using different suites of mitigation options and/or options that cannot as yet be evaluated using OVERSEER®. As such, the benefits of mitigations provide estimates of potentially achievable nutrient load reductions, and they should not be interpreted as prescriptive measures that are the only choices to mitigating nutrient leaching from farms in Southland.

Another important assumption was that farms have not already adopted some of these mitigations. The current level of uptake of mitigation measures is unknown. If the uptake of mitigation throughout the region is significant, the potential to reduce existing loads will be overestimated by this study.

We made some pragmatic assumptions concerning wintering-off of dairy cows on sheep & beef farms. First, our analysis assumed that nitrogen losses due to wintering-off are not mitigated under any scenario. There may be measures that could reduce these loads to some extent. This means that the benefits of mitigations may be underestimated. However, wintering-off of dairy cows accounted for only 7% of the total nitrogen source load regionally, so mitigating this to some extent would not greatly change our conclusions. Second, we assumed that wintering-off would be evenly distributed over all sheep & beef farms that had LUC categories of A and B. It is likely that wintering-off is not evenly distributed, and will tend to be located on dryer and well drained parts of the region. However, there is currently a lack of data on wintering-off practices across the region to support a more sophisticated spatial distribution analysis. Because our analysis was based on total loads of eight large catchments, it is unlikely that results would be strongly influence by the distribution of wintering farms. The location of wintering-off, however, may strongly influence water quality at more localised scales.

Estimates of realised loads, derived from monitoring data, are subject to at least two major sources of error. First, there is error associated with estimating loads from monthly water quality samples because these are unlikely to be representative of the total flux of nutrients. This error cannot be estimated until more data is collected that represents the full range of flows. Second, we used empirical modelling to extend the load estimates from the monitoring sites to other locations and to make catchment scale estimates. The empirical model errors are known, and it has been established that the models are unbiased (Aqualinc, 2014). This gives us confidence that at least the relative differences in realised loads estimated between the eight study catchments are reasonable. We also note that the apparent attenuation of nutrients in the eight study catchments was generally within the range that is reported in the literature. This suggests that the estimated loads are reasonable and that the analysis is reasonable from a mass balance perspective.

Two other sources of error in our estimates of realised loads are contributions from point sources and the influence of groundwater lags. Aqualinc (2014) assessed the contribution of the largest 25 point sources in Southland to nitrogen loads at the monitoring sites used to define the empirical model. They found the contribution from point sources was relatively minor, and that point sources affected on 10 of the 73 SOE sites. Of the 10 sites affected by point sources, the point source contribution to nitrogen loads was <10% at all sites and <5% at most sites. We therefore consider that point source loads are unlikely to be a significant source of error in our analysis. Loads of nitrogen estimated from monitoring data can underestimate ‘true’ loads due to delays in the movement of nitrogen through the groundwater system (or groundwater lags). In general, groundwater lags are not thought to be large in

Southland (Clint Rissman, SRC. *pers comm*), and therefore we do not consider this is likely to be a large source of error.

On the basis of the above factors, we consider that, provided the load reductions due to mitigation derived from OVERSEER® are accepted, the relative benefits of mitigations are well represented by the analysis. We also consider the estimates of load reductions and their conversion to 'additional capacity' estimates on a catchment basis are reasonable in absolute terms (i.e. in percentage reduction from current, as area of farms converted from sheep & beef to dairy farms and as years of productivity increase).

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