Nitrogen, Phosphorus and Sediment losses from rural land uses in Southland

Technical Report

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Executive Summary

Nitrogen (N), Phosphorus (P) and Suspended Sediment (SS) have been identified as key contaminants of Southland's water bodies. The purpose of this study was to estimate losses of these contaminants from contrasting land uses to enable council to better understand the magnitude of nutrient losses and loads from differing land uses and, in addition, to be able to put them in context with natural state losses prior to the pastoral development of the region.

Loss estimates of N, P and SS (kg/ha) were calculated after an extensive literature review and up-scaled across the region using land use data to produce inventories of total load estimates (t/yr). Productive land uses were classified into the following classes: Intensive sheep/beef/deer, Extensive sheep/beef/deer, Dairy, Wintering (all stock types), Arable and Forestry. In the literature review both empirical and modelled data (e.g. Overseer®) were used to derive estimated losses (below the root zone) for each land use. Priority was given to studies conducted in Southland. However, if local data were unavailable or inconsistent, particularly for P and SS, national datasets were used to validate local estimates or as a substitute. Total excretal N loads (N*ex*) were also calculated for the region using animal loads derived from the National Greenhouse Gas Inventory (2011) and up-scaled for the region using regional stock number data.

The approach used here found good agreement with other N loss estimates derived for the region. However, poor agreement was found for SS loads due to the lack of relevant studies from which to derive land use loss estimates for the inventory. P losses also differed from two other studies investigated for the region. Although good agreement was found for N loss, and to a lesser extent P loss, we do not recommend this approach be used for any detailed catchment loss estimates in the region due to its present inability to account for biophysical and management influences on losses at the farm scale.

The approach used here reveals that, 16,871 tons of N is lost per annum from productive land uses across the region. Of this, 50% of losses come from land used for sheep/beef/deer farming (38% intensive; 12% extensive), 31% comes from dairying, and 16% from wintering. Forestry and arable contributed the remaining 2% and 1% respectively. Although contributing to 50% of N losses, sheep/beef/deer farming occupies over 70% of the production landscape, with dairying and wintering occupying 15% and 4%, respectively. The total regional loss calculated for P was 636 tons per annum, with 66% coming from sheep/beef/deer, 22% from dairying and 9% from wintering. Due to the high variability of SS loss data within land uses, our confidence in the resulting loss estimates is low and further research and modelling is required to validate our results.

Natural losses (ca. 1840) were estimated for the region based on historical land use data and loss figures based on natural state ecosystems. Natural state N losses were calculated at 11% of current day losses while P losses were calculated at 40% of current day losses. N*ex* loads in 2011 were calculated at 159,055 tons per annum, an order of magnitude higher than the amount of N leached for the region. Regional stock number data highlights that although stock numbers in the region have plateaued since the early 1980s the regional N*ex* load has continued to climb. This phenomenon is likely to be a result of the decline and increase in sheep and cow numbers in the region, respectively, with dairy cows having a higher N*ex* load per stock unit equivalent.

This study has highlighted that although land uses such as dairying and wintering are high loss systems on a loss per hectare basis, sheep/beef/deer farming is still responsible for approximately 50% and 66% of the region's N and P losses respectively. Whilst mitigation efforts across all land uses will achieve benefits, this report highlights how small reductions in losses from sheep/beef/deer systems could make large differences to net regional losses. Additionally, large increases in dairying or wintering may have a disproportionately significant effect on increasing losses unless mitigation efforts can alleviate these. It must be acknowledged that, particularly for SS and a lesser extent P, the inventories reported here do have deficiencies and need to be treated with some caution. However, the good agreement between models for N and the large amount of research into N losses gives us confidence that the results are accurate and the

data can be used to inform council and the community on the relative losses from different land uses within the Southland Region.

Background

As a regional council, Environment Southland is responsible for managing the Southland Region's water and land resources. With the intensification of land use within the region there are increasing environmental pressures on soil, water, air and coastal resources, with some ecosystems declining in health as a result. As a resource manager it is the Council's responsibility to monitor and manage the influence of these pressures in the region while protecting the integrity of its environment.

Understanding the interactions between land use and the environment, and the resulting ecological, social and economic effects of these interactions, is key to managing these resources effectively and sustainably. As land use is the key driver of change in these terrestrial environments, and the impacts on the region's water quality resources of these changes are wide-reaching across the community, it is important to understand the impacts they are having.

A key first step in understanding the impacts of land use on water quality is to understand the loads and losses of nutrients and sediment from the major land uses in the region. This then enables council to understand the key contributing land uses, assess them against baseline levels and further examine biophysical or management factors that may influence their impact.

This research is also vital to feed into regional and catchment-based loss pathway and magnitude modelling which is part of the council's Foundation Science program. The program has been developed to fill in major science knowledge gaps for the region to enable council to adopt and implement Interim Measures and Catchment Limit setting approaches required of them under the new National Policy Statement for Fresh Water.

On completion of this initial region-wide assessment of loads and losses, it is intended to utilise and expand on this research in greater detail to enable a more thorough assessment of sub catchment land use and geophysical influences on loads and losses to help fulfil future catchment load setting requirements.

Introduction

Nitrogen, Phosphorus and Sediment losses from land present significant issues for both surface and groundwater quality in the Southland Region (Environment Southland, 2010). Although the effects of excessive sediment and nutrient inputs to water are comparatively well understood in the region, the sources and relative loads of these contaminants is less well understood. Quantifying regional nutrient and sediment losses is the first step in enabling Environment Southland to gain a better understanding of the relative contributions of differing land uses to the total loads and resulting losses of these below the root zone, or beyond the farm boundary. Furthermore, it provides the platform to further classify and spatially delineate land uses or parts of the landscape from where disproportionately large losses may originate, allowing council to better target research, advice, compliance and policy.

Over the last 5 years there has been an increasing focus on the region's water quality in response to well documented regional (Southland Water SOE, Environment Southland , 2010) and localised (Waituna lagoon, 2011) declines in freshwater quality. In order to understand and interpret these declines in water quality, a fundamental knowledge of land use and the relative losses of key contaminants from different land use activities needs to be gained for the region. Nutrient losses from pastoral land uses have been studied in some parts of New Zealand and Southland is no exception, with a number of studies documenting modelled (e.g. Monaghan et al., 2007; NZIER, 2013) and measured losses (e.g. Monaghan, 2000; 2009). Land use information is readily available and has been thoroughly documented in the land technical report (Ledgard 2013 in prep). However, generalised losses under differing land uses at a regional scale have not been investigated for Southland.

The land technical report (Ledgard, 2013 in prep) highlighted large land use changes across the region post European colonisation. One key finding of this research was the increasing trend in the intensification of agricultural land use across the Southland landscape. This has primarily been led by a large expansion in the dairy industry within Southland, with cow numbers increasing 9-fold across the region since the early 1990s, a period which marked the beginning of the rapid rise of dairying within the province which has continued through until today. Parallel to this rapid expansion in cow numbers was the corresponding expansion of dairy and dairy support land in the region. Dairying, a comparatively high nutrient loss land use in Southland (Monaghan et al., 2010; NZIER, 2013; Muirhead, 2013), is taking the place of (comparatively) less intensive sheep, beef and deer pastoral systems. In addition to this rapid dairy expansion, sheep farms have slowly intensified across the region (Ledgard, 2013 in prep). Together, both industries represent an on-going region-wide intensification of existing pastoral land. This intensification is best illustrated in Figure 7 which outlines the changes in regional stock numbers from 1860 through to 2011. Although total stock numbers in the region have stabilised over the past 25 years, there is still evidence of increasing intensification within the pastoral agricultural sector. Data from both beef and lamb and dairy statistics show stock numbers still increasing in the region (Ledgard, 2013 in prep), along with increases in carcass weights and milk solids production (Fennesy, 2013).

Elevated concentrations of nitrogen and phosphorus within the fresh water bodies of agricultural catchments is often attributed to land uses and their management practices (Larned et al., 2004; Monaghan, 2007). High levels of N and P can cause unwanted algal growth in waterways, while high N levels can render groundwater unsuitable for drinking (Environment Southland, 2010). Sediment can fill in estuaries and drains or smother aquatic vegetation, reducing aquatic habitat and biodiversity values (Quinn & Stroud, 2002). Southland is not immune to these effects of intensive land use, with many of the regions agriculturally-dominated catchments having poor or declining water quality (Environment Southland, 2010). This study attempts to calculate regional loads and losses of nitrogen (as NO_3^-), phosphorus (as TP) and suspended sediment generated from productive land in the region, based on reported or assumed loss figure estimates (kg/ha) at a land use level for pastoral, cropping, exotic forest and indigenous land use categories.

Methodology

There are a number of ways to calculate regional nutrient loads from agriculture. This report uses a simplistic inventory method to compute regional N, P and SS loads from different rural land uses. Other models used for Southland have been more complex; however, here we have used a minimal input inventory type model and compare results with other more detailed approaches.
There have been four modelling attempts to calculate nutrient losses for the Southland region in recent years and these are briefly outlined below. Dymond et al. (2013) and Parfitt et al. (2012) provide regional loss estimates derived from national models, while Aqualinc (2013) and NZIER (2013) provide Southland specific estimates. A brief review of these models follows.

Dymond et al 2013:
For regional N loss estimates Dymond et al. (2013) calculated a stock unit loss figure for each unit in LENZ level II within the region using Overseer® and stock carrying capacity data. This was then extrapolated across the region using AgriBase™ land use data (AsureQuality, 2012) and Statistics NZ stock number data for each year (1990-2011). P loss estimates were calculated using estimates of water yield with calculated DRP concentrations in subsurface flow. The map of DRP concentration was produced from an equation relating DRP to Olsen P and the P retention of the soil through which the water drains (McDowell & Condron, 2004).

Parfitt et al. 2012:
Regional losses presented in this model were calculated for the entire Southland Region including national parks. Loss estimates also included dissolved organic nitrogen (DON), however this only accounts for a fraction of losses (pers comm. Roger Parfitt, Landcare Research 24/07/13) and a small percentage <5% of the total regional losses. Overseer® (version 5.4.9) was used to estimate the N leaching from soil profiles under dairy, sheep and beef land under two slope classes for each region. For drystock they used regional average stock units and fertilizer rates, and assumed, on average, pastures were 'developed' on the flat and rolling land, and 'developing' in hill country. Land use losses were also calculated for cropping, forest, and point source discharges (meat processing, dairy factory etc.). These loss estimates were applied across the region using land use data from LCDB, LUCAS and the NZLRI and stock number data from Statistics New Zealand.

Aqualinc Research 2013:
Aqualinc research developed a model for the Southland region, utilising SOE water quality data, from which predictions of catchment loads were made across the major catchments in the region (Excluding National Parks). A model was then developed to backwards calculate the realised loads for the region as Total Nitrogen (TN). As this research is in preparation, detailed methodologies are yet to be released.

NZIER 2013:
Load estimates were developed for agricultural and exotic forest land within the Southland Region. Land use data was extracted from AgriBase™ and N loss figures were applied based on Overseer® loss estimates developed for 121 different farm type scenarios across the region. These farm type scenarios were based on drainage, soil type and land use class across the different enterprises analysed (Sheep and Beef, Dairy, Exotic Forestry etc.).

Losses from productive land
The approach taken in this study to calculate losses from private land is similar to that of the NZIER and Parfitt et al. (2012) models and to a lesser extent Dymond et al., (2013). In this study, N, P and SS loss estimates from different land use activities were collated from both empirical research and values derived from models, principally the Overseer® Nutrient Budgeting model (hereafter referred to as *Overseer*). Where possible, data was used from research undertaken in the Southland Region. However, if this was unavailable, or offered poor resolution, data from further afield supplemented or replaced regional data. When all relevant data was considered, a loss estimate (kg/ha) was derived based on the mean loss estimates for each of the contaminants considered (N, P, SS).

Relevant data on the losses of these contaminants to enable these calculations varied in its availability across land use types and contaminant. For example, nitrogen losses have been widely studied under dairying in the region and data was readily available to develop an estimated loss under this land use. In contrast, there is no source of information documenting losses from sheep winter grazing systems, obviously resulting in a greater degree of uncertainty around the accuracy of this figure. As a result, there is a considerable degree of uncertainty attached to some of the estimates given. Table 1 gives a breakdown of the estimated losses across different land uses, the studies used to derive these estimates and comments on the degree of certainty around the loss figures used.

Nitrogen loss estimates are considered to have relatively less un-certainty due to the greater amount of research into this nutrient, in contrast to that reported for P and SS. As a result, the results and discussion focus on comparing N loss estimates as these are considered the most reliable. Nevertheless, P and SS are also presented and discussed as the data highlight key loss land uses and general trends.

To enable the calculation of regional loss figures, the hectares of different land use types for the region had to be calculated. The Southland Region Land Use Change Report (Ledgard 2013, in prep) provides detailed land use data for the region derived from various spatial datasets available to the council (e.g. LCDB3; ES Dairy Layer, 2011). For a detailed methodology on the formulation of these figures please refer to this report. Consequently, data on the hectares of land use are available for the following land uses:

- Extensive Sheep/Beef/Deer (Derived from Environment Southland's Ratings database & LCDB3)
- Intensive Sheep/Beef/Deer (Derived from Environment Southland's Ratings database & LCDB3)
- Exotic Forest (Derived from LCDB3, 2008)
- Dairy (Derived from Environment Southland's dairy consent database; 2011)
- Arable (Foundation of Arable Research)
- Wintering Support (Ledgard, 2013 in prep)

Table 1: Estimated loss figures developed for N, P and SS under different land uses in the Southland Region

Nitrogen (NO_3)	***Loss (Kg/Ha/Yr)***	***Range (Kg/Ha/Yr)***	***Confidence+***	***References***
Dairy Platform (Wintering off)	30	22-49	Good	NZIER, 2013; Robson et al., 2010; Monaghan et al., 2009 Lillburn et al., 2010; Monaghan et al., 2008; Monaghan et al. 2005.
Wintering Support (All animals)	55	39 - 114	Good	Smith et al., 2012; De Klein et al., 2010; Monaghan et al., 2013
Sheep/Beef/Deer pasture (Intensive)	12	8 - 23	Good	Lillburn et al., 2010
Sheep/Beef/Deer pasture (Extensive)	6	4 - 8	Good	Parfitt et al., 2012; Robson et al., 2011; Monaghan et al., 2007
Forestry	2	0.5 - 5	Good	Parfitt et al., 2012 Note: Parfitt et al., 1997; Magnesan et al., 1998 predict between 3 & 5 kg N/ha)
Crop - Arable	45	12 - 45	Moderate	Thomas et al., 2005 - Modelled estimates of N losses under 'typical' cropping rotations in Canterbury; Lillburn et al., 2010.
Phosphorus (TP)				
Dairy Platform (Wintering off)	0.8	0.8 - 1.3	Moderate	Monaghan et al., 2007; Journeaux & Wilson, 2013; Muirhead, 2013.
Wintering support (All animals)	1.2	0.7 - 2.0	Moderate	Estimate based on data from Telford study (Orchiston et al., 2012) and McDowell and Stevens, 2008; McDowell and Houlbrooke, 2008.
Sheep/Beef/Deer pasture (Intensive)	0.6	*	Moderate	Monaghan et al., 2007; McDowell & Houlbrook 2008.
Sheep/Beef/Deer pasture (Extensive)	0.3	*	Moderate	Estimated to be half that of S/B/D intensive
Forestry	0.2	*	Moderate	Monaghan et al., 2007
Suspended Sediment				
Dairy Platform (Wintering off)	60	*	Poor	Mean derived from Tussock Creek values in Monaghan 2010 et al., Table 3.4
Wintering support (Dairy)	330	*	Poor	McDowell and Houlbrooke, 2008; Orchiston et al 2012.
Wintering support (Sheep/Beef)	250	*	Poor	Estimated mean derived from McDowell and Houlbrooke, 2008
Wintering support (Deer)	1000	*	Poor	McDowell and Stevens, 2008
Sheep/Beef/Deer pasture (Intensive)	50	*	Poor	Note - S/B losses are 32kg/ha but with deer included this increases the average loss per hectare to 50kg
Sheep/Beef/Deer pasture (Extensive)	61	*	Poor	Estimate derived from Ledgard and Hughes (2012); McDowell and Stevens (2008) and Monaghan et al., (2010)
Forestry	34	*	Poor	Fahey, 2000

+ Confidence estimates based on the number of studies conducted and/or the variance in the data reviewed
*Insufficient data to develop a meaningful range

Table 2 below outlines the hectares of each of these productive land uses in the Southland Region. The hectares of productive land do change slightly for the calculations of P and SS loads in the region. This is because no data was available to calculate P or SS loss estimates for arable land. Consequently, 8000ha was taken out of these calculations.

Table 2: Hectares of productive land use classes in the Southland Region

Productive Land Use Type	Hectares	% Productive Land
Sheep/Beef/Deer High Producing Pasture	536,017	45
Sheep/Beef/Deer Low Producing Pasture	322,449	27
Dairy	173,721	15
Wintering (Dairy + S/B/D)	50,000	4
Exotic Forest	91,281	8
Arable	8,000	1
Total	**1,181,468**	

In the calculation of SS loads an additional land use, deer wintering, was added because of its propensity to lose high amounts of SS (McDowell & Stevens, 2008). There is estimated to be c. 27,000ha of deer farms in Southland (Emma Moran, unpublished data 2013). Of this, it was estimated that 20,000 deer were located on intensive pasture and approximately 10% of this would be used as winter support land for deer (2000ha). This figure was then added as an extra land use activity and the SS loss figure derived from the data of McDowell and Stevens (2008) (1000kg/ha/year).

Deer are recognised as accelerating sediment loss in comparison to sheep and beef farming systems. This accelerated loss was accounted for in the SS losses assumed for the Sheep/Beef/Deer land use class. SS losses were estimated as 800 kg/ha/year for deer (McDowell and Wilcox, 2008), while sheep and beef losses were estimated at 32 kg/ha (McDowell and Houlbrooke, 2008). Of the 27,000ha under deer farming 20,000 ha were estimated to be on intensive pasture while the other7000 ha was estimated to be on extensive pastoral land.

Background losses circa 1840

To enable current day losses from productive land to be put into context with natural losses, losses were calculated based on assumed land cover in the Southland Region for ca. 1840. The land cover data was derived from estimates of land cover for the region from McGlone (2001). The historic wetland extent for the region c.1840 (Clarkson et al., 2011) was then overlaid to derive the area occupied by wetlands. From these two datasets land cover estimates for Forest, Tussock/Shrubland and Wetland categories were developed. Nitrogen, P and SS loss figures were obtained for these land cover types and are presented in Table 3.

Table 3: Estimated loss figures of N, P and SS from natural state land uses circa 1840.

Nitrogen	***Kg/Ha***	***Confidence+***	***References***
Forest	2	Medium	Parfitt et al., 2012 (2); Barton et al., 1999 (1.7)
Wetland	0.2	Low	Unpublished data from Greg Ryder based on Waituna wetland loss estimates
Shrub/Tussock	2	Medium	Parfitt et al., 2012 (2) Barton et al., 1999 (1.7)
Phosphorus			
Forest	0.32	Low	Elliot and Sorrell, 2002
Wetland	0.32	Low	Elliot and Sorrell, 2002
Shrub/Tussock	0.32	Low	Elliot and Sorrell, 2002
Suspended Sediment			
Forest	40	Low	Fahey et al., 2002
Wetland	40	Low	Fahey et al., 2002
Shrub/Tussock	40	Low	Fahey et al., 2002

+ Confidence estimates based on the number of studies conducted and/or the variance in the data reviewed

Excretal N loads to productive land

Average excretal N loads were calculated for dominant stock types in the region. The New Zealand Greenhouse Gas Inventory (MFE, 2011) estimates N excretion for deer, dairy, sheep and beef animals on a loss per head per year basis. These were then normalised to a stock unit equivalent loss rate using stock unit equivalent figures from Fleming (2003). These losses are presented in Figure 6.

Results

2011 Losses:

Nitrogen
There have been a number of studies from which to derive our nitrogen loss figures from and the confidence we have in these land use loss estimates (kg/N/ha) is therefore relatively high. Extrapolating these loss figures to a regional scale for land uses on productive land highlights some interesting points as displayed in Figure 1. The calculated total N loss for productive land within the Southland region is 16,871 tonnes. The largest land use contributor is intensive sheep, beef, deer land, with 38% of the N loss (6,432 t/N), followed by dairy at 31% (5,212 t/N). As expected the contributions relative to the areas occupied differed between land use categories, with dairy losing N at a 2:1 N loss to land area ratio. In contrast, intensive sheep and beef was running at a 0.84:1 N loss to land area ratio. The highest N loss to land area ratio was for wintering, with a 4:1 ratio. Arable land, although occupying a small area, had a 2:1 N loss to land ratio, while extensive sheep, beef, deer and forestry had low ratios of 0.44:1 and 0.12:1 respectively.

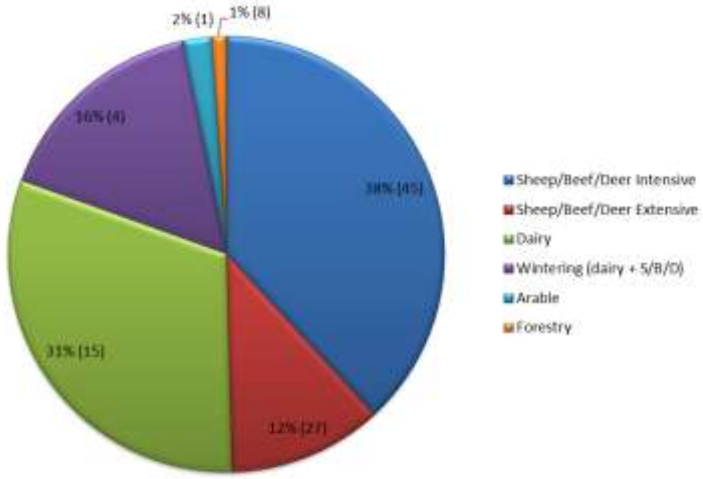

Figure 1: Total nitrogen loss from the Southland region under different productive land uses. Brackets next to percentage loss figures represent the percent occupancy of the total productive land area by the respective land uses.

A number of studies have recently been undertaken in Southland to try and estimate regional N loss. Table four summarises these studies and provides their regional estimates for N loss. The lowest record from published data on regional N losses was from Dymond et al., (2013). This dataset used an earlier version of Overseer® which probably underestimated nitrate losses and did not account for wintering losses, which likely also contributed to this low estimate (Pers comm, John Dymond, 16/08/2013). The estimate generated by Parfitt et al., (2012) was for the whole of Southland and was unable to be recalculated for productive land in the region. In addition, it included Dissolved Organic Nitrogen rendering the dataset incomparable to the others. The studies undertaken by Aqualinc and NZIER are the most detailed and recent for the region. The NZIER study has good agreement with the figures generated in this report for NO_3. The Aqualinc study generated realised loads for the region; these are calculated as within-stream loads and summed across the region for TN. Analysis of water quality data at Environment Southland's State of the Environment monitoring sites reveals median in-stream nitrate levels are approximately 0.65 (±0.28; n =7755) of TN values. With estimated regional attenuation levels of approximately 50% within the vadose zone we can back calculate an approximate below the root zone loss figure for nitrate which equates to 18,400 t/n/yr. This is very much in-line with the figures generated in the NZIER report and this study, however caution must be aired as this is a very basic approximation that warrants further validation.

Table 4: Comparison of N loss estimates for Southland from different regional studies

Study	Units	Tonnes/ha/yr	Km^2	N Loss kg/ha
Dymond et al. 2013	NO_3	10,000	11,000	9
Ledgard 2013	NO_3	16,871	11,814	14
NZIER 2013	NO_3	18,645	10,880	17
Aqualinc 2013 *	TN	14,179	11,000	13
Parfitt et al. 2012 **	NO_3 (+ DON)	27,000	29,684	9

*Aqualinc estimates are 'realised' loads in stream and represent Total Nitrogen. TN losses from the land surface are expected to be approximately double those realised in-stream.
** Parfitt et al. loss estimate was for the whole of Southland including DON. A revised N loss estimate was unable to be calculated for productive land.

Phosphorous
There is a greater degree of uncertainty around estimates of phosphorus losses calculated for land uses in the Southland region. Most of the land use loss estimates used have been derived from the Bog Burn study conducted by AgResearch (Monaghan et al., 2007). Arable loss estimates were unavailable and were left out of the calculations. The losses from the Bog Burn study were calculated from Overseer®. There is limited data from empirical research from the region however there have been other Overseer® modelling efforts undertaken in the Waituna catchment (Muirhead, 2013) which offer similar figures for the two dominant land uses in the region, dairy and intensive sheep and beef.

Figure 3 below highlights proportionate P losses from sheep, beef and deer farming are higher than those for N, with intensive sheep, beef, deer operations contributing 51%, dairy 22%, wintering 9% and extensive sheep, beef, deer at 15%. Forestry is still a minor contributor contributing only 3%. Their proportionate loads when compared to land area have not differed greatly from the proportionate N loads, with sheep, beef, and deer getting closer to a 1.1:1 percentage loss to land area ratio while wintering losses declined to near a 2:1 ratio.

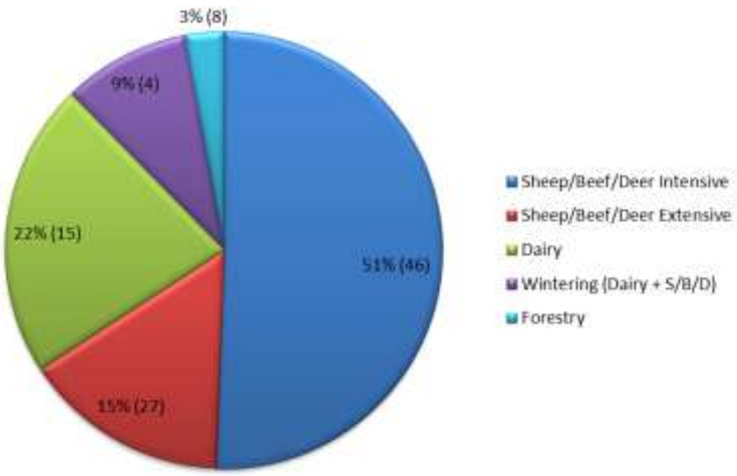

Figure 2: Total Phosphorus loss from the Southland region under different productive land uses. Brackets next to percentage loss figures represent the percent occupancy of the total productive land area by the respective land uses.

In total, approximately 636 tonnes of Total Phosphorus are calculated to be lost from Southland each year. Unfortunately we have no other regional data estimates against which to compare our estimates. The accuracy of the nutrient leaching maps can only be as good as the accuracy of the underlying models. The Overseer® model has an accuracy of approximately ±20% for N loss (Ledgard & Waller, 2001) and this is higher for P loss as the model is built to calculate P loss risk not to predict amounts of P being lost. This coupled with the limited amount of modelling or empirical research undertaken in the Southland Region, and complex soil, physiographic and climatic interactions affecting P loss means the estimates presented for P have significant uncertainty associated with them.

Suspended Sediment
Data available to derive estimates of suspended sediment is sparse and highly variable. A variety of studies were reviewed with some land use types providing highly disparate sediment loss figures. Consequently, the SS losses represented below in Figure 4 should be treated with some caution as there is a large amount of variation within the land use loss calculations. This is illustrated in Figure 3, which displays the range of sediment losses reported from reviewed studies (Monaghan et al., 2010).

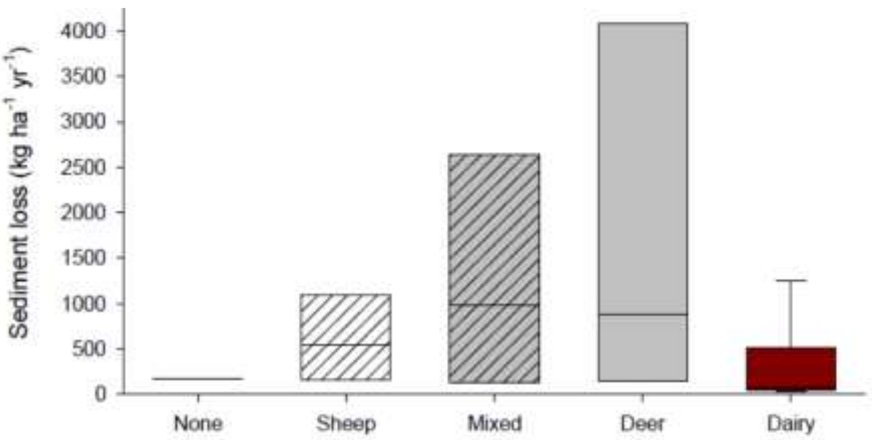

Figure 3: Boxplots showing the mean bounded by the 25th and 75th percentiles, with the whiskers showing the 90th and 10th percentiles for sediment losses under differernt land uses. None referrs to non-agricultural land uses e.g. Forestry or Native tussock; Mixed refers to mixed farming systems e.g. sheep/beef/deer.

Based on the limited information available, Sheep/Beef/Deer farming systems appear to be the leading contributors of sediment to Southland waterways with extensive systems, which typically occur on hill country land, losing proportionately more sediment to land area than intensive systems. If calculated sediment losses are expressed as a proportion of land area, the highest loss systems are wintering systems, particularly deer wintering on sloping land.

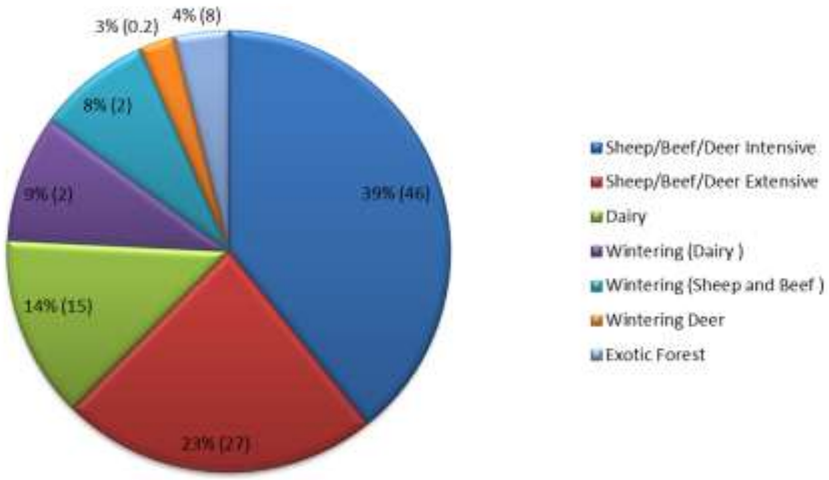

Figure 4: Suspended sediment losses from the Southland region under different productive land uses. Brackets next to percentage loss figures represent the percent occupancy of total productive land area by the respective land uses.

In total approximately 77,896 tonnes of sediment are calculated to be lost from productive land in Southland each year. As there have been no other regional estimates calculated for Southland it is very hard to ascertain if this methodology is producing an estimate that is realistic for the region. Nevertheless the proportional contribution from each land use is likely to be a fair reflection of the actual land use losses and offers insight into the region's leading sources of suspended sediment lost from productive land.

Baseline losses ca. 1840

Land cover data from ca. 1840 for the Southland region is available from data presented in the Ledgard (2013 in prep) report. The data highlights that current day productive land extent was occupied in ca. 1840 largely by wetlands (both forest and shrub dominated), forest and shrub/tussock land. A breakdown of the extent of these land cover classes across Southland along with estimated loss figures for ca.1840 is presented in Table 5 below.

Table 5: Land cover in ca. 1840 on current productive land in Southland and associated N, P and SS loss figures.

Land cover 1840	Ha	% of total	N	P	SS
Wetlands	271,816	24	54	87	10,873
Forest	250,827	22	502	80	10,033
Shrub & Tussock	625,032	54	1,250	200	25,001
	1,147,675	**100**	**1,806**	**367**	**45,907**

When these data are compared to current estimated losses it is clear that the region has undergone significant increases in losses related to the productive development of the land. Compared to ca. 1840 levels, nitrogen losses have increased 9-fold across the region while phosphorus losses have increased 2-fold and Suspended Sediment almost 2-fold (Figures 5 a-c).

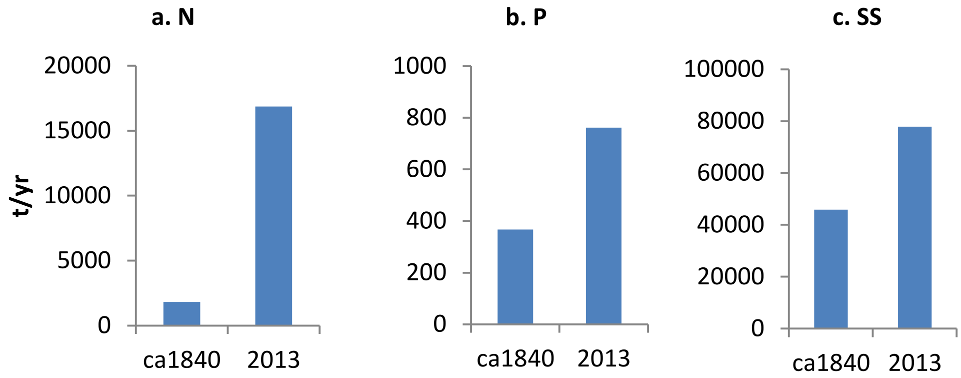

Figure 5: Losses of N (a), P (b) and SS (c) for ca. 1840 and 2013 from productive land use extent in the Southland Region.

Excretal Nitrogen (N*ex*) loads

Figure 6 below displays the stock unit equivalent annual excretal N loads (N*ex*) for sheep, beef cattle, dairy cattle and deer. Although relatively close in their annual loads, with only 2kg separating the highest load species from the lowest, there are differences between animal populations.

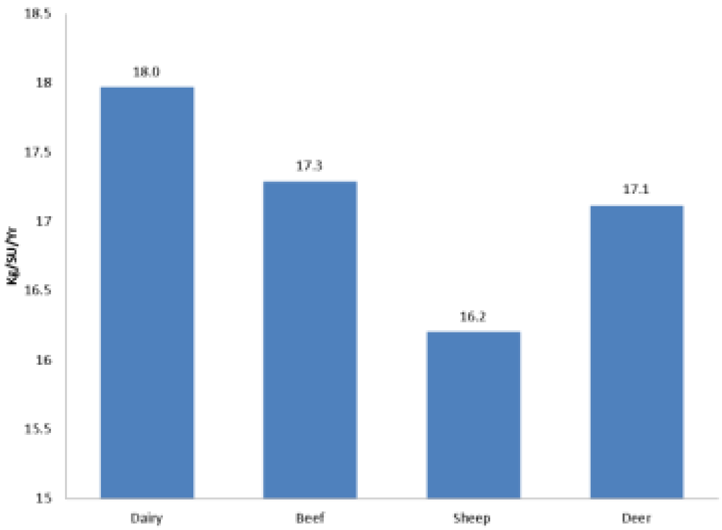

Figure 6: Mean estimated annual excretal N loads per animal species type.

Dairy cattle loads are the highest at 18kg per stock unit equivalent per year while sheep loads are 1.8kg less at 16.2 kg per year. Beef cattle and deer interestingly are similar at 17.3 and 17.1 kg respectively per year. These figures were then applied to the stock unit data available for the Southland Region from the Ledgard (2013 in prep) regional land use report to produce total annual excretal nitrogen loads for the region. These are presented in Figure 7 below.

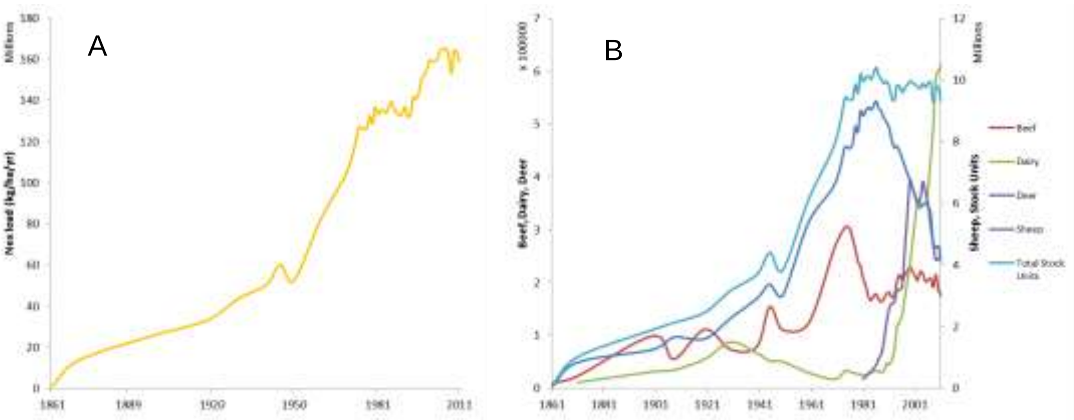

Figure 7: Change in N*ex* load in the Southland Region (A) and corresponding changes in stock numbers (B).

Nitrogen (excreted) loads have increased significantly from the period between 1950 and 1970 and then again between 1990 and 2002, while total stock numbers have remained relatively stable over this latter period. In 2011 the regional N*ex* load was 159,055 tonnes, while the calculated loss below the root zone represents only 16,871 tonnes. Interestingly, this loss represents only 10.6% of the annual applied N*ex* load.

Discussion

The inventory method used in the estimation of nutrient losses for this report is a simplistic approach when compared to other models that have been developed for the region (Aqualinc, 2013; NZIER, 2013; Dymond et al., 2013). Loss estimates across these studies can only be compared for N; however, there is a reasonable level of agreement between these models in terms of their final loss estimates. Interestingly, the Aqualinc report is unique in that it develops loss estimates based on water quality analysis while Dymond et al., (2013), NZIER (2013) and this study all use land use data, or inputs, to calculate loss estimates.

Although it is encouraging that the data are in agreement from the different studies for N, there are few data available against which to compare estimates of P and SS losses. The only other report that has summarised P losses using Overseer® was the NZIER (2013) report. The NZIER estimated regional total for P loss is 430 tonnes. This is considerably less than the estimated 636 tons calculated in this report. The only other comprehensive catchment studies done, other than the Bog Burn, have been the MPI Aparima study and the Waituna Catchment Studies. Loss figures by land use in these studies are similar to those reported in this study, however all are based on Overseer® outputs. For P losses, Overseer® estimates loss risk rather than actual losses and models such as CLUES and Sednet are recommended for more realistic catchment loss estimates. Aqualinc Research's realised load calculations are expected to be less as they are calculations based on the loads in the receiving environment (rivers and streams). Their estimation for the region excluding National Parks is 649 tonnes per annum, considerably higher than the NZIER calculations. Unfortunately the NZIER methodology is currently unavailable so the reasons for these differences are unclear.

None of the regional level studies have attempted to quantify SS losses. However, the MPI Aparima catchment study does attempt to do this. The Aparima studies' estimates for sediment losses from different land uses are as follows: Sheep 1,000 kg/ha/annum, sheep & beef 2,500 kg/ha/annum and dairy 500 kg/ha/annum. After reviewing data from a wider selection of studies it is this reports view that the estimates used in the Aparima study are at the higher end of the spectrum. As indicated in Table 1, the suspended sediment calculations are expected to have the highest error due to the limited amount of data available from which to derive our estimates. Consequently the estimates for suspended sediment and the relative contributions of different land uses needs to be treated with considerable caution.

The relative losses indicate that sheep, beef and deer farming systems contribute approximately 50% and 66% of the total N and P loss respectively, while occupying 70% of the productive land in the region. Due to the dominance of this land use in the region (despite increases in dairying), any significant reductions in N loss from these farming systems is likely to have a large impact on total regional losses of N. For example, a 30% reduction in N loss from this land use reduces N loss by 2500 tonnes, or 15% of the total. Similarly for P loss, a reduction in losses for sheep, beef, deer by 30% reduces total regional P loss by 22%.

Clearly, from the data presented and other literature cited (e.g. Monaghan et al., 2010), wintering and dairy farm land use categories are high N and P loss systems, with a disproportionate amount of N and P lost when compared to the land area occupied. There can be significant gains made in reducing losses from these systems to make them more proportionate to the land area occupied. The simplistic nature of this modelling exercise did not make any allowance for disproportionate losses from different landforms within a land use. Shallow free draining soils and tile drainage make some parts of the landscape prone to leaching higher amounts of N, while topography and poor soil drainage can have a large impact on P and SS losses. Any further, more detailed, investigations into losses from differing land uses in the region should account for these farm system and geophysical differences. Consequently, the methodology used in this assessment is unsuitable for such exercises and a more detailed approach, such as those used in the NZIER report which created over 150 farm scenarios to account for these differences, needs to be considered of developing N loss estimates. For the calculation of SS and P losses in particular, it probably needs the application of more powerful, spatially-explicit modelling tools e.g. CLUES, Sednet.

Results from Figure 7 clearly demonstrate a sharp increase in the excretal N loads for the region since around the 1950s. This corresponds with a period of intensive farming development in the region and nationally (Moller & Mcleod, 2008). While this report does not estimate what the below-root zone losses were at the beginning of this rapid intensification of stock numbers in the region, it is reasonable to expect that modelled losses were considerably lower than present day losses. Interestingly, although total stock units in the region have stabilised since the mid to late 1970s, the total N*ex* load and consequently losses below the root zone have continued to rise, particularly between 1990 and 2000. This period coincided with a rapid rise in dairy cow and deer numbers in the region. The subsequent plateauing of N*ex* loads in the 2000s is a result of a sharp decline in deer numbers on the back of continued declines in sheep numbers, which began in the mid-1980s. However, although declines in other stock numbers can be seen, the continued increase in dairy cow numbers in Southland has prevented any significant declines in estimated N*ex* loads.

The environmental ramifications of this switch in excretal N load, from being dominated by sheep in the 1970s to dairy over the past decade, are likely to be significant. The urine patch dynamics of different stock types has an important influence on the losses of nitrogen from differing farming systems, with dairy urine patches equating to loads of 500 to 1000kg/N/ha (Chicota et al., 2013). These highly concentrated urine patches exceed the assimilative capacity of the plants and soil, with potentially large amounts of N being lost, either in drainage below the root zone or via gaseous forms to the atmosphere. These situations are further exacerbated under high stocking densities, when overlapping urine patches occur and there are slow plant growth and uptake conditions e.g. winter grazing. Williams and Haynes (1994) found greater leaching losses of NO_3 occurred below cattle patches (equivalent to 60 kg N ha−1 below 300 mm and 37 kg N ha−1 below 600 mm) compared with sheep patches (10 kg N ha−1 below 300 mm and 1 kg N ha− below 600 mm). These factors highlight that the shift to more cows in the region, the increase in wintering support to cater for this increase and the general trend in intensification across all farming systems, despite the total stock units within the region remaining relatively stable, is resulting in greater N*ex* loads being applied across the region. In the face of further deterioration of water quality in the region, offsetting these loads is the next challenge for industry, regulators and community alike.

This report highlights that not one land use type alone is responsible for the majority of N losses in the region. Mitigation efforts across all productive land uses will reduce total loads of N, P and SS in the region and there is the opportunity for large reductions in losses through implementing various mitigation options, but this comes at a cost as there will be differences in the cost-benefit ratios of different mitigation options. It is clear that if the continued growth in the dairy industry continues, total regional N losses will continue to climb through both dairy platform losses and winter grazing losses unless practices are changed. In saying this, the sheep, beef and deer sector may have the opportunity, with comparatively less cost, to reduce regional losses significantly due to its sheer extent across the region and potential ability to implement low cost mitigation options. A collaborative effort is needed across the primary industries, business, local and central government to implement mitigation and reduce losses across the board if council is to achieve its water quality objectives. In addition, other point source and diffuse losses need to be quantified in order for council to be able to prioritise and target efforts to attain the best water quality outcomes for the region while minimising the social and economic impacts.

Recommendations

Recommendations for future follow-on work are as follows:

- Point source and diffuse losses from other activities impacting on water quality in the region, such as industry and waste water treatment, need to be quantified.
- Loss models need to be developed and applied on a catchment-by-catchment basis in order to link losses with land use/landscape risk and the receiving environment risk.
- The inventory approach used in this report is not suitable for more detailed catchment analysis. We recommend using modelling approaches such as those used by Dymond et al., (2013) and NZIER (2013) or investigating other catchment models such as CLUES and Sednet.
- R&D into mitigation options is being led by the dairy industry with much progress; however there is little coordinated information available for the sheep, beef and deer sectors. The sheep, beef and deer sectors need to formulate mitigation strategies and evaluate their effectiveness on N, P and SS losses on a cost-benefit basis.
- The dairy industry and fertiliser companies have the most accurate and up to date information on Overseer® losses from different farming systems in Southland. Council needs to develop collaborative relationships to share this information in order to generate the most accurate figures possible.
- Sediment and phosphorus loss estimates used in this inventory have greater un-certainty due to limited research in this field. Further research is needed and should be encouraged at a local and national level in order to gain more confidence around the figures assumed here.

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