Nutrient Budgets for Three Mixed Farming Catchments in New Zealand

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Executive Summary

The aim of this report is to examine the effects of change in land use and intensification on nutrient inputs, outputs and balances in three New Zealand catchments using the OVERSEER® nutrient budget model. The three catchments were Bog Burn (Southland), Waikakahi (Canterbury) and Toenepi (Waikato) and all currently have a mix of dairy farming and sheep and cattle farming.

Nitrogen (N) leaching was estimated at 2-16 kg N/ha/yr on current sheep and cattle farms and 18-41 kg N/ha/yr on current dairy farms. A 20% increase in productivity was estimated to increase N leaching from 23-28 or 23-71 kg N/ha/yr for sheep and cattle or dairy farms, respectively. Conversion to forage or grain cropping gave N leaching estimates of 16-47 kg N/ha/yr. The average nitrate-N concentration in leachate from current farming systems in the three catchments was estimated at 7-8 ppm (equivalent to mg/L), which is below the recommended maximum for drinking water of 11 ppm. Levels measured in one of the catchment streams was about half the modelled estimates and reflected removal of leached nitrate-N by denitrification in subsoil and wetlands, and N removal by algae and plants in drains and stream margins. Intensification and conversion to intensive dairying was estimated to increase N leaching and nitrate-N concentrations by up to 100%.

Farm- and catchment-scale nutrient budgets showed relatively large surpluses of P on dairy farms within the Bog Burn and Waikakahi catchments. As P soil test values for dairy farms are already high in both catchments, these surpluses indicate that P fertiliser inputs may be able to be reduced to avoid the excessive accumulation of P in soil. This will in turn decrease the risk of P runoff into surface waterways. This correction to P fertiliser management will be particularly important for the Bog Burn catchment, where, as observed for much of lowland Southland, surface water eutrophication is currently limited by P rather than N.
Factors influencing differences between catchments were differences in rainfall, drainage, soil texture, nutrient inputs, stocking rate and management practices. Scenarios are presented to show that the effects of intensification can be reduced by winter management (grazing off, stand-off or feed-pads), feed manipulation (low protein supplements instead of N-boosted pasture) and land application of farm dairy effluent. The latter is also effective in reducing P losses to waterways that occur from two-pond systems and increasing P use efficiency.

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1. Introduction

The OVERSEER® nutrient budget model (Ledgard *et al*. 1999, 2001) was developed as a tool to estimate nutrient inputs, outputs and balances for a wide range of pastoral and cropping farm systems. This modelling tool has traditionally been used to identify situations of nutrient excess or deficit for individual farms or farm blocks. However, model outputs from groups of individual farms can also be combined to evaluate nutrient balances at a catchment or regional scale. Because the impacts of diffuse or non-point pollution are generally observed at this wider scale, calculations of nutrient balances at this scale can help to prioritise and formulate ***relevant*** policies regarding nutrient flows within landscapes and ecosystems. Analyses of nutrient budgets at this scale can also allow us to make ***Environmental Projections*** of how future combinations of land use and farming systems will impact on nutrient flows.

The aim of this report is to apply the OVERSEER® model to farm data for mixed farming systems in three New Zealand catchments. Estimates are made of the effect of farming intensification, change in farm system (dairy conversion, cropping) and farm management practices on nutrient budgets, with emphasis on nitrogen (N) and phosphorus (P). These two nutrients are generally responsible for many of the concerns that have been raised regarding the impacts of intensive agriculture on the wider environment. Leaching of N from soil to groundwater, particularly shallow aquifers, can contaminate domestic drinking waters supplies to a degree where the water is not recommended for human consumption. Leakage of P and N from farms to waterways also contributes to the eutrophication of surface waters.

Stream monitoring within the catchments during 2001 has shown that nutrient levels within all catchments are above water quality guidelines for minimising the growth of nuisance weeds and algae (Figure 1). Whereas both P and N levels are equally high in the Waikakahi stream, within the Toenepi and Bog Burn streams P is the nutrient that is most limiting nuisance weed and algal growth. Hence, strategies to improve water quality within these 2 streams should focus first on reducing P losses from soil to waterways. In this report we shall demonstrate how nutrient budgeting can be a useful tool for evaluating nutrient management strategies at a catchment scale. This will be done with a particular focus on (i) N management, within the context of groundwater quality, and (ii) P management, within the context of surface water quality.

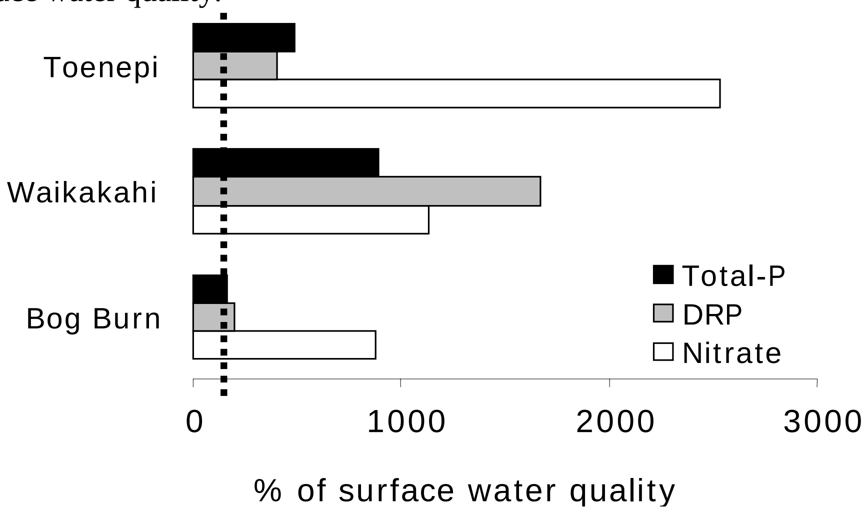

Figure 1: Nitrate and phosphorus levels in the Toenepi, Waikakahi and Bog Burn streams, expressed as percentages of the surface water quality guidelines (ANZECC 2000). Data supplied by R. Wilcock (NIWA). (Levels above dotted line are non-limiting to algal growth).

2. Catchment Description

Data inputs and outputs for the OVERSEER® nutrient budget model for current dairy and sheep and beef operations were obtained from a combination of data collected from farm surveys within the catchments, MAF monitor farms and the NZ Meat and Wool Board's Economic Service (1998-1999). Data used to estimate nutrient budgets due to intensification of farming operations was calculated from inputs required to increase production to levels indicated. The potential effect of conversion of sheep and beef farms to cropping farms was calculated using information collected on typical cropping practices and crop yields relevant to each of the catchments.

The three catchments used for this project are being used as part of a monitoring project supported by Fonterra Research Centre and FertResearch.

2.1 BOG BURN

The Bog Burn catchment is situated on the northern end of the Oreti Plains in central Southland. The main catchment area consists of an 8 km length of the lower Bog Burn between Dunearn Road and the Hundred Line Road. The soil type within this lower part of the catchment is predominantly a Pukemutu silt loam, which is an imperfectly drained Fragic Pallic soil. The Jacobstown silt loam, a Recent Gley soil, is the only other significant soil within the lower catchment occupying a narrow margin immediately adjacent to the Bog Burn stream. Mole-tile drainage systems are widespread due to the poor drainage that these two soils have in their natural state.

The catchment area is generally flat with an altitude of 118 m above mean sea level (AMSL) at Dunearn Road and 85 m at Hundred Line Road. Annual rainfall within the catchment is approximately 900 mm (NZMS, 1980). Modest summer rainfall and high potential evapo-transpiration are frequent constraints to pasture production during summer/early autumn. There are currently no farms using irrigation within the catchment.

There are 14 farms within the Bog Burn catchment, with five dairy farms covering 80% of the lower Bog Burn catchment. The dairy farms were all converted from sheep farms, with the first conversion taking place in 1991. The other farms are predominantly sheep/beef farms. Average size of the dairy farms is 222 ha and annual milksolids (MS) production is 1060 kg/ha. Dairy stock are wintered off-farm at locations outside the catchment for an average of 68 days. The average area of sheep and cattle farms is 141 ha.

2.2 WAIKAKAHI CATCHMENT

The predominantly flat Waikakahi catchment is in South Canterbury, north of the Waitaki River, and west of Glenavy township. The Waikakahi Stream which flows through the catchment is spring-fed and has increased flow rates in summer compared with winter, due to irrigation. Most of the farms in the catchment were converted to dairying from the early to mid 1990s.

The catchment is approximately 18 km long by about 4 km wide. Soils comprise deep Te Muka silt loams (Typic Orthic Gley Soil; Kear *et al.* 1967; Wallace *et al.* 2000) in the upper catchment, with the remainder mainly Eyre very stony sandy loam and very stony silt loams (Weathered Orthic Recent Soil; Wallace *et al.* 2000). In this catchment, many of these free-draining Eyre soils contain alluvial gravels below 5 to 10 cm depth.

The catchment has an altitude of 30-60 m AMSL and an average rainfall of 540 mm p.a. (NZMS, 1980).The catchment contains 16 farms with 11 dairy units and five being dry stock units with sheep and cattle. The average area of dairy farms is 173 ha and these are largely border dyke irrigated, with some using Rotorainer or K-line irrigation. Mean stocking rate is 3.1 cows/ha and mean annual production is 1070 kg MS/ha. The average area of the dry stock farms is 73 ha.

2.3 TOENEPI

The Toenepi catchment is in the Eastern Waikato basin approximately 5 km south of Morrinsville. The Toenepi Stream is a tributary of the Piako River and flows through the catchment forming the basis of the catchment area.

The soils in the catchment are predominantly volcanic in origin and are Typic Orthic Allophanic soils comprising the Kiwitahi and Kereone yellow brown loams in the lower slopes and the Morrinsville clay loam on the upper slopes, with some “recent” sedimentary soils (Topehaehae silt loam) along the valley bottoms. These soils are generally free draining. The catchment has an altitude of 70-100 m AMSL and an average rainfall of 1200 mm p.a. (NZMS, 1980).

The catchment is predominantly dairying and contains 26 farms, consisting of 21 dairy farms, and five farms running sheep and beef or dairy replacements. Average dairy farm area is 76 ha and most farms use a two-pond system for processing farm dairy effluent (FDE). There is no irrigation used on any of the farms. Mean stocking rate is 2.5 cows/ha and mean annual dairy production 870 kg MS/ha. The average area of the sheep and cattle farms is 111 ha.

3. Catchment Data

The following catchment data is the input data entered into the OVERSEER® nutrient budget model for the current sheep/beef and dairy farms in each catchment. Additional data for intensified scenarios are listed in the text.

3.1 BOG BURN

General catchment data				
Catchment area	2146 ha			
Topography	Flat lower catchment, hilly upper catchment			
Rainfall	900 mm p.a.			
Soil type	Sedimentary			
Soil drainage	Poor			

Current Dairy Farms				
Area under dairy farming	1110 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	71	67	85	92
Stocking rate	3.1 cows/ha			
Farm production	1062 kg MS/ha			
Dairy effluent management	Spray on 15% of farm			
Winter grazing management	Grazed off farm			
Farm supplements brought in	1.1 t DM/ha			
Olsen P	43			
Soil potassium	7			

Current Sheep and Beef Farms				
Area under sheep and beef farming	1036 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	12	26	11	33
Farm production	70 kg wool/ha			
Stock (numbers/ha): Sheep	14.7			
Beef	8			
Olsen P	18			
Soil potassium	5			

3.2 WAIKAKAHI

General catchment data				
Catchment area	2281 ha			
Topography	Flat			
Rainfall	540 mm p.a.			
Soil type	Sedimentary			
Soil drainage	Good			

Current Dairy Farms				
Area under dairy farming	1913 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	172	57	56	64
Stocking Rate	3.0 cows/ha			
Farm production	1055 kg MS/ha			
Dairy effluent management	Spray on 15% of farm			
Winter grazing management	Grazed off farm			
Irrigation	600 mm			
Farm supplements brought in	1.8 t DM/ha			
Olsen P	38			
Soil potassium	10			

Current Sheep and Beef Farms				
Area under sheep and beef farming	368 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	5	20	3	21
Farm production	36 kg wool/ha			
Stock (number/ha): Sheep	7.7			
Beef	1.6			
Olsen P	30			
Soil potassium	7			

3.3 TOENEPI

General catchment data	
Catchment area	1819 ha
Topography	Rolling
Rainfall	1200 mm p.a.
Soil type	Volcanic
Soil drainage	Good

Current Dairy Farms				
Area under dairy farming	1598 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	74	57	44	62
Stocking rate	2.5 cows/ha			
Farm production	870 kg MS/ha			
Dairy effluent management	Two-pond and discharge to streams			
Winter grazing management	Grazed on farm paddocks			
Farm supplements brought in	0.4 t DM/ha			
Olsen P	49			
Soil potassium	10			

Current Sheep and Beef Farms				
Area under sheep and beef farming	221 ha			
Fertiliser inputs (kg/ha/yr)	N	P	K	S
	6	42	17	55
Farm production	21 kg wool/ha			
Stock (numbers/ha): Sheep	6.5			
Beef	4.8			
Farm supplements brought in	0.2 t DM/ha			
Olsen P	43			
Soil potassium	13			

4. The OVERSEER® Nutrient Budget Model and Estimates of N Leaching

The OVERSEER® nutrient budget model is an empirical, annual time-step model (Ledgard *et al.* 1999). It provides average estimates of the fate of the nutrients N, P, K and S in kg/ha/year, ignoring year-to-year variability due to climate. The model contains a number of internal databases with nutrient concentrations of fertilisers, animals, products, crop framework, and crop residues. These are used for estimating the nutrient inputs or outputs on a per-hectare basis.

From an environmental perspective, N is often the nutrient of most interest because of its potential effects on water quality (e.g. Boothroyd *et al.* 2000). The OVERSEER® nutrient budget model provides average estimates of the fate of N for a range of pastoral, arable and horticultural systems, including N leaching. It gives long-term average annual estimates (ignoring year-to-year variability) of N flows and for the pastoral and horticultural systems it is assumed that the soil organic N is at an equilibrium level. An N balance model concept is used whereby Σ N inputs = Σ N outputs.

In pastoral systems, N leaching is determined by the amount of N in fertiliser, farm dairy effluent and that excreted in urine and dung by grazing animals. The latter is calculated from the difference between N intake by grazing animals and N output in animal products, based on user inputs of stocking rate or production and an internal database with information on the N content of pasture and animal products. The loss factor for urine or dung is dependent on soil and rainfall, based on a summary of New Zealand and overseas research.

Figure 2 summarises data from field studies where N leaching has been estimated under dairy farm grazing systems. The study at Dexcel No.2 dairy with three different rates of N fertiliser is the most detailed and long-term dairy farmlet experiment in New Zealand (Ledgard *et al*. 1999) and highlights the relatively large increases in N leaching with N fertiliser input. A farmlet study at the Westpac Trust Taranaki Research Station compared an intensive nil-N fertiliser farmlet under standard winter grazing management with a farmlet which simulated cows going onto a feed-pad from April to July, and highlights the significance of N excreted in autumn and winter to total leaching losses (Ledgard *et al*. unpublished). The other two farm sites in Otago and Southland in Figure 2 refer to measurements made over two years on commercial dairy farms (Monaghan *et al*. 2002). Over all sites and treatments, there was good agreement between measured and modelled estimates of N leaching with values differing by <20% in all cases.

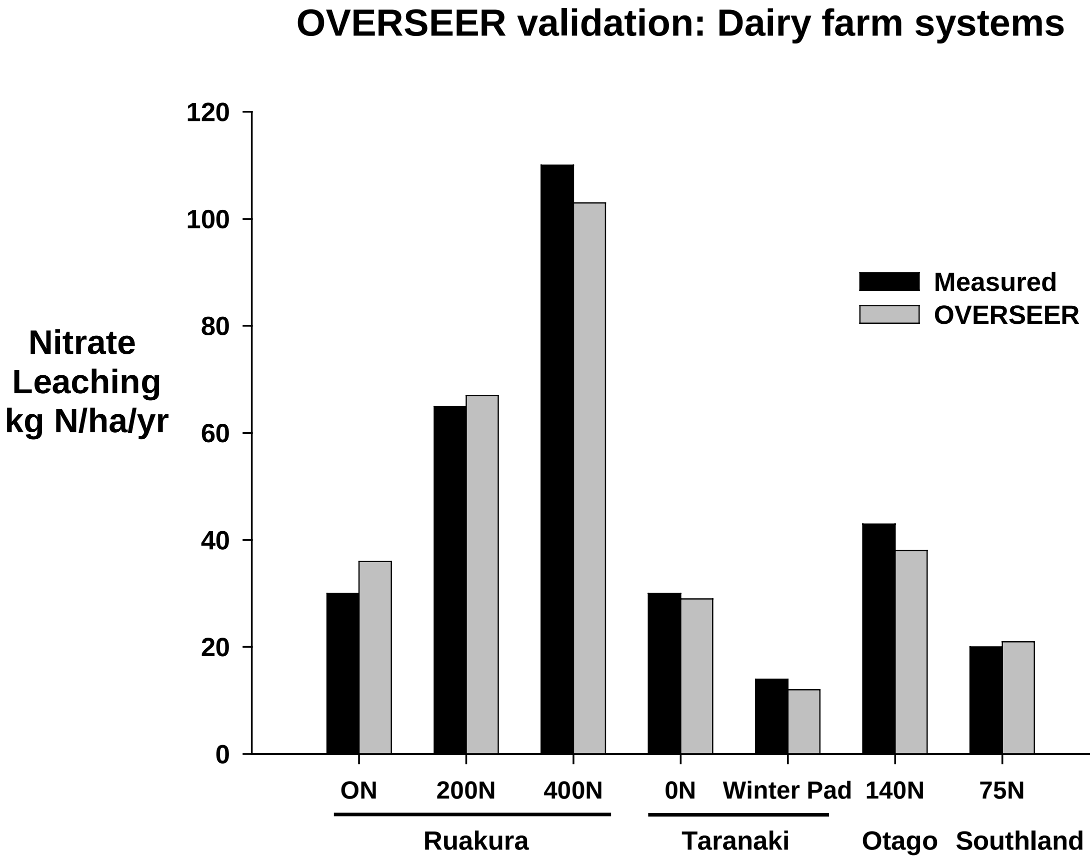

Figure 2: Comparison of average annual N leaching measured in dairy farm systems with estimates using the OVERSEER® nutrient budget model.

In cropping systems, N leaching is a product of the monthly N surplus (Σ N inputs – N in products) and estimated monthly drainage (based primarily on rainfall). The N inputs from fertiliser, supplements or irrigation are calculated from user-defined values for the amount of fertiliser, supplements or irrigation used in their farm system and values for the N concentration of these inputs from the database within the model. An important N input occurs from mineralisation due to cultivation and is calculated to decline exponentially with increasing time out of pasture, with some adjustment for soil group, rainfall and region (temperature effect). The N output in product is a function of user-defined yield and an average N concentration of the product from the model database.

5. Catchment Nutrient Balances

5.1 BOG BURN

5.1.1 The effects of sheep and beef intensification

The nutrient budget for the current average sheep and beef farm in the Bog Burn catchment is set out in Table1. This nutrient budget is based on a stocking rate of 22.7 SU/ha and a sheep:cattle SU ratio of 65:35. In the table, N_2-fixation and rainfall inputs refer to nutrients in rainfall, except for N where most is that calculated from N_2-fixation by pasture legumes. The slow-release inputs of P and K refer to that released from weathering of soil minerals.

Outputs of nutrients in products are from meat and wool sold off the farm. Gaseous N losses occur from ammonia volatilisation and denitrification. Leaching of N, K and S and runoff of P are estimated as well as immobilisation of N, P and S into soil organic matter and absorption of P onto soil. The change in the inorganic pool is essentially the nutrient balance and refers to accumulation of inorganic nutrients, which would be reflected in an increase in soil test levels. Table 1 shows moderate leaching/runoff losses and some accumulation of P, K and S in soil.

Table 1. Nutrient budget for an average sheep and beef farm in the Bog Burn catchment

	Average Sheep and Beef			
Inputs (kg ha/yr)	N	P	K	S
Fertiliser	12	26	11	33
N_2-fixation & rainfall	115	0	2	4
Irrigation	0	0	0	0
Slow release	0	3	72	0
Supplements	0	0	0	0
Outputs (kg ha/yr)	**N**	**P**	**K**	**S**
Product	23	3	2	4
Gaseous N losses	61	0	0	0
Leaching/runoff	16	1	11	21
Immobilisation/absorption	27	15	0	3
Change in inorganic pool	0	10	72	9

The current average Sheep and Beef farm in the Bog Burn catchment has considerable potential for intensification. Table 2 presents the N budget for the current average sheep and beef farm and the effects of intensification achieved by two different methods: i) increasing stock production by increasing fertiliser N inputs and ii) by keeping fertiliser N inputs the same as the average farm, but increasing pasture utilisation by better pasture management.

Intensification through the addition of extra fertiliser N (based on a rate estimated to provide the required increase in pasture production), was calculated to cause some suppression of N_2-fixation by pasture legumes and subsequently inputs of N from N_2-fixation and rainfall decreased. Nitrogen outputs in product and gaseous N losses increased with intensification, as did immobilisation in soil organic matter. Leaching/runoff losses also increased under intensification by 44% from 16 kg N/ha/yr to 23 kg N/ha/yr through N fertiliser use.

Intensification of the sheep and beef farm system by increasing pasture utilisation and better pasture management was estimated to require larger inputs of N from legume N_2-fixation. Outputs in product are the same in both intensification options, but gaseous N losses and immobilisation/absorption losses are lower than when using increased fertiliser N.

Leaching/runoff losses are only slightly lower from intensification by increasing pasture utilisation than from using fertiliser N. Both scenarios are within the range (5-25 kg N/ha/yr) for average leaching losses from New Zealand sheep and beef farms. Nitrate-N concentration in leachate was estimated at 7 ppm for the current average sheep and beef farm in the Bog Burn catchment and 9 ppm in both intensified operations. All three scenarios are below the recommended maximum for drinking water of 11 ppm.

Table 2. The effects of intensification (plus 20% production and stocking rate), on the farm N budget of an average sheep and beef farm in the Bog Burn catchment

Inputs (kg N/ha/yr)	Average Sheep and Beef	Intensive Sheep and Beef (better pasture management)	Intensive Sheep and Beef (increased use of N fertiliser)
Fertiliser	12	12	140
N_2-fixation & rainfall	115	152	101
Irrigation	0	0	0
Supplements	0	0	0
Product	23	31	31
Gaseous N losses	61	79	108
Leaching/runoff	16	21	23
Immobilisation	26	33	79
Nitrate-N concentration in leachate (ppm)	*7*	*9*	*9*

5.1.2 The effects of dairy farm intensification

The nutrient budget for the current average dairy farm in the Bog Burn catchment is presented in Table 3. This nutrient budget is based on 3.0 cows/ha producing 1060 kg MS/ha and with higher N fertiliser inputs than in the sheep and beef system. Some nutrient inputs also occurred in purchased supplementary feed. Loss of N from leaching/runoff is moderate at 18 kg N/ha/yr. Considerable accumulation of inorganic P and K is predicted. As soil P levels are already high (Olsen P test 43), this accumulation is of concern.

Table 3. Nutrient budget for an average dairy farm in the Bog Burn catchment

	Average Dairy			
Inputs (kg ha/yr)	N	P	K	S
Fertiliser	71	67	85	92
N_2-fixation & rainfall	121	0	2	4
Irrigation	0	0	0	0
Slow release	0	3	41	0
Supplements	15	3	11	2
Outputs (kg ha/yr)				
Product	82	14	19	5
Gaseous N losses	74	0	0	0
Leaching/runoff	18	1	22	86
Immobilisation/absorption	33	27	0	3
Change in inorganic pool	0	31	98	4

The average dairy farm in the Bog Burn catchment has considerable potential to increase production by intensification. Table 4 presents the N budget for an intensive dairy farm compared to an average dairy farm in the Bog Burn catchment. To achieve this, cow numbers were assumed to increase from 3.0 to 3.5 cows/ha and MS from 1060 to 1220 kg/ha/yr. This was assumed to be achieved by increasing N fertiliser by 100 kg N/ha/yr and providing 1.4 t DM/ha of barley as extra supplementary feed.

Intensification through increased N inputs in fertiliser and feed was estimated to decrease N_2-fixation by pasture legumes and reduce inputs of N from N_2-fixation and rainfall.

Outputs from the farm system increased with extra N in product (mainly in milk) and higher gaseous N losses. Leaching losses of N increased from 18 to 23 kg N/ha/yr and immobilisation/absorption losses from 33 to 54 kg N/ha/yr. These leaching losses are within the range for an average New Zealand dairy farm of 5-25 kg N/ha/yr. The nitrate-N concentration in leachate increases from 7 to 9 ppm through intensification but is within the recommended maximum for drinking water of 11 ppm.

Table 4. The effects of dairy intensification on the farm N budget of an average dairy farm in the Bog Burn catchment

Inputs (kg N/ha/yr)	**Average Dairy**	**Intensive Dairy**
Fertiliser	71	170
N_2-fixation & rainfall	121	74
Irrigation	0	0
Supplements	15	40
Outputs (kg N/ha/yr)		
Product	82	98
Gaseous N losses	74	109
Leaching/runoff	18	23
Immobilisation	33	54
Nitrate-N concentration in leachate (ppm)	*7*	*9*

5.1.3 The effects of dairy farm development

For this report the current average dairy farm within the Bog Burn catchment was assumed to be in a developed state (i.e. more than 10 years since conversion to dairying). However, many of the dairy farms in the catchment have been in dairying for less than 10 years. Table 5 lists the N budgets predicted for a recently converted dairy farm, compared to a developed dairy farm within the Bog Burn catchment. Both farms were assumed to have the same farm management, production, fertiliser and supplementary feed inputs.

The N budgets presented in Table 5 show that the recently converted dairy farm system was estimated to have higher N inputs due to increased N_2-fixation and much higher immobilisation of N into soil organic matter. Gaseous N losses and leaching/runoff losses are slightly higher in the developed system. The nitrate-N concentration in leachate is also lower in the recently converted dairy farm.

Table 5. Nitrogen budgets of recently converted and developed dairy farms within the Bog Burn catchment

	Average Dairy	
Inputs (kg N/ha/yr)	Recently converted[1]	Developed [2]
Fertiliser	71	71
N_2-fixation & rainfall	181	121
Irrigation	0	0
Supplements	15	15
Outputs (kg N/ha/yr)		
Product	82	82
Gaseous N losses	72	74
Leaching/runoff	16	18
Immobilisation	97	33
Nitrate-N concentration in leachate (ppm)	*6*	*7*

[1] recently converted refers to farms being in dairying for less than 10 years.
[2] developed refers to farms being in dairying for at least 10 years.

5.1.4 The effects of integration of forage-cropping

Conversion to cropping as an alternative to intensification is a viable option for Sheep and Beef farmers within the Bog Burn catchment. Table 6 presents the N budgets for a forage-cropping farm growing barley followed by oats for silage, for years one and 10 after converting from a sheep and beef farm system.

To achieve this change in farm systems, fertiliser inputs were increased (especially N inputs) with a greater N input in year 10 than in year one after conversion. Less N was required in year one after conversion due to a higher amount of N being mineralised after cultivation in year one than in year 10. Inputs of N from N_2-fixation and rainfall were low (2 kg/ha/yr in rainfall) due to the absence of legumes and subsequently no N inputs from N_2-fixation.

Table 6. The effects on the farm N budget of converting an average sheep and beef farm to a forage-cropping farm in the Bog Burn catchment

			Cropping	
Inputs (kg N/ha/yr)	**Average Sheep and Beef**	**Inputs (kg N/ha/yr)**	**Year 1**	**Year 10**
Fertiliser	12	Fertiliser	75	200
N_2-fixation & rainfall	115	N_2-fixation & rainfall	2	2
Irrigation	0	Irrigation	0	0
Supplements	0	Net mineralisation	156	58
		Carried in-residues	54	54
Outputs (kg N/ha/yr)		**Outputs (kg N/ha/yr)**		
Product	23	Product	203	203
Gaseous N losses	61	Gaseous N losses	18	54
Leaching/runoff	16	Leaching/runoff	34	25
Immobilisation	26	Residues left	32	32
		Immobilisation	0	0
Nitrate-N concentration in leachate (mg N/L)	*7*	*Nitrate-N concentration in leachate (mg N/L)*	*14*	*10*

N losses via leaching/runoff were high in year one after conversion and declined by year 10, although both cropping scenarios have a higher leaching/runoff loss than the sheep and beef farm system. The nitrate-N concentration in leachate was estimated to double from 7 ppm in the current average sheep and beef system to 14 ppm in year one after cropping due to increased leaching, and decrease to 10 ppm by year 10.

5.1.5 The effects of change in land use

The scenarios so far are presented for individual farm systems and the inputs and outputs of N are on a per hectare basis. Table 7 presents data on N inputs and outputs on a catchment scale (tonnes of N per catchment). Table 8 presents catchment data on P inputs and outputs (t P per catchment) and table 9 presents catchment data on K inputs and outputs (t K per catchment). There are six farm scenarios presented as a progression from the original catchment of all sheep and beef, through to the current mixed sheep and beef and dairy, then to all dairy (at current production), all intensive dairy, and intensive dairy plus sufficient forage-cropping to supply all the supplementary feed required by the dairy farms.

Table 7 clearly shows the increase in fertiliser N inputs (from 26 to 377 t N) associated with farming systems changes from all sheep and beef to intensive dairy plus cropping. N_2-fixation and rainfall inputs of N also increased from all sheep and beef to all dairy as pasture legume N_2-fixation increased. Nitrogen inputs in supplementary feeds increased from nil with all sheep and beef farms to 86 t N in the all intensive dairy scenario. There was no net input of N in supplementary feed in the intensive dairy plus cropping system, although transfer would occur within the catchment. Other N inputs are through net mineralisation (with cultivation) and carried in residues (organic matter) in the all intensive dairy plus cropping scenario.

Outputs from the catchment increased from 49 t N for the all sheep and beef scenario to 210 t N for the all intensive dairy scenario. Gaseous N losses and immobilisation also increased from all sheep and beef to all intensive dairy and decreased slightly when cropping was integrated into the all intensive dairy option. Leaching/runoff losses increase steadily from 34 t N to 50 t N, representing a 47% increase. Associated nitrate-N concentrations in leachate were also estimated to increase from 7 through to 9 ppm, which are below the maximum recommended limit for drinking water of 11 ppm in all scenarios.

Table 8 shows the increase in P inputs (from 56 to 144 t N) required as farming systems change from all sheep and beef to all dairying. No increase in P input under intensive dairying was assumed because of the positive P balance in the current system (Table 1). P inputs in supplementary feeds increased from nil with all sheep and beef to 17 t P in the all intensive dairy scenario. Other P inputs were through slow release from soil weathering and are the same for all scenarios.

Outputs of P in product from the catchment increased from 6 t P for the all sheep and beef scenario to 36 t P for the all intensive dairy scenario. Leaching/runoff losses of P were similar at 2 t P for all scenarios, although this is only crudely estimated by the model. Removal through immobilisation/absorption and change in the inorganic pool increased from all sheep and beef to intensive dairy but was lower where land was taken out for cropping (all intensive dairy plus cropping).

Potassium inputs and outputs also increased markedly with change in farm system and intensification (Table 9). Forage cropping greatly increased K fertiliser requirements and there were large transfers within the catchment associated with use of forage crops. The net effect was an overall accumulation of K in soil.

Table 7. The effects on the catchment N budget of conversion from all sheep and beef farming through to intensive dairying and forage-cropping in the Bog Burn catchment

Inputs (t N/catchment)	All Sheep And Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy plus cropping
Fertiliser	26	91	122	153	365	377
N_2-fixation & rainfall	247	254	257	260	159	131
Net mineralisation	0	0	0	0	0	23
Supplements	0	17	24	32	86	0
Carried in residues	0	0	0	0	0	21
Outputs (t N/catchment)						
Product	49	115	145	176	210	181
Gaseous N losses	131	145	152	159	234	212
Leaching/runoff	34	37	38	39	49	50
Residues left	0	0	0	0	0	12
Immobilisation	59	65	68	71	117	97
Nitrate-N concentration in leachate (ppm)	*7*	*7*	*7*	*7*	*9*	*9*

Table 8. The effects on the catchment P budget of conversion from all sheep and beef farming through to intensive dairying and forage-cropping in the Bog Burn catchment

Inputs (t P/catchment)	All Sheep and Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy plus cropping
Fertiliser	56	101	123	144	144	133
Slow release	6	6	6	6	6	6
Net mineralisation	0	0	0	0	0	0
Supplements	0	3	5	6	17	0
Outputs (t P/catchment)						
Product	6	19	24	30	36	30
Leaching/runoff	2	2	2	2	2	2
Residues removed	0	0	0	0	0	2
Net residues left	0	0	0	0	0	5
Immobilisation/absorption	35	44	51	55	58	47
Change in inorganic pool	19	45	57	69	71	53

Table 9. The effects on the catchment K budget of conversion from all sheep and beef farming through to intensive dairying and forage-cropping in the Bog Burn catchment

Inputs (t K/catchment)	All Sheep and Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy plus cropping
Fertiliser	24	106	144	182	182	277
Rainfall	4	4	4	4	4	4
Slow release	155	120	104	88	88	80
Supplements	0	12	18	24	37	0
Outputs (t K/catchment)						
Product	4	23	32	41	47	45
Leaching/runoff	24	36	42	47	54	48
Net Residues left	0	0	0	0	0	15
Change in inorganic pool	155	183	196	210	210	253

5.2 WAIKAKAHI

5.2.1 The effects of sheep and beef intensification

The nutrient budget for the current average sheep and beef farm in the Waikakahi catchment is presented in Table 10. This nutrient budget is based on a stocking of 9.3 SU/ha and a sheep:cattle SU ratio of 83:17. Stocking rate on sheep and beef farms in the Waikakahi catchment is low due to the low rainfall (540 mm/yr) and no irrigation. Nutrient inputs and outputs from the average sheep and beef farm in the Waikakahi catchment are also low due to the low rainfall and lack of irrigation.

Table 10. Nutrient budget for an average sheep and beef farm in the Waikakahi catchment

	Average Sheep and Beef			
Inputs (kg ha/yr)	N	P	K	S
Fertiliser	5	20	3	21
N_2-fixation & rainfall	46	0	3	5
Irrigation	0	0	0	0
Slow release	0	3	59	0
Supplements	0	0	0	0
Outputs (kg ha/yr)				
Product	12	1	1	2
Gaseous N losses	27	0	0	0
Leaching/runoff	2	1	7	30
Immobilisation/absorption	10	20	0	1
Change in inorganic pool	0	1	57	-7

The current average Sheep and Beef farm in the Waikakahi catchment has considerable potential for intensification. Table 11 presents the N budget of the current average sheep and beef farm and the same farm after intensification. Intensification was achieved by increasing stock production and stock numbers by increasing fertiliser N inputs by 95 kg N/ha/yr and the inclusion of irrigation (irrigation results in additional N inputs of 15 kg N/ha/yr).

Addition of extra fertiliser N again decreased inputs of N from N_2-fixation and rainfall due to suppression of N_2-fixation by pasture legumes. Intensification increased N outputs in product and increased gaseous N losses and immobilisation. Losses through leaching/runoff increase markedly from 2 kg N/ha/yr to 28 kg N/ha/yr (largely due to irrigation), which is above the range for the average New Zealand sheep and beef farm of 5-25 kg N/ha/yr. The nitrate-N concentration in leachate is 5 ppm for the current average sheep and beef farm in the Waikakahi catchment and 6 ppm after intensification. Both scenarios are below the recommended maximum for drinking water of 11 ppm. The nitrate-N concentration is low after intensification even though leaching/runoff losses are high due to a dilution effect through irrigation increasing drainage from 40 mm to 450 mm per annum.

Table 11. The effects of intensification (plus 20% production and stocking rate, plus irrigation), on the farm N budget of an average sheep and beef farm in the Waikakahi catchment

Inputs (kg N/ha/yr)	Average Sheep and Beef	Intensive Sheep and Beef
Fertiliser	5	100
N_2-fixation & rainfall	46	25
Irrigation	0	15
Supplements	0	0
Outputs (kg N/ha/yr)		
Product	12	15
Gaseous N losses	27	54
Leaching/runoff	2	28
Immobilisation	10	43
Nitrate-N concentration in leachate (ppm)	*5*	*6*

5.2.2 The effects of dairy intensification

The nutrient budget for the current average dairy farm in the Waikakahi catchment is presented in Table 12. This nutrient budget is based on 3.0 cows/ha and 1055 kg MS/ha. Table 12 shows higher inputs of nutrients to the current average Waikakahi dairy farm than in the other catchments, especially fertiliser N inputs. Leaching/runoff, gaseous N losses and immobilisation of N were also higher than for average dairy farms in the other catchments. Some accumulation of inorganic P and K in soil was predicted.

Table 12. Nutrient budget for an average dairy farm in the Waikakahi catchment

	Average Dairy			
Inputs (kg ha/yr)	**N**	**P**	**K**	**S**
Fertiliser	172	57	56	64
N_2-fixation & rainfall	49	0	3	5
Irrigation	15	1	6	15
Slow release	0	3	33	0
Supplements	42	5	40	5
Outputs (kg ha/yr)				
Product	81	14	19	5
Gaseous N losses	87	0	0	0
Leaching/runoff	39	1	21	72
Immobilisation/absorption	71	25	0	7
Change in inorganic pool	0	26	98	5

The average dairy farm in the Waikakahi catchment has potential to increase production by intensification. Table 13 presents the N budget for an intensified dairy farm compared to an average dairy farm in the Waikakahi catchment. To achieve this, cow numbers were increased from 3.0 to 3.7 cows/ha and MS from 1055 to 1300 kg/ha. This was achieved by two methods: i) by increasing N fertiliser by 132 kg N/ha/yr over the whole farm and providing 1.6 t DM/ha of silage as extra supplementary feed, and ii) by increasing N fertiliser to 200 kg N/ha/yr over the whole farm and increasing supplementary feed by 3.4 t DM/ha of pasture silage.

Intensification through increased use of N fertiliser and supplements decreased N_2-fixation and rainfall N inputs to the system through the suppression of N_2-fixation by pasture legumes, particularly at the highest N fertiliser rate. Total inputs (and outputs) of N were highest for the high N fertiliser system.

Outputs from the farm system increased with extra N in product (mainly milk), and higher gaseous N losses. Leaching losses of N increased from 39 to 64 kg N/ha/yr in the high N system and to 59 kg N/ha/yr in the high supplement system. Leaching losses are slightly lower in the high supplement system (59 kg N/ha/yr) than the high N system (64 kg N/ha/yr). These leaching losses after intensification are above the range of 30-45 kg N/ha/yr for an average New Zealand dairy farm. Immobilisation losses increased from 71 in the current average dairy farm to 117 and 104 kg N/ha/yr for the high N and high supplement systems, respectively. The nitrate-N concentration in leachate increased from 9 ppm to 14 and 13 ppm through intensification for the high N and high supplement systems, respectively. Both intensified systems are above the recommended maximum for drinking water of 11 ppm.

Table 13 effects of intensification on the farm N budget (plus 23% production and stocking rate) of an average dairy farm in the Waikakahi catchment

Inputs (kg N/ha/yr)	**Average Dairy**	**Intensive (+23%) Dairy (high N)**	**Intensive (+23%) Dairy (high supp.)**
Fertiliser	172	304	200
N_2-fixation & rainfall	49	18	38
Irrigation	15	15	15
Supplements	42	84	121
Outputs (kg N/ha/yr)			
Product	81	100	100
Gaseous N losses	87	140	111
Leaching/runoff	39	64	59
Immobilisation	71	117	104
Nitrate-N concentration in leachate (ppm)	*9*	*14*	*13*

5.2.3 The effects of dairy farm development

For this report the average dairy farm within the Waikakahi catchment was assumed to be in a developed state (more than 10 years since conversion to dairying). However, like the Bog Burn catchment, many of the dairy farms in the Waikakahi catchment have been in dairying for less than 10 years. Table 14 shows the N budgets for a recently converted dairy farm, compared to a developed dairy farm within the Waikakahi catchment. Both farms were assumed to have the same farm management, production, fertiliser and supplementary feed inputs.

The N budgets for the two scenarios indicate that a recently converted dairy farm system would have higher inputs of N due to increased N_2-fixation and higher immobilisation of N into soil organic matter. Leaching losses and the nitrate-N concentration in leachate were estimated to be lower in the recently converted dairy farm.

Table 14. Nitrogen budgets for recently converted and developed dairy farms in the Waikakahi catchment.

	Average Dairy	
Inputs (kg N/ha/yr)	**Recently converted**[1]	**Developed** [2]
Fertiliser	172	172
N_2-fixation & rainfall	66	49
Irrigation	15	15
Supplements	42	42
Outputs (kg N/ha/yr)		
Product	81	81
Gaseous N losses	82	87
Leaching/runoff	29	39
Immobilisation	103	71
Nitrate-N concentration in leachate (ppm)	*6*	*9*

1 recently converted refers to farms being in dairying for less than 10 years.
2 developed refers to farms being in dairying for at least 10 years.

5.2.4 The effects on dairy farm N budgets of poor soil drainage

In the Waikakahi catchment there is a large area (approx 40%) of poorly drained soils. For this report the current average dairy farm within the Waikakahi catchment was assumed to be on the well-drained Eyre soils. Table 15 compares N budgets for the current average dairy farm on well-drained soils with current average dairy farms on poorly-drained soils within the Waikakahi catchment. Both farms were assumed to have the same farm management, production, fertiliser and supplementary feed inputs.

Gaseous N losses were lower in the well-drained soil and leaching/runoff and immobilisation/adsorption losses of N were both higher. Losses through leaching/runoff are lower in the poorly drained soil due to higher N removal by denitrification (Scholefield *et al*. 1993). The nitrate-N concentration in leachate of poorly drained soil was lower than in the well-drained soil but both soils are within the recommended maximum for drinking water of 11 ppm.

Table 15. The effects on the farm N budget of well-drained soils compared to poorly drained soils in the Waikakahi catchment.

	Average Dairy	
Inputs (kg N/ha/yr)	**Good drainage**	**Poor drainage**
Fertiliser	172	172
N_2-fixation & rainfall	49	49
Irrigation	15	15
Supplements	42	42
Outputs (kg N/ha/yr)		
Product	81	81
Gaseous N losses	87	102
Leaching/runoff	39	31
Immobilisation	71	64
Nitrate-N concentration in leachate (ppm)	*9*	*7*

5.2.5 The effects of integration of cropping

Conversion to cropping is a viable option for sheep and beef farmers within the Waikakahi catchment as an alternative to intensification. Table 16 presents the N budgets for a mixed cropping system which is the average for a seven year rotation covering ryegrass seed, white clover seed, spring peas, two crops of winter wheat and two crops of spring barley. This system and the level of inputs, crop yields and OVERSEER® nutrient budget model output was based on a “typical” Canterbury system as used in a MAF report by Thomas (2002).

Table 16 shows an increase in fertiliser N applied from 5 kg N/ha/yr for sheep and beef farms to 142 kg N/ha/yr for cropping. White clover and peas in the rotation provided an average input of 28 kg N/ha/yr. Net mineralisation of N occurs after conversion to cropping due to cultivation and accounted for an input of 34 kg N/ha/yr.

Output of N in crop produce was high at an average of 111 kg N/ha/yr. Nitrogen losses via leaching/runoff were high under cropping at 47 kg N/ha/yr and are significantly greater than the current sheep and beef system Nitrogen leaching/runoff losses (2 kg N/ha/yr). In the cropping system, gaseous N losses were lower while immobilisation was higher than in the sheep and beef system.

The nitrate-N concentration in leachate increased from 5 ppm in the sheep and beef system to 39 ppm in the cropping option. The latter is significantly above the recommended maximum for drinking water of 11 ppm.

Table 16. The effects on the farm Nitrogen budget of converting sheep and beef farms to intensive cropping in the Waikakahi catchment

Inputs (kg N/ha/yr)	Average Sheep and Beef	Inputs (kg N/ha/yr)	Cropping Average*
Fertiliser	5	Fertiliser	142
N_2-fixation & rainfall	46	N_2-fixation & rainfall	28
Irrigation	0	Irrigation	0
		Net mineralisation	34
		Carried in-residues	20
		Carried in-inorganic	36
Outputs (kg N/ha/yr)		**Outputs (kg N/ha/yr)**	
Product	12	Product	111
Gaseous Nitrogen losses	27	Gaseous Nitrogen losses	12
Leaching/runoff	2	Leaching/runoff	47
Immobilisation	10	Residues left	20
		Immobilisation	36
		Change in inorganic pool	34
Nitrate-N concentration in leachate (ppm)	*5*		*39*

* Cropping average is a seven year average from a mixed cropping rotation typical for Canterbury

5.2.6 The effects of change in land use

The scenarios in sections 6.2.1-6.2.5 were for individual farm systems and the inputs and outputs of Nitrogen were on a per hectare basis. Table’s 17-19 presents data on inputs and outputs of N, P, and K respectively, on a catchment scale (tonnes of nutrient per catchment). There are six farm scenarios presented as a progression from the “original” catchment of all sheep and beef, through to the current mixed sheep and beef and dairy, to all dairy, all intensive dairy, and intensive dairy plus cropping (the latter converted from sheep and beef farming).

Table 17 shows the increase in fertiliser Nitrogen inputs (from 11 to 693 t N) associated with farming system changes from all sheep and beef to intensive dairy farming. The other major increase with intensification was the increase in Nitrogen input in supplementary feeds. N_2-fixation and rainfall inputs showed little change but decreased in the all intensive dairying scenario and then increased with cropping because the cropping rotation included peas (an N_2-fixing plant).

Outputs in product from the catchment increased from 27 t Nitrogen for the all sheep and beef scenario to 228 t Nitrogen for the all-intensive dairy and 221 for the all intensive dairy plus cropping. Gaseous Nitrogen losses and immobilisation also increased from all sheep and beef to all intensive dairy and decreased slightly as cropping was integrated with the intensive dairy option. Leaching/runoff losses of Nitrogen increased steadily from 5 t Nitrogen to 146 t Nitrogen (a 29-fold increase) as sheep and beef converted to intensive dairying. In the intensive dairy plus cropping scenario, Nitrogen leaching/runoff losses decreased slightly due to lower losses under cropping. Associated nitrate-N concentrations in leachate also increased from 5 ppm in the all sheep and beef scenario through to 9 ppm in the all dairy scenario, to 14 and 23 ppm in the intensive dairy and in the intensive dairy plus cropping scenarios respectively. Both the intensive dairy and the intensive dairy plus cropping scenarios were above the maximum recommended for drinking water of 11 ppm. The higher nitrate-N concentration in leachate, but lower amount of N leached associated with cropping, occurred because cropping was non-irrigated and therefore had no dilution of N in leachate from increased drainage due to irrigation that occurred under dairying.
Table 18 shows the increase in P inputs (from 46 to 130 t P) required as farming systems change from all sheep and beef to intensive dairying. P inputs through supplementary feeds increased from 0 t P/catchment in all sheep and beef to 21 t P in the all intensive dairy scenario.

Outputs of P in product from the catchment increased from 2 t P for the all sheep and beef scenario to 39 t P for the all intensive dairy scenario. Leaching/runoff losses of P were estimated at approximately 2 t P for all scenarios. Losses through immobilisation/absorption increased from all sheep and beef to intensive dairy. Accumulation of inorganic P would be expected to coincide with an increase in soil P test in the farm systems which included dairying.

Potassium budgets (Table 19) showed a similar pattern to those for P, except that under all intensive dairying there was an increase in leaching losses and a relatively large increase in the soil inorganic K pool. This suggests that fertiliser K inputs could be reduced to counter the K inputs in extra supplementary feed.

Table 17 The effects on the catchment N budget of conversion from all sheep and beef farming through to intensive dairying and cropping in the Waikakahi catchment

Inputs (t N/catchment)	All Sheep and Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy Plus S & B to cropping
Fertiliser	11	331	362	392	693	634
N_2-fixation & rainfall	105	111	111	112	41	45
Irrigation	0	29	31	34	34	29
Net mineralisation	0	0	0	0	0	13
Supplements	0	80	88	96	192	161
Carried in residues	0	0	0	0	0	7
Carried in inorganic	0	0	0	0	0	13
Outputs (t N/catchment)						
Product	27	159	172	185	228	221
Gaseous N losses	62	176	187	198	319	272
Leaching/runoff	5	75	82	89	146	140
Residues removed	0	0	0	0	0	11
Residues left	0	0	0	0	0	7
Immobilisation	22	141	151	162	267	239
Change in inorganic pool	0	0	0	0	0	12
Nitrate-N concentration in leachate (ppm)	5	8	9	9	14	23

Table 18. The effects on the catchment P budget of conversion from all sheep and beef farming through to intensive dairying in the Waikakahi catchment

Inputs (t P/catchment)	All Sheep and Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy
Fertiliser	46	116	123	130	130
Irrigation	0	2	2	2	2
Slow release	7	7	7	7	7
Supplements	0	10	10	11	21
Outputs (t P/catchment)					
Product	2	27	30	32	39
Leaching/runoff	2	2	2	2	2
Net Residues left	0	0	0	0	0
Immobilisation	47	53	54	55	57
Change in inorganic pool	2	53	56	61	62

Table 19. The effects on the catchment K budget of conversion from all sheep and beef farming through to intensive dairying in the Waikakahi catchment

Inputs (t K/catchment)	All Sheep and Beef	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy
Fertiliser	5	108	118	128	128
Rainfall	7	7	7	7	7
Irrigation	0	11	13	14	14
Slow release	135	85	80	75	75
Supplements	0	77	84	91	182
Outputs (t K/catchment)					
Product	2	37	40	43	52
Leaching/runoff	16	43	45	48	55
Change in inorganic pool	129	208	217	224	299

5.3 TOENEPI

5.3.1 The effects of sheep and beef intensification

The nutrient budget for the current average sheep and beef farm in the Toenepi catchment is set out in Table 20. This nutrient budget is based on a stocking rate of 11.3 SU/ha and a sheep:cattle SU ratio of 49:51.

Table 20. Nutrient budget for an average sheep and beef farm in the Toenepi catchment

	Average Sheep and Beef			
Inputs (kg ha/yr)	**N**	**P**	**K**	**S**
Fertiliser	6	42	17	55
N_2-fixation & rainfall	68	0	2	4
Irrigation	0	0	0	0
Slow release	0	3	18	0
Supplements	0	0	0	0
Outputs (kg ha/yr)				
Product	9	1	1	1
Supplements sold	5	1	5	1
Gaseous N losses	23	0	0	0
Leaching/runoff	14	1	38	60
Immobilisation/absorption	23	39	0	2
Change in inorganic pool	0	3	-7	-5

The current average sheep and beef farm in the Toenepi catchment has considerable potential for intensification. Intensification was evaluated using two different methods: i) increasing stocking rate by 20% through increasing fertiliser N inputs, and ii) changing the system from sheep and beef to an intensive bull beef system (+80% SU/ha) with the addition of extra fertiliser N (see Table 21).

With the addition of extra N fertiliser inputs of N from N_2-fixation and rainfall decreased due to suppression of N_2-fixation by pasture legumes in the intensified sheep and beef system, but increased in the more productive bull beef system. Nitrogen outputs in product increased, as did gaseous N losses in both intensive systems, with the bull beef system having the highest outputs. Leaching/runoff losses of Nitrogen also increased significantly from 12 kg N/ha/yr in the average sheep and beef farm to 24 and 39 kg N/ha/yr in the intensive sheep-beef and intensive bull beef systems, respectively. Immobilisation was also higher under intensification.

Nitrate-N concentration in leachate was 2 ppm for the average sheep and beef farm in the Toenepi catchment and 5 and 8 ppm for the intensified operations. All systems were below the recommended maximum concentration of nitrate-N for drinking water of 11 ppm.

Table 21. The effects of intensification (plus 20% production and stocking rate; Intensive bull beef) on the farm Nitrogen budget of an average sheep and beef farm in the Toenepi catchment

Inputs (kg N/ha/yr)	Average Sheep and Beef	Intensive Sheep and Beef	Very intensive Bull Beef
Fertiliser	6	90	150
N_2-fixation & rainfall	68	51	81
Irrigation	0	0	0
Supplements	0	0	0
Outputs (kg N/ha/yr)			
Product	9	12	24
Supplements sold	5	5	5
Gaseous Nitrogen losses	23	44	71
Leaching/runoff	14	24	39
Immobilisation	23	56	92
Nitrate-N concentration in leachate (ppm)	*3*	*5*	*8*

5.3.2 The effects of dairy farm intensification

The nutrient budget for the current average dairy farm in the Toenepi catchment is presented in Table 22. This nutrient budget is based on 2.5 cows/ha producing 870 kg MS/ha, which is similar to that for the average Waikato dairy farm.

Table 22. Nutrient budget for an average dairy farm in the Toenepi catchment

	Average Dairy			
Inputs (kg ha/yr)	**N**	**P**	**K**	**S**
Fertiliser	74	57	44	62
N_2-fixation & rainfall	118	0	2	4
Irrigation	0	0	0	0
Slow release	0	3	21	0
Supplements	6	1	5	1
Outputs (kg ha/yr)	**N**	**P**	**K**	**S**
Product	68	12	15	4
Transfer	13	3	26	3
Gaseous Nitrogen losses	57	0	0	0
Leaching/runoff	41	1	34	56
Immobilisation/absorption	19	41	0	2
Change in inorganic pool	0	4	-3	2

The current average dairy farm in the Toenepi catchment has considerable potential to increase production by intensification of the farm system. Table 23 presents the Nitrogen budget for three potential intensive dairy farm operations: i) Intensive dairy (plus 20% production),ii) Intensive dairy (plus 50% production with high Nitrogen fertiliser use), and iii) Intensive dairy (plus 50% production with high use of supplements), compared to the current average dairy farm in the Toenepi catchment

Increased Nitrogen fertiliser use resulted in decreased N inputs from N_2-fixation and rainfall to the system through the suppression of N_2-fixation by pasture legumes.

Outputs from the farm system increased with extra Nitrogen in product (mainly in milk) and gaseous N losses increased as use of Nitrogen fertiliser increased. Leaching/runoff losses of Nitrogen increased from 41 kg N/ha/yr for the current farm to 71 kg N/ha/yr in the intensive plus-20% scenario, and to 99 kg N/ha/yr in the intensive plus-50% high Nitrogen scenario. When extra supplements were used instead of Nitrogen fertiliser to increase production, leaching losses of Nitrogen were lower at 61 kg N/ha/yr (Table 23). This occurred because the 1.5 t DM/ha assumed to be grown from fertiliser Nitrogen at 150 kg N/ha was replaced by 1.5 t maize DM/ha which contains only 18 kg N/ha, thereby reducing Nitrogen cycling and giving lower leaching losses. These leaching/runoff losses are significantly above the average range for a New Zealand dairy farm of 30-45 kg N/ha/yr in all scenarios.

In addition to the leaching losses there is also 6-10 kg N/ha/yr discharged to waterways from the two-pond FDE system. This discharge increased with increasing productivity and effectively increases the total overall losses of Nitrogen to water.

The nitrate-N concentration in leachate for the current average dairy farm (8 ppm) is below the recommended maximum for drinking water (11 ppm). However, all the intensified dairy scenarios are above the limit, with the high Nitrogen system being the highest at 20 ppm (Table 23).

Table 23. The effects of intensification on the farm Nitrogen budget of an average dairy farm in the Toenepi catchment. Intensification was achieved through increased (20 or 50%) MS production using increased Nitrogen fertiliser and/or supplements.

Inputs (kg N/ha/yr)	**Average Dairy**	**Intensive (+20%) Dairy**	**Intensive (+50%) Dairy + High N**	**Intensive (+50%) Dairy High Supplements**
Fertiliser	74	200	300	150
N_2-fixation & rainfall	118	88	61	81
Irrigation	0	0	0	0
Supplements	6	12	42	66
Outputs (kg N/ha/yr)				
Product	68	81	100	100
Transfer	13	17	23	21
Gaseous Nitrogen losses	57	92	125	83
Leaching/runoff	41	71	99	61
Immobilisation	19	39	56	32
Discharge from effluent ponds	*6*	*7*	*10*	*9*
Nitrate-N concentration in leachate (ppm)	*8*	*14*	*20*	*12*

5.3.3 The effects of changes in dairy farm management

The dairy farms within the Toenepi catchment currently graze dairy cows on pasture over winter and have a two-pond farm dairy effluent disposal system. Two possible options for the dairy farmers in the Toenepi catchment are to: i) use a stand-off pad and graze pasture for about four hours daily over winter, and ii) install a spray irrigation system for FDE (Table 24).

Higher removal of Nitrogen in excreta onto the stand-off pad and then to the effluent ponds resulted in a greater requirement for N_2-fixation by pasture legumes. Outputs of Nitrogen due to leaching/runoff were lower in the stand-off option in both current and intensified systems due to reduced excretion of urine Nitrogen on pasture in winter when leaching occurs.

However, associated increases in discharge of Nitrogen from the ponds in the stand-off pad options also occurred due to extra excreta-N from the pond. Land application of this FDE could increase overall Nitrogen efficiency and reduce losses.
Total losses from discharge of Nitrogen from the ponds and leaching/runoff were the same for winter management options on the average dairy farm, and similar for winter management options on the intensive scenario. Nitrate-N concentration in leachate was lower in the winter stand-off pad option due to more FDE being transferred to the ponds.

Table 24. The effects on the farm Nitrogen budget of utilising stand-off pads during winter with four hours daily grazing for an average and an intensified dairy farm in the Toenepi catchment

	Average Dairy		Intensive (+50%) Dairy + High N	
Inputs (kg N/ha/yr)	**On Paddock**	**Stand off and 4–hr Grazing**	**On Paddock**	**Stand off and 4–hr Grazing**
Fertiliser	74	74	300	300
N_2-fixation & rainfall	118	170	61	136
Irrigation	0	0	0	0
Supplements	6	6	42	42
Outputs (kg N/ha/yr)				
Product	68	68	100	100
Transfer	13	40	23	61
Gaseous Nitrogen losses	57	81	125	160
Leaching/runoff	41	29	99	80
Immobilisation	19	32	56	77
Discharge from two-pond	*6*	*18*	*10*	*27*
Nitrate-N concentration in leachate (ppm)	*8*	*6*	*20*	*16*

Table 25 shows the impact on N and Phosphorus (P) budgets for an average dairy farm with either a two pond FDE or a spray irrigation FDE disposal system. In the spray system, fertiliser N inputs were lower due to not applying fertiliser N on the area receiving FDE. Inputs of N from N_2-fixation and rainfall also decreased due to the high amount of N in the FDE being applied to 15% of the farm suppressing N_2-fixation. Inputs of P on the FDE area were also reduced according to the extra P in the FDE applied to the farm.

Leaching/runoff losses of N were similar for both the spray irrigation and two-pond FDE disposal system. However the two-pond FDE system had a discharge of 6 kg N/ha/yr to waterways meaning that the two-pond system had greater total losses of N. The nitrate-N concentration in leachate is the same for both the two-pond and spray irrigation FDE systems. Losses of P to waterways are also greater in the two-pond system when discharge to the waterways from the ponds is accounted for.

Table 25. The effects on the farm Nitrogen and Phosphorus budgets of using a two-pond or spray irrigation system for FDE on dairy farms in the Toenepi catchment

	Nitrogen		Phosphorus	
Inputs	**Two-Pond (kg N/ha/yr)**	**Spray Irrigated (kg N/ha/yr)**	**Two-Pond (kg P/ha/yr)**	**Spray Irrigated (kg P/ha/yr)**
Fertiliser	74	63	57	54
N_2-fixation & rainfall	118	111	0	0
Slow release	0	0	3	3
Supplements	6	6	1	1
Outputs				
Product	68	68	12	12
Transfer	13	0	3	0
Gaseous Nitrogen losses	57	48	0	0
Leaching/runoff	41	42	1	1
Immobilisation	19	22	41	41
Change in inorganic pool	0	0	4	4
Discharge from secondary ponds (kg/ha)	*6*	*0*	*1*	*0*
Nitrate-N concentration in leachate (ppm)	*8*	*8*		

5.3.4 The effects of integration of cropping

Conversion to cropping is a viable option for sheep and beef farmers within the Toenepi catchment as an alternative to intensification. Table 26 presents the N budgets for a forage-cropping farm growing maize silage followed by oat silage, for years one and 10 after converting from a sheep and beef farm system. To achieve this change in farm systems, fertiliser inputs were increased (especially Nitrogen inputs) with a greater Nitrogen input in year 10 than in year one after conversion. Less Nitrogen was required in year one after conversion due to a high amount of Nitrogen being mineralised after cultivation.

Table 26 shows the increase in fertiliser N from 6 (sheep and beef) to 140 kg N/ha/yr in year 1,and to 280 kg N/ha/yr in year 10. Net mineralisation of Nitrogen occurs after conversion to cropping due to cultivation and there is a significantly greater input of Nitrogen in the first year after conversion than in year 10.

Removal of Nitrogen in maize and oat silage was high at 515 kg N/ha/yr. Nitrogen losses via leaching/runoff were lower in year one than year 10, but both cropping scenarios were higher than the average sheep and beef farm system. The nitrate-N concentrations in leachate increased from 2 ppm in the sheep and beef system to 3-5 ppm under cropping, and are below the recommended maximum for drinking water of 11 ppm.

Table 26. The effects on the farm Nitrogen budget of converting sheep and beef farms to forage-cropping farms in the Toenepi catchment

	Average		Cropping	
Inputs (kg N/ha/yr)	**Sheep and Beef**	**Inputs (kg N/ha/yr)**	**Year 1**	**Year 10**
Fertiliser	6	Fertiliser	140	280
N_2-fixation & rainfall	58	N_2-fixation & rainfall	2	2
Irrigation	0	Irrigation	0	0
Supplements	0	Net mineralisation	457	340
Outputs (kg N/ha/yr)		**Outputs (kg N/ha/yr)**		
Product	8	Product	515	515
Supplements sold	5	Gaseous Nitrogen losses	13	25
Gaseous Nitrogen losses	19	Leaching/runoff	16	27
Leaching/runoff	12	Net residues left	55	54
Immobilisation	20	Immobilisation	0	0
Nitrate-N concentration in leachate (ppm)	*2*		3	5

5.3.5 The effects of change in land use

The scenarios so far are presented for individual farm systems and the inputs and outputs of Nitrogen on a per hectare basis. Table's 27-29 present data on inputs and outputs of N, P and K, respectively, on a catchment scale (tonnes of nutrient per catchment). There are five farm scenarios presented as a progression from the current mixed sheep and beef and dairy to all dairy, all intensive dairy, and intensive dairy plus sufficient forage-cropping to supply all the supplementary feed required by the dairy farms.

Table 27 shows the increase in Nitrogen inputs (from 120 to 368 t N) associated with farming system changes from current to intensive dairy plus cropping. Inputs of Nitrogen from N_2-fixation and rainfall generally showed little change, although they did decrease in the two intensive dairy scenarios with high Nitrogen fertiliser use. Nitrogen inputs through supplementary feeds increased from 10 t Nitrogen in the current scenario to 22 t Nitrogen in all-intensive dairy.

Outputs in product from the catchment increase from 110 t N for the current scenario to 147 t N for the all-intensive dairy scenario. Gaseous N losses and immobilisation also increased with intensification. Leaching/runoff losses of N increased steadily from 68 t N to 129 t N in the all intensive dairy scenario, then decreased to 127 t N where some land was used for cropping. Associated discharges of N from the two pond FDE disposal system increased as intensification increased and decreased slightly as land was taken out for cropping. Nitrate-N concentrations in leachate were estimated to increase from 7 ppm in the current scenario through to 14 ppm in the all-intensive dairy scenario, and to 13 ppm in the intensive dairy plus cropping scenario.

Table 27. The effects on the catchment N budget of increasing dairy intensification and intensive dairying plus cropping in the Toenepi catchment

Inputs (t N/catchment)	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy plus cropping
Fertiliser	120	127	135	364	368
N_2-fixation & rainfall	201	208	215	160	156
Net mineralisation	0	0	0	0	17
Supplements	10	10	11	22	0
Outputs (t N/catchment)					
Product	110	117	124	147	140
Transfer	21	22	24	31	30
Supplements sold	1	1	0	0	0
Gaseous N losses	96	99	103	168	164
Leaching/runoff	68	71	75	129	127
Net residues left	0	0	0	0	3
Immobilisation	35	35	35	71	77
Discharge from secondary ponds	*9*	*10*	*11*	*14*	*13*
Nitrate-N concentration in leachate (ppm)	*7*	*8*	*8*	*14*	*13*

Table 28 shows the increase in P inputs (from 100 to 105 t P) associated with farming system changes from current mixed farming through to intensive dairying plus cropping. P inputs in supplementary feeds increased from 2 to 4 t P/catchment in the all intensive dairy scenario. Outputs of P in product from the catchment increased from 19 t P for the current mixed farming scenario to 25 t P for the all intensive dairy scenario. Leaching/runoff losses of P were estimated at approximately 2 t P for all scenarios. Less accumulation of inorganic P in soil was estimated under intensive dairying due to more output in products and less surplus on farm. Additional losses of P are from discharge from the two-pond system. This increased with intensification from 1.6 t to 2.3 t P/catchment.

Table 28. The effects on the catchment P budget of increasing dairy intensification and intensive dairying plus cropping in the Toenepi catchment

Inputs (t N/catchment)	Current Status Quo	Half S & B to Dairy	All Dairy	Intensive Dairy	Intensive Dairy plus cropping
Fertiliser	100	102	104	104	105
Slow release	6	6	6	6	5
Net mineralisation	0	0	0	0	1
Supplements	2	2	2	4	0
Outputs (t P/catchment)					
Product	19	21	22	25	24
Transfer	5	5	5	7	7
Leaching/runoff	2	2	2	2	2
Net residues left	0	0	0	0	1
Immob./absorption	75	75	76	76	74
Change in inorganic pool	7	7	7	4	3
Discharge from secondary ponds	*1.6*	*1.7*	*1.9*	*2.3*	*2.2*

Potassium inputs in fertiliser and outputs in produce also increased with intensification of dairying and forage-crop integration (Table 29). In the intensive dairying scenario, K inputs in supplements increased but there was an increase in the various K losses, which resulted in a decrease in soil K. Integration of forage cropping in the catchment resulted in a further decrease in soil K and highlights the increase in K fertiliser requirements with farm intensification within the Toenepi catchment.

Table 29. The effects on the catchment K budget of increasing dairy intensification and intensive dairying plus cropping in the Toenepi catchment

Inputs (t K/catchment)	**Current Status Quo**	**Half S & B to Dairy**	**All Dairy**	**Intensive Dairy**	**Intensive Dairy plus cropping**
Fertiliser	74	77	80	80	90
Rainfall	4	4	4	4	4
Slow release	38	38	38	38	38
Supplements	8	9	9	18	0
Outputs (t K/catchment)					
Product	24	26	27	33	32
Transfer	43	44	47	56	55
Supplements sold	1	1	0	0	0
Leaching/runoff	63	63	62	67	68
Net Residues left	0	0	0	0	4
Change in inorganic pool	-7	-6	-5	-16	-27

6 Discussion and Implications

6.1 N LEACHING LOSSES

This evaluation of three mixed pastoral farming catchments using the OVERSEER® nutrient budget model indicates that the nitrate-N concentration in water draining below the root zone of pastures under current farming is about 7-8 ppm. However, some removal of this nitrate can occur by denitrification in the subsoil or as the drainage water or groundwater moves through wetland zones. Such zones are evident visually in all catchments. Additionally, nitrate is removed from water in small drains, streams and their margins through uptake by algae and plants. Thus, the modelled estimate of nitrate in drainage water is a potential value. The effects of subsoil or wetland denitrification and drain removal is indicated from monitoring of N concentrations in the Toenepi stream where measured levels are about half the modelled estimates for drainage water.

Nitrate concentrations in leachate estimated for the Bog Burn and Waikakahi catchments are also likely to be overestimates of current levels because the soils under dairying will still be accumulating organic N due to the increase/transition in productivity and C and N cycling (e.g. Ledgard, 2001). This was evident from lower (c. 20-30%) estimates of N leaching when the development mode of the OVERSEER® nutrient budget model was used, although there is limited field data to validate the magnitude of this transition effect.

Intensification and complete conversion of land to dairying were predicted to increase N leaching losses in all catchments. The potential increase above current levels was up to 50% for the Bog Burn catchment and up to 100% for the other two catchments. There are a number of reasons for differences in estimates of N leaching between catchments. The lower rainfall and drainage in Bog Burn and non-irrigated Waikakahi farms results in lower N leaching (e.g. Scholefield *et al*. 1993). In the Bog Burn catchment, dairy cattle were wintered off out of the catchment and this was predicted to reduce N leaching compared to when animals graze over winter (de Klein and Ledgard, 2001). Heavier-textured, poor-draining soils also result in lower N leaching and higher denitrification losses than free-draining soils (e.g. Scholefield *et al*. 1993).

There is also a level of uncertainty in the estimates from the OVERSEER® nutrient budget model (and any other model) which are stated in the model output at approximately ±25% for the estimated nitrate-N concentration in drainage, based on validation estimates (e.g. Figure 1). Indeed, there is greater uncertainty in estimates of N leaching from non-irrigated and border-dyke irrigated Waikakahi farms due to the lack of field validation data for these more extreme conditions. Similarly, there is high uncertainty with the estimates for forage-cropping due to lack of field data in New Zealand. The OVERSEER® nutrient budget model doesn't currently cover forage-cropping and estimates in this report were derived by modifying inputs using the grain-cropping mode.

The potential increase in N leaching losses from intensification can be reduced using management practices which increase N use efficiency. Three practices identified in this report were winter management, feed manipulation and FDE treatment. Grazing animals off farms over winter (although transferring the N elsewhere!) or use of a stand-off or feed pad have the potential to reduce N leaching by up to 60% (de Klein *et al*. 2000). This decreases returns of urine-N at the time of greatest susceptibility to leaching. If the excreta is then collected (via feed-pad) and applied to land in spring/summer it can markedly increase N use efficiency (Chadwick and Ledgard, 2002). Substitution of N-fertilised grass with a low protein supplement such as maize silage results in lower N inputs, increased N use efficiency and reduced N leaching (Ledgard *et al*. 2000). Land-application of FDE with an associated reduction in N fertiliser use can also decrease total N losses to waterways and increase the utilisation of N within the dairy farm system (Ledgard *et al*. 2000).

6.2 P AND K SURPLUSES

Losses of P to waterways can lead to a deterioration in water quality. However, such losses are highly event-driven (e.g. dominated by specific high rainfall events) and determined by spatial configurations of soils, and the degree of "connectivity" between P source areas and streams within a landscape. Thus, quantitative prediction of P loss is difficult without the use of detailed daily time-step, mechanistic models. Although the OVERSEER® nutrient budget model only gives a crude estimate of P runoff from an agronomic perspective, it does highlight situations where P inputs, mainly via fertiliser, exceed that required to maintain soil test P levels Additionally, it does give a reasonable estimate of P output from FDE ponds on dairy farms and utilises average FDE pond survey data from Environment Waikato (Ledgard *et al*. 1996).

Farm- and catchment-scale nutrient budgets showed relatively large surpluses of P on dairy farms within the Bog Burn and Waikakahi catchments. As P soil test values for dairy farms are already high in both catchments (Table 30), these surpluses indicate that P fertiliser inputs should be reduced to avoid the excessive accumulation of P in soil. This will in turn decrease the risk of P runoff into surface waterways. This correction to P fertiliser management will be particularly important for the Bog Burn catchment, where, as observed for much of lowland Southland, surface water eutrophication is currently limited by P rather than N. Within the Toenepi catchment, P budgets indicated that land-application of FDE can reduce (e.g. by c. 50%) P loss to waterways and increase P use efficiency on dairy farms.

As noted for P, large K surpluses were also observed within the Waikakahi and Bog Burn catchments, again at both farm and catchment scales. Estimated K surpluses on dairy farms within both catchments were 98 kg/ha. In the case of the Bog Burn catchment, soil Quick test K values were at the lower end of the target ranges for dairy farms (6-8). In this situation, surplus K will have the beneficial effect of increasing soil test values to a desired level. In contrast, average soil K levels in the Waikakahi catchment were above the target range for dairy production, and in this situation some adjustment of K fertiliser input is required if excessive K build-up in soil is to be avoided. Excessive levels of K in soil can contribute to hypomagnesaemia in lactating stock.

Table 30. Farm and catchment scale P and K surpluses

Catchment	Farm scale nutrient surplus (kg/ha)		Soil Test	Catchment surplus	
	Sheep-beef	Dairy	Dairy	tonnes	% of input[1]
Phosphorus (P)					
Toenepi	3	4	49	7	7
Waikakahi	1	26	38	53	41
Bog Burn	10	31	43	45	43
Potassium (K)					
Toenepi	-7	-3	10	-7	-9
Waikakahi	57	98	10	208	106
Bog Burn	72	98	7	183	155

[1] % of combined inputs from fertiliser, supplements and irrigation.

This report indicates that intensification has the potential to significantly increase N and P losses to waterways but that management practices can be used to greatly reduce the magnitude of these losses.

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