Environment Waikato Technical Report 2008/39

Improving Nutrient Efficiency Through Integrated Catchment Management in Little Waipa and Waipapa

Reporting Summary for Upper Waikato Project

www.ew.govt.nz
ISSN 1172-4005 (Print)
ISSN 1177-9284 (Online)

Environment Waikato REGIONAL COUNCIL

Prepared by:
RD Longhurst and DC Smeaton
AgResearch

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

July 2008

Document #: 1346604

Peer reviewed by:
Ross Abercrombie Date July 2008

Approved for release by:
Chris McLay Date July 2008

Disclaimer

agresearch Farming, Food and Health. First

Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Improving nutrient efficiency through integrated catchment management in Little Waipa and Waipapa –

Reporting summary for Upper Waikato Project

July 2008

2020 SCIENCE

New Zealand's science. New Zealand's future.

Improving nutrient efficiency through integrated catchment management in Little Waipa and Waipapa -

Reporting summary for Upper Waikato Project

Environment Waikato

July 2008

RD Longhurst and DC Smeaton

Table of Contents

Executive Summary

In 2006, Environment Waikato (EW) launched an Integrated Catchment Management (ICM) initiative to improve nutrient efficiency in two sub-catchments (Little Waipa and Waipapa) within the Upper Waikato Catchment. At the time of compiling this report, fifteen dairy farmers had been approached by EW and had agreed to participate in the ICM study. On eight farms, detailed Environmental Farm Plans had been constructed and form the basis of the case studies presented here.

AgResearch was contracted to undertake nutrient management analysis and to integrate this with agronomics and farm economics. A modelling study using the OVERSEER® nutrient budget model was undertaken on these farms to investigate nitrogen (N) and phosphorus (P) losses through on-farm mitigation strategies. Two of the eight farms were then used as case studies using the UDDER[1] dairy production farm model to determine the likely cost of implementing these various mitigation strategies.

The soils in the catchment are predominantly free-draining allophanic and pumice. Average annual rainfall is 1470 mm (range 1400 to 1550 mm). On an average ICM Farm, 500 dairy cows were stocked at 3.0 cows/ha and produced 1,070 kg milk solids/ha. Average N and P losses on the ICM farms were 45 and 2.2 kg/ha/yr respectively.

Greatest contributors to N loss were stocking rate and the amount of fertiliser N input as fertiliser. Most ICM farms used land application for effluent treatment and all but one farm had some form of effluent storage. Average nutrient loading rates on effluent blocks were 120 kg N/ha and 158 kg K/ha. Potassium (K) loadings were far in excess of pasture K maintenance requirements. Surface runoff losses of P were predicted to be higher when soil Olsen P concentrations were above optimum levels and greater with pumice soils than on allophanic soils.

The most effective mitigation strategies that were investigated for reducing N losses were a reduction in fertiliser N rates, avoiding fertiliser N applications in winter and using a DCD nitrification inhibitor (over two applications) on grazed pasture in autumn/winter. Wintering the herd off the farm was also very effective but was unacceptable to the ICM catchments involved in this study because of its N exporting effects. Increasing the size of the effluent block and reducing fertiliser inputs to this block reduces the overall amount of fertiliser N required and reduces the K loading to pastures.

Following best management practices and using a combination of the above strategies could reduce N losses by approximately 10 kg N/ha, down to an average of 35 kg N/ha. Further reductions in N leaching can only be achieved if cows are removed from pastures as much as possible during the high-risk leaching period (May-July).

Construction of specialised stand-off/animal shelters to achieve this requires substantial capital and operational costs and is difficult to justify although farmers report other benefits.

The UDDER model was used for in-depth case study analysis of two ICM dairy farms. Several mitigation scenarios were tested and reductions in N loss were calculated to be of the order of 6% for not applying fertiliser N in winter; 4-10% for using nitrification inhibitors, 12% for switching to a land based effluent treatment system; 8-10% for stock wintering systems. Large reductions in N leaching can, potentially, be obtained through reducing fertiliser N inputs (0-40% depending on the level of fertiliser N reduction). An organic farming scenario was predicted to greatly reduce N leaching, and deserves serious consideration, as it was also quite profitable, although further study is required to confirm this.

Some of the N reduction scenarios had a slightly positive to neutral effect on farm profitability and some reduced profitability. Gross Margins were affected to a greater or lesser degree depending on the level of milk payout ($5, $6, and $7/kg MS were tested). Generally speaking, scenarios to reduce N leaching were more likely to be profitable at high payouts. This is a major consideration in the adoption of any mitigation system.

A simplistic approach to reducing N loss would be to limit N inputs to a farm as has been the legislative approach in Europe. Another approach, however, is to allow farmers to develop management systems that limit leaching losses by building a number of mitigations into their systems (i.e., putting an emphasis on N outputs rather than on N inputs).

Overall, the ICM project has demonstrated a need for EW and AgResearch to work with farmers on how they can fit mitigations into their current dairying systems and has shown that progress can be made in the management of N leaching without compromising farm profitability.

[1] UDDER is a dairy production software model that includes financial assessments of any changes in farming practices made.

1. Introduction

Nutrient management is a key focus for Environment Waikato (EW) in managing water quality throughout its region. In recent years, farming intensification and land use changes have been occurring rapidly within EW jurisdiction. In particular, the Upper Waikato catchment (up-stream of the Karapiro dam) has been highlighted as such an area of increasing concern because of the clear link between land use intensification and rising nutrient levels in waterways. The two plant nutrients of major concern are nitrogen (N) and phosphorus (P). Enrichment of waterways with these nutrients promotes algal growth in the Waikato River, which is then further exacerbated by the retention of water in the hydro lakes giving the algae the opportunity to grow.

In 2006, EW launched an Integrated Catchment Management (ICM) initiative to improve nutrient use efficiency in two sub-catchments within the Upper Waikato Catchment. The two sub-catchments chosen were: 1) the Little Waipa containing 12,210 ha of land and 188 km of streams; and 2) the Waipapa containing 10,049 ha of land and 158 km of streams. To date, 15 dairy farmers have so far been approached by EW and had agreed to participate in the ICM study. On eight farms, detailed Environmental Farm Plans had been constructed and form the basis of the case studies presented here.

2. Objectives

The objectives of the pilot project were to:

1) assess possible gains in nutrient efficiency on farms;
2) ascertain how reductions in N and P losses could be achieved using current policy tools to address water quality;
3) identify barriers to, and benefits of appropriate technologies to reduce nutrient losses;
4) test the theory that an integrated delivery of EW's policies – compliance, education and incentives – in a catchment would enable the farming community to achieve reductions in nutrient losses.

This report presents a general overview of the findings from the eight dairy farms after reviewing the nutrient management aspects of the Environmental Farm Plan, a summary of the OVERSEER® nutrient budget model (Wheeler *et al*., 2003) mitigations used and in-depth financial case studies on two of the farms.

3. Approach

EW staff undertook environmental farm plans for eight dairy farms across the catchments to highlight each farm's environmental strengths and weaknesses and to identify natural risks and management practices that may be affecting the environment. As part of this phase, the OVERSEER® nutrient budgets 2008 model (version 5.3.6, hereafter referred to as OVERSEER) was used to provide an initial estimation of the average N and P losses from each property.

AgResearch's role was then to explore the OVERSEER files to determine how best to reduce these N and P losses through on-farm mitigation strategies. These mitigation explorations were in two stages: 1) a number of strategies were examined for each farm to determine their potential reduction in N and P losses when used in isolation, and 2) then, these mitigations were optimised, usually giving a combination of mitigations, to achieve the smallest nutrient losses from the farm. Financial analysis, using the UDDER model, was undertaken on two case study properties to determine the likely cost of implementing these various mitigation strategies. UDDER is a dairy production model that includes financial assessments of any changes in farming practices made.

4. Farms

4.1 Basic farm details

An overview of the data collected from the eight farms, during the 2006/07 dairying season, is presented in the following eight tables. In Table 1, some vital statistics of each property are given. Five farms were in the Little Waipa Catchment and three in the Waipapa Catchment. The predominant soil in the catchments is volcanic ash (allophanic). Some of these farms also contained sizeable areas of pumice soils or intergrades of both soil types. The average annual rainfall in these catchments is 1470 mm and this ranges from 1400 to 1550 mm. On average, 500 dairy cows were stocked at 3.0 cows/ha and produced 1,070 kg milk solids/ha. Friesian/Jersey cross cows were the main dairy breed. On three of the dairy farms nearby run-off blocks were included in the total farm area as they were such an integral part of the milking platform; the percentage of the run-off block to the total farm is also presented in Table 1.

Table 1: Some basic farm details for ICM farms.

Farm	1	2	3	4	5	6	7	8	Av
Statistic									
Catchment *	LW	LW	LW	LW	W	W	W	LW	
Main soil type	Pumice	Ash	Ash	Ash	Pumice	Ash	Ash	Ash	
Rainfall (mm)	1450	1500	1450	1500	1400	1550	1500	1400	**1470**
Herd size	670	760	390	400	220	700	420	420	**500**
Cow breed	F x J	Friesian	Friesian	F x J	F x J	F x J	Friesian	F x J	**F x J**
SR (cows/ha)**	3.1	2.5	3.4	3.2	2.8	3.2	3.0	2.9	**3.0**
MS (kg/ha)	1000	1400	1200	1200	1010	1000	900	860	**1070**
Run-off (%)	no	9	no	15	5	no	no	no	

* LW = Little Waipa, W = Waipapa; ** Stocking rate based on herd size in November

4.2 Nitrogen management

A summary of the main N inputs and N indices is presented in Table 2. Of the total external N inputs on the farms, the main contribution was clearly from fertiliser N, averaging 153 kg N/ha/yr (range 109–198). The model predicted that clover N fixation only averaged 72 kg N/ha/yr with no farm achieving over 95 kg N/ha/yr. All the farms also imported some N in the form of feed supplements, although the amount varied, ranging from 3 to 101 kg N/ha/yr.

Table 2: Summary of N inputs (kg/ha) and N indices for ICM farms.

Farm	1	2	3	4	5	6	7	8	Av
N inputs									
Clover N	84	70	80	95	71	58	68	48	**72**
Fertiliser N	180	109	152	136	120	198	140	191	**153**
Feed N	3	101	37	52	13	26	21	37	**36**
Total N inputs	267	280	269	283	204	282	229	276	**261**
N indices									
Farm N surplus	204	188	190	180	145	215	173	223	**190**
Conversion (%)	23	33	29	36	29	22	24	19	**27**
N loss									
N leached (kg/ha)	50	31	47	50	42	47	37	52	**45**

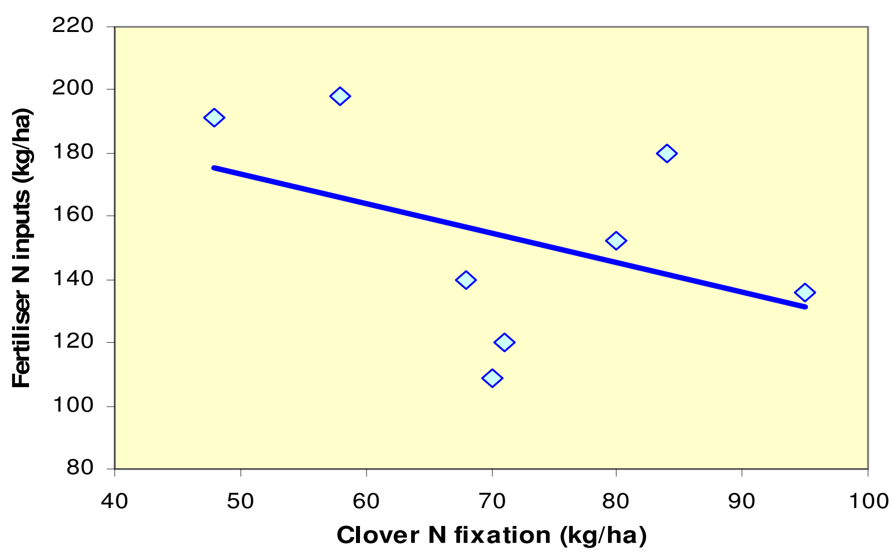
The average farm N surplus was 190 kg N/ha/yr and ranged from 145 to 223. The farm N surplus is the sum of external N inputs minus the N output in products and identifies the amount of extra N in the system, which can then contribute to N losses. The typical range for N surplus on NZ dairy farms is 100-180 kg N/ha/yr (OVERSEER data), so the ICM farms have a higher than average surplus of N. The N conversion efficiency (N in products/total N inputs) of the ICM farms averaged 27% (range 19-

36%). Typically, the higher the N conversion efficiency, the lower the amount of N leached; the typical range for NZ farms is 25-40% (OVERSEER data). The N conversion figures found in this ICM study indicate that management has a key role to play to ensure that external N inputs (fertiliser in particular), are used efficiently and that the use of higher application rates of N are reflected in increased milk production.

Nitrogen losses as nitrate-N (NO_3-N) averaged 45 kg N/ha/yr (range 31-52). The main influence on N losses on a dairy farm is generally from stock urinations and fertiliser N applications, these factors will be discussed in the following section.

Declining N fixation by clover is a reflection of higher fertiliser N inputs over the last 10-15 years as farmers are relying more on this method of boosting pasture production. Figure 1 shows there is a weak trend (R^2 = 0.18) for less modelled clover N fixation when more fertiliser N is applied. This would be expected as it costs the clover less energy to use mineral N than to biologically fix N. Another management consideration is the presence of clover root weevil (CRW). Fertiliser N responses would be highly visible in CRW infested paddocks and, the more CRW (nodule damage) the greater the clover response to fertiliser N (Pip Gerald, AgResearch, pers. comm.).

Figure 1: Effect of fertiliser N inputs on modelled clover N fixation on ICM farms.



4.3 Phosphorus management

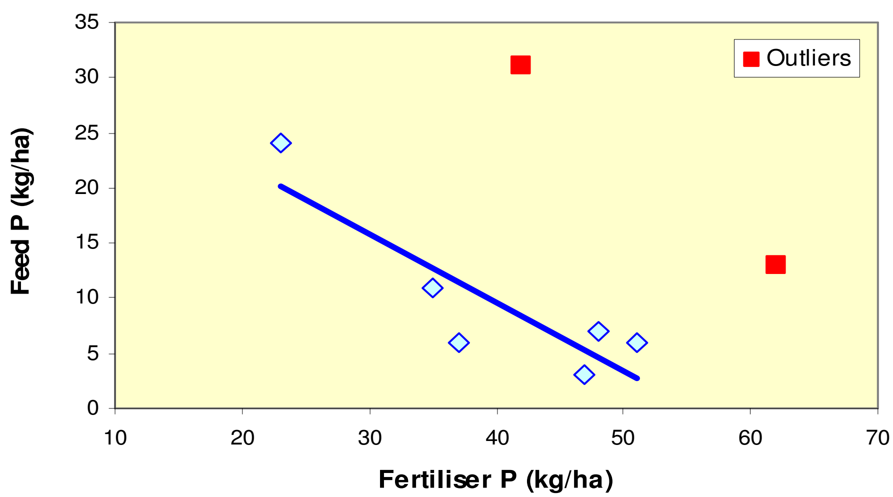
Fertiliser P made the largest contribution to farm P inputs, averaging 43 kg P/ha/yr (range 23-62) (Table 3) while supplementary feeds, which ranged from 3 to 31 kg P/ha/yr, averaged 13 kg P/ha/yr. This meant that total P inputs onto farms, coming from fertiliser and feed, averaged 56 kg P/ha/yr (range 43-75). Part of the variation in the range of fertiliser P is that as feed P increases, fertiliser P inputs reduce, except on Farms 3 and 4 (Figure 2). Farm P surplus represents the sum of external P inputs minus the P output in products and identifies extra P that potentially contributes to P losses. On the ICM study farms, P surplus averaged 45 kg P/ha/yr (range 33-60), which is towards the top end of the typical range (20-50) for NZ dairy farms.

Table 3: Summary of P inputs (kg/ha), P indices, soil P fertility status and P loss.

Farm	1	2	3	4	5	6	7	8	Av
P inputs									
Fertiliser P	47	23	42	62	51	37	48	35	**43**
Feed P	3	24	31	13	6	6	7	11	**13**
Total P inputs	50	47	73	75	57	43	55	46	**56**
P indices									
Farm P surplus	40	33	60	57	49	34	47	38	**45**
P soil status									
Olsen P *	39	32	53	37	50	31	58	52	**44**
P loss									
Runoff (kg P/ha)	4.3	0.7	4.2	2.0	3.1	0.7	1.3	1.0	**2.2**

* Olsen P calculated on weighted average (concentration x block area) from data provided on 8 ICM farms.

Figure 2: Fertiliser P inputs versus feed P inputs on ICM farms. Fitted line (R^2 = 0.76) excludes two outliers (Farms 3 and 4), which are discussed within the text of the report.



Soil Olsen P concentrations averaged 44 (range 31-58); there was no difference between allophanic or pumice soils, nor between catchments. However, soil Olsen P did indicate a trend of higher fertiliser P inputs at higher Olsen P concentrations (Figure 3). There was also a clear trend between farm P surplus and soil Olsen P when Farm 5 is omitted from the data (Figure 4).

Phosphorus losses showed greater variation, ranging from 0.7-4.3 kg P/ha/yr (a six-fold variation) and with an average of 2.2 kg P/ha/yr. Phosphorus loss to waters is largely by surface runoff and although the amounts are relatively small in agronomic terms (typically 0.3 to 1.7 kg P/ha/yr), these quantities can be significant for increasing algal and plant growth in waterways. Soil Olsen P values above optimum levels contribute greatly to higher P losses (McDowell *et al.*, 2001), this will be discussed in the following section.

Figure 3: Relationship between Olsen P and fertiliser P inputs on ICM farms. Fitted line (R^2 =0.33) excludes outlier Farm 5.

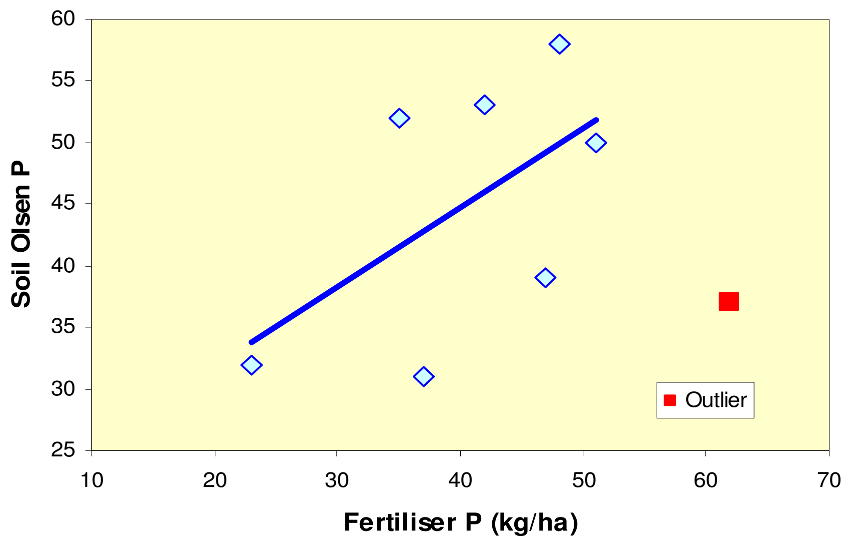
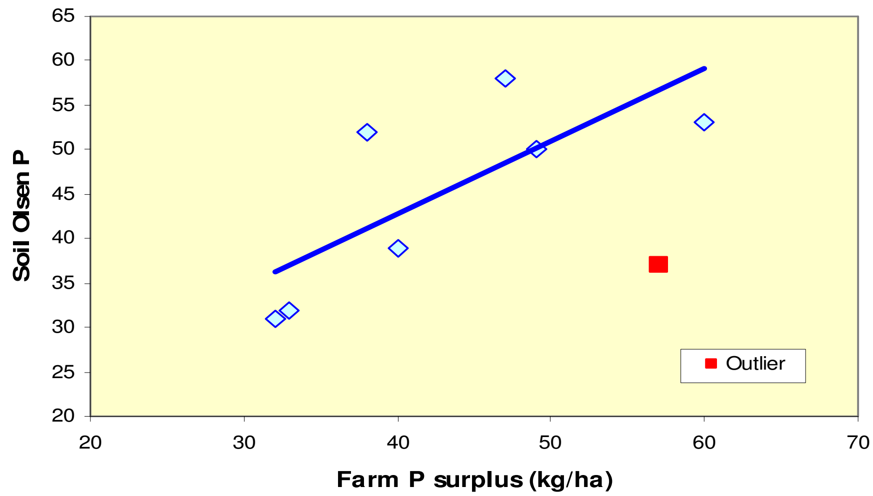


Figure 4: Relationship between soil Olsen P and farm P surplus on ICM farms. Fitted line (R^2 =0.56) excludes outlier Farm 5.



4.4 Effluent management

Land application was the preferred option for effluent treatment, with 75% of the farms using this system (Table 4). Of those farms using land application, the size of the effluent block varied from 11-27% of the farm area. Nitrogen loading on the effluent blocks ranged from 75-173 kg N/ha/yr (average 120). However, potassium (K) applied in effluent on the effluent blocks ranged from 97-235 kg K/ha/yr (average 158). These loadings were typically far greater than N inputs and were in excess of plant K maintenance requirements. Given the average 1070 kg MS/ha production on the ICM farms, the K pasture maintenance rate for allophonic and pumice soils is 75 kg K/ha, based on 0.6-0.8 kg/ha 20% potassic superphosphate or equivalent fertiliser for every kg MS produced (Roberts and Morton, 2004).

The farms using pond treatment for effluent had the typical anaerobic-aerobic system and held resource consents for discharge to water. While these farmers were looking to switching to land application systems, topography usually limited the degree of change possible.

Table 4: Summary of effluent management: treatment system, land area for effluent block (% of farm), nutrient loadings for N and K (kg/ha) on effluent blocks.

Farm	1	2	3	4	5	6	7	8	Av
Treatment system	ponds	land	ponds	land	land	land	land	land	**land**
Effluent area - %		27		18	25	18	21	11	**19**
Fertiliser applied		no		yes	yes	yes	no	no	
Effluent kg N/ha		90		93	119	75	173	168	**120**
Effluent kg K/ha		235		155	97	130	177	154	**158**
Storage pond		yes		yes	no	yes	yes	no	
Storage capacity		3 mth		1 mth	sump	2 mths	2 wks	sump	

4.5 Feed management

Half of the farms in the ICM study area had feed pads for improving utilisation efficiencies when feeding out supplements (Table 5). The amount of supplementary feeds brought onto farms varied from 54 to 2,200 kg DM/cow and averaged 614 kg DM/cow (equivalent to about 15% of total cow intake), however, Farm 2 heavily influenced the average, and the median range was a lot lower (around 430-480 kg DM/cow).

Table 5: Summary of feed management.

Farm	1	2	3	4	5	6	7	8	Av
Feed pad	yes	yes	no	yes	no	no	yes	no	
Feed, kg DM/cow	54	2200	690	500	260	300	430	480	**614**

4.6 Winter management

Winter management practices within the catchments were highly variable. The most common feature was for the farmers to have a run-off block nearby as a support unit for the main milking platform (Table 6). Two farms grazed part of their herd off farm but still within the ICM area. One farm grazed two thirds of the herd on a winter crop of swedes. On two of the ICM farms, the cows were stood off-pasture and held on feed pads for longer periods than normal during winter (~4 hours/day).

Table 6: Summary of feed management on ICM Farms.

Farm	1	2	3	4	5	6	7	8
Graze off-farm			yes		yes			
Stand-off		yes				yes	yes	
Winter crop	yes							
Run-off block		yes		yes	yes			

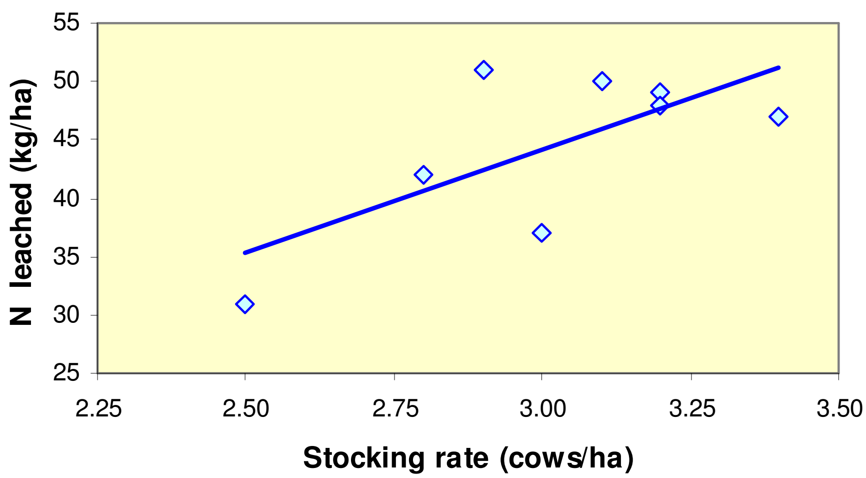
4.7 Comparison between farms

4.7.1 Stocking rate and N leached

With the intensification in the dairy industry herd size and stocking rate have increased. The main effect of increased stocking rates on dairy farms is that more cows per hectare equates to more urine spots per hectare. Much of the N leached comes from urine spots deposited in autumn-early winter. During this period, increased rainfall leads to wet soil conditions with greater drainage and N leaching occurring. Because of the cooler soil conditions, plant growth and N uptake are also slower than at other times of year. As a result, nitrate accumulates in the topsoil and cannot be utilised fast enough by the plant due to slow growth in cold weather. This N is then prone to leaching below the plant rooting depth due to excessive drainage and eventually reaches groundwater.

On the ICM study farms, stocking rates ranged from 2.5 to 3.4 cows/ha (Table 1). When stocking rate is plotted against N leaching (Table 2), there is a trend (R^2 =0.49) for greater N leaching with increasing stocking rate (Figure 5).

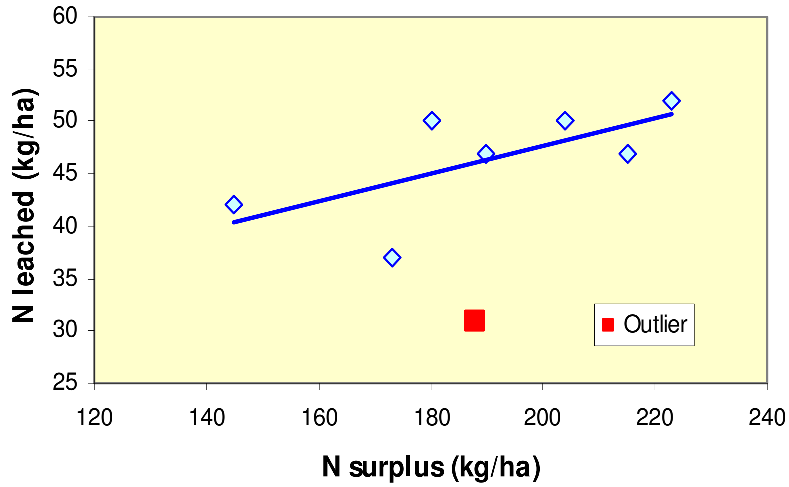
Figure 5: Calculated effect of stocking rate on N leached for 8 ICM Farms.



4.7.2 Farm N surplus and N leached

There was a weak relationship between farm N surplus and N leached for all eight farms. However, when an 'outlier' (Farm 2) was removed, the relationship between farm N surplus and N leached strengthened (Figure 6). Farm 2 is a high feed input, high milk output system.

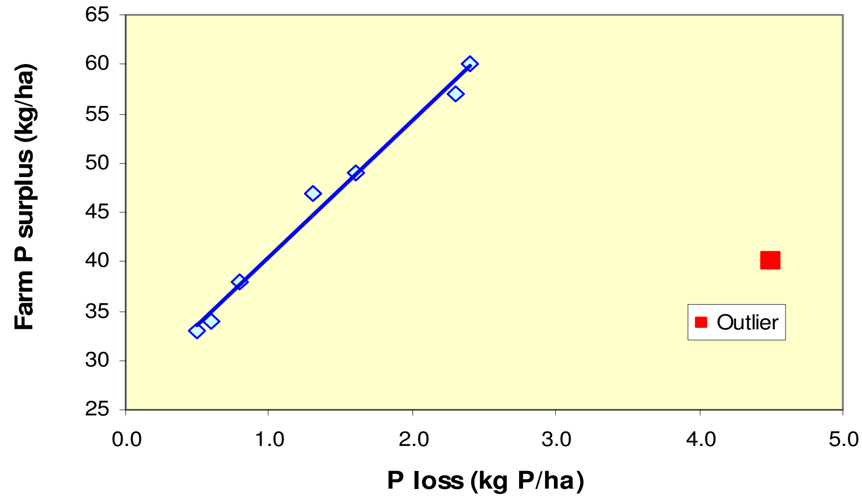
Figure 6: Calculated Farm N surplus and N leached (excluding farm 2). Fitted line (R^2 =0.46) excludes outlier (Farm 2).



4.7.3 Farm P surplus and P loss

Like farm N surplus and N losses, looking at farm P surplus and P losses showed an interesting trend. When all eight farms were included, the relationship between P surplus and P loss was weak (R^2 =0.14), because Farm 1 was an outlier that showed much higher P losses per unit surplus than the other seven farms. This particular farm had a combination of factors that made it an outlier: high Olsen P (65) on 30% of farm, a winter crop, and pond treatment of effluent. When this outlier, Farm 1, was removed, the linear correlation for the other seven farms strengthened (R^2 =0.99) (Figure 7). Over all eight sites, farm P surplus was also highly correlated with P inputs (R^2 =0.93).

Figure 7: Farm P surplus and P losses. Fitted line excludes outlier Farm 1.



4.7.4 The highly efficient farm

From the above tables in Section 4 one feature is striking. Farm 2 achieved the highest MS production (1,400 kg MS/ha) yet had the lowest amount of N leached (31 kg N/ha) in a high rainfall (1,500 mm) area. Some features of this farm were the lower stocking rate (2.5 cows/ha) and large inputs of supplementary feed (2.2 t DM/cow) to achieve a whole balanced diet. This is encouraging for other farmers as it shows that by using sound management high production is achievable in a sustainable manner and with a low environmental impact. The result on this particular farm was achieved largely through aiming for high per cow production (550 kg MS/cow), by replacing fertiliser N with feed N, having sufficient effluent storage area and a large effluent block.

4.7.5 Nitrogen efficiency versus carbon efficiency

However, while achieving low N leaching losses, will other on-farm emission losses (carbon dioxide (CO_2) emissions, carbon (C) be likely to rise? To evaluate this, Table 7 has been constructed to look at on-farm total N losses (leaching and atmospheric (nitrous oxide, nitrogen gas, and ammonia)) compared to on-farm C losses (from methane (75% C) and CO_2 (27% C)). Information on gaseous emissions is available from the greenhouse gas (GHG) report of the OVERSEER nutrient budget model. From the extracted data, a simple C/N ratio can then be used to gauge if emissions from the high input - high output farm was different from the other farms. Data from Table 8 reveals that Farm 2 is placed near the average of the other farms (C/N 42) indicating that lower N losses are not offset by greater C losses at Farm 2. Another method to evaluate whether there is a false economy at play is to assess the environmental efficiency of each farm in terms of N and C losses per kg MS produced.

Table 7: Summary of relative on-farm losses of nitrogen and carbon (kg/ha/yr).

Farm	1	2	3	4	5	6	7	8	Av
Nitrogen									
Atmospheric N	76	94	77	76	50	77	69	70	**74**
Leached N	50	31	47	49	42	48	37	51	**45**
TN emissions	126	125	124	126	93	125	106	121	**119**
Carbon									
Methane	4662	5256	5200	5597	4061	4279	4252	4124	**4679**
CO_2	227	324	281	314	185	264	216	260	**252**
TC emissions	4889	5580	5480	5911	4246	4542	4467	4384	**4931**
C/N ratio	39	45	44	47	46	37	42	36	**42**

4.7.6 Total farm emissions and energy usage

The concept of "environmental efficiency" was recently raised by Tillman *et al.* (2008). In the context of dairy farming, one measure of "environmental efficiency" is:

kg milk solids produced/ kg N leached

For this study C was not included in the formula. This information can be extracted from the OVERSEER nutrient budget model. Table 8 presents a summary of on-farm losses relative to milk solids output. By using the C/N ratio for evaluation, a quick snap-shot of between farm emissions can be determined. It should be acknowledged that there are also off-farm emissions associated with production, (e.g., growing supplementary feeds, transportation). However, these emissions are outside the farmers' ability to influence or control and, therefore, these emissions should be the responsibility of the producer concerned. A complete life-cycle analysis would be required to fully assess the total cost of production to the farming system (Ledgard *et al*., 2007).

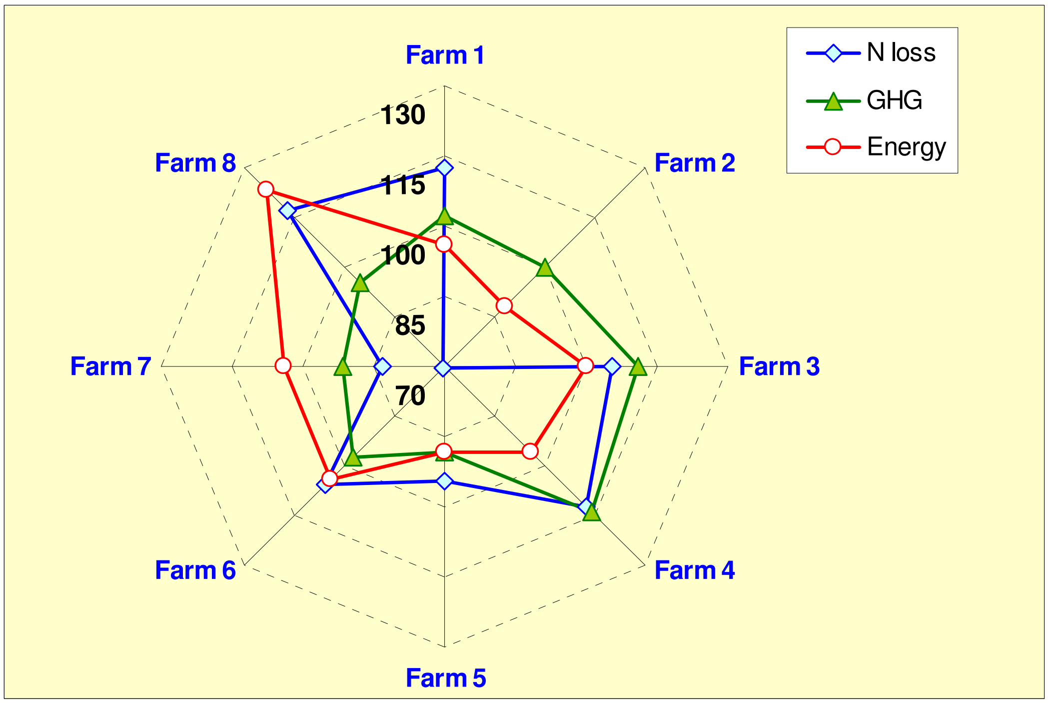
Table 8: Summary of "environmental efficiency" of on-farm emissions. Annual losses of nitrogen and carbon (kg/ha) and energy (MJ/ha) required to produce 1 kg MS/ha.

Farm	1	2	3	4	5	6	7	8	Av
Environmental									
Total N	0.13	0.09	0.10	0.11	0.09	0.13	0.12	0.14	**0.11**
Total C *	3.0	1.9	2.6	2.8	2.7	2.9	3.0	3.2	**2.8**
C/N ratio	24	22	25	26	29	23	25	23	**25**
Energy									
MJ/kg MS/ha	25	23	26	25	23	27	27	32	**26**

* derived from kg CO_2 equivalent per kg milk solids.

The data in Table 8 confirms that Farm 2 has the lowest amount of both on-farm N and C emissions in producing per kg milk solids. These findings highlight the fact that a highly efficient farmer can achieve high production with a low environmental footprint. When on-farm energy costs are compared across the eight farms, Farm 2 is again shown to be a highly efficient farming operation (Figure 8). Figure 8 shows N loss relative to GHG emissions and energy consumption per kg MS production. The lower N loss is below 100%, along with GHG and energy consumption, the more efficient is the on-farm management.

Figure 8: Radar plot showing relationship between N loss, GHG emissions and energy consumption per kg MS *. Data expressed relative to the average values found for the eight ICM Farms, i.e., 100% = average (figures in black).



* Phosphorus losses have been excluded from Figure 8 because of the range between farms meant that, in relative terms, the scale would have to double and clarity for the other factors would diminish.

5. Factors influencing nutrient losses

Several on-farm factors can have a significant impact on the amount of nutrient loss, and therefore, these were examined in a series of mitigation options. These factors include timing and rate of fertiliser N applications, the size of effluent blocks, optimising Olsen P soil status, stocking rate, winter management, nitrification inhibitors, feed supplementation and organic farming. It should be noted that there are no “silver bullet” solutions (i.e., a single mitigation solution) but, rather, a series of incremental changes in nutrient loses can be achieved by adopting these mitigation practices.

5.1 Fertiliser N

5.1.1 Fertiliser N applications in winter

Good N management ensures that fertiliser N is applied when required (i.e. 4-6 weeks before a feed deficit), and when there is rapid plant N uptake by actively growing pasture to minimise environmental impacts. Management techniques to consider during winter are to limit or avoid fertiliser N applications when pasture growth is slow and drainage risk high during the leaching period (May, June, July).

Only one out of the eight farms in this ICM study did not apply any N fertiliser during this high-risk leaching period (Farm 6). On the other seven farms, an average of 20 kg N/ha (range 11-37) was applied during this period. Removing fertiliser N applications in winter would generally reduce N leaching by 1-3 kg N/ha/yr (3-8%). A better strategy would be to bring forward fertiliser N applications to March-April when better pasture responses are likely and then carrying this feed through for winter grazing. However, it does require good pasture management discipline to ensure that the feed does actually get carried forward. The nitrification inhibitor, DCD, could also be used as a slow-release N fertiliser, during this high-risk N leaching period.

5.1.2 Fertiliser N applications to effluent blocks

On the majority of farms in the ICM study, fertiliser N was applied, in addition to effluent N, on the effluent blocks. Under land application systems a significant amount of effluent N is taken up by pastures as observed by farmers who attest to the enhanced growth seen on effluent blocks. The effluent block should therefore be the first area of a farm to consider when reducing fertiliser N inputs. Omitting fertiliser N inputs to effluent blocks can reduce N leaching by 1-2 kg N/ha/yr (on average 5%).

5.1.3 Rate of fertiliser N applications

During the past 10-15 years fertiliser N application rates have risen steadily throughout New Zealand’s dairying regions. The average amount of fertiliser N applied on the ICM farms in this study was 152 kg N/ha/yr (Table 2). Nitrate leaching will always occur on free-draining allophanic and pumice soils, especially under a high rainfall regime (> 1400 mm). There was a significant correlation ($P < 0.05$) between fertiliser N rate and predicted amount of nitrate-N leached on the ICM farms (Figure 9). So, for example, average N leaching on the ICM farms could be expected to be 39 and 49 kg

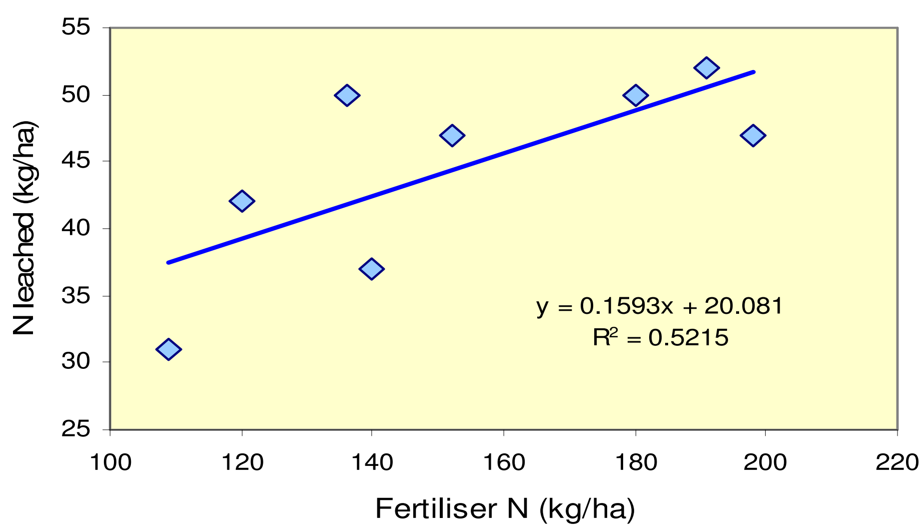
N/ha/yr from fertiliser N inputs of 120 and 180 kg N/ha/yr, respectively. Other factors such as stocking rate and annual rainfall will influence specific farm N loss.

One way to reduce the amount of N leached is by increasing the N use efficiency. Producing more milk product for a given N input means that less N is available for leaching. From a financial perspective, there is generally little pressure for this to happen because fertiliser has been relatively cheap. In fact, as demonstrated by rising rates of fertiliser N applications in the last 10 to 15 years, the reverse has happened. Nitrogen use efficiency can also be increased by using feed supplements, such as maize silage, that have lower crude protein content than pasture. This brings less N onto the farm resulting again in less N being available for leaching. However, purchased supplements are vastly more expensive, so that from a profit maximisation perspective, pasture is always likely to be the cheapest form of feed.

In some situations, it is not possible to reach environmental targets for N leaching even when using good N management techniques. In these cases, reducing fertiliser N rates, reducing stocking rates and/or changing live weight per ha (less maintenance requirements) could be considered.

Any reduction in the amount of fertiliser N applied however is likely to impact on pasture production. When calculating the change in productivity within OVERSEER, two parameters are used: average annual N response and the average ME of pasture (MJ ME/kg DM). Average N (kg DM pasture grown per kg N applied) is used to determine the decrease in pasture growth if N fertiliser rates are reduced.

Figure 9: Effect of fertiliser rate on modelled amount of N leached in Upper Waikato catchment from the eight ICM Farms.



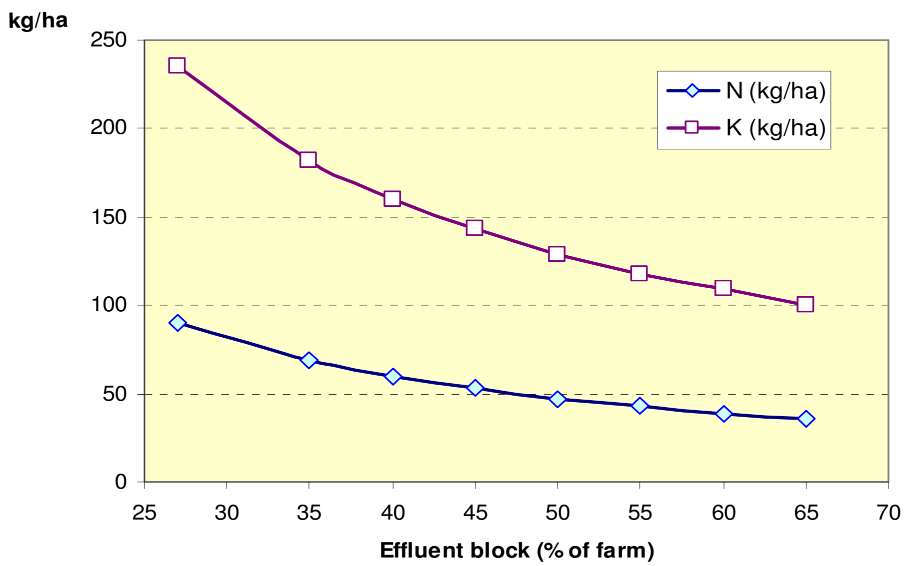
For example, a typical pasture response to fertiliser N of 10 kg DM per kg N applied can be expected. Therefore, lower milk production could also be expected as approximately 13 kg DM is required to produce 1 kg MS. Using the example of a typical dairy farm applying fertiliser N at 152 kg N/ha/yr and producing 1,070 kg MS; if fertiliser N inputs were reduced to 120 kg N/ha/yr then it could be expected that 320 kg DM/ha less pasture would be grown and MS production could drop by around 25 kg MS/ha. The effect on Gross Margins is discussed in the Financial section of the report.

5.2 Effluent management

Land application of farm dairy effluent (FDE) through spray irrigation is the preferred option of effluent treatment. When managed wisely, FDE is an effective method for recycling valuable nutrients back to pastures and can substitute for fertiliser. However, if FDE is mismanaged, spray irrigations can have a detrimental impact on water quality and animal health (through excessive K inputs).

Prior to the current intensification within the dairy industry over the past 10 years, the general 'rule of thumb' for estimating the size of an effluent block was 4 ha per 100 cows. During the mid-1990s, before the rapid intensification, a survey of FDE concentrations on 40 Waikato dairy farms (Longhurst *et al.,* 1999) found mean N concentrations were 445 mg N/L. However, since then, fertiliser N inputs have increased, and greater amounts of supplementary feeds are now imported onto farms, along with an increasing use of feed pads to maximise utilisation and reduce feed wastage. The overall effect of these factors is that FDE concentrations are now likely to be far greater than those N concentrations found pre-intensification, although there is scant data available. Famers have tended to underestimate the nutrient content of their FDE and, as a result, effluent blocks have tended to be too small as a proportion of the total farm (< 20%). This is particularly important from the K loading perspective. Potassium concentrations in FDE are often higher than N concentrations and therefore the effluent application rate should be based on meeting the pasture K maintenance requirements. Excessive K loadings on pastures can cause mineral imbalances of the other cations (calcium, magnesium and sodium) and lead to metabolic problems in stock (Bolan, 2001). The risk of applying excessive quantities of K on effluent blocks is exacerbated by importing nutrients in feed supplements. As an example, the effect of increasing the effluent block area on Farm 2 in reducing N and K nutrient loadings is presented in Figure 10.

Figure 10: Modelled effect of increasing effluent block size on reducing N and K nutrient loading for a farm where large amounts of feed N and K were coming onto the farm in supplements. Farm 2 was applying 90 and 235 kg/ha of N and K respectively in the effluent.



5.3 Stocking rate

Increased stocking rates affect nutrient losses on pastoral farms in two major ways:

1) stock hooves put pressure on soil structure and increases the risk of soil disturbance and loss of soil particles, increasing sediment P loss; and

2) more cows equals more urine spots, as was covered in Section 4.7.1. Much of the N leached comes from stock urinations in the late autumn-early winter period. Therefore, moving animals off pasture as much as possible between April to July can reduce N leaching, provided the effluent from these animals is captured and handled using best management practices, such as, adequate effluent storage, deferred irrigation, and using a low rate of effluent application.

5.4 Winter management

The aim of winter management options is to reduce dung and urine deposition on pasture, and thus reduce direct leaching of N from these sources. However, the effect of winter management on reducing N leaching depends on several factors:

1) The accumulation of nitrate-N concentration in the soil. If this soil nitrate-N build-up is high, particularly in autumn, then N leaching can still be high despite the cows being removed from pasture.

2) The length of time that cows are removed from pasture. Removing animals early in the winter (April/May/June) tends to have a larger effect than removing animals in later months.

3) Construction of a specialised wintering off facility such as a stand-off pad means that effluent can be collected, contained and treated before application to pasture at an appropriate time later in the season. Storing the effluent until spring, or applying the effluent at low rates over a large area increases N utilisation and decreases N leaching.

Removing animals from a farm usually results in reduced leaching on that farm, but may then increase N leaching in the catchment where the stock are grazed. For this reason in the ICM project, grazing off animals was not considered to be a viable option for farmers from an environmental perspective. The reason being, that farmers within the two ICM catchments have stated to EW in public meetings that this a "sunset technology", as they believe that in the future there will be nowhere that is not N limited to take stock.

5.5 Nitrification inhibitors

Nitrification inhibitors, such as DCD, are a new technology designed to slow the conversion by specific soil bacteria of soil ammonium to nitrate (Cameron *et al.,* 2007). In order to derive the maximum benefit from their use, DCD should be applied before the first drainage event of the autumn season occurs. Research findings on free-draining allophanic and pumice soils indicate that DCD applications should occur in April/May to cover the high-risk leaching period and with a further July/August application to further retain any autumn nitrogen remaining in the soil. The OVERSEER nutrient budget model is set up in this manner and assumes that the DCD product is applied twice, according to the suppliers' specifications, at an effective application rate of 10 kg/ha. The use of DCD for Upper Waikato Catchment farms, modelled using OVERSEER 5.3.6, is likely to reduce N leaching by 2-3 kg N/ha/yr (5-10% reduction). The use of nitrification inhibitors were identified as another targeted best management practice that could be implemented to achieve significant improvements in reducing N leaching in intensively farmed dairying catchments (Monaghan *et al.,* 2007). However, further research is required to provide the best advice on timing of applications and use, particularly for the milder climate of the North Island.

5.6 Feed supplementation

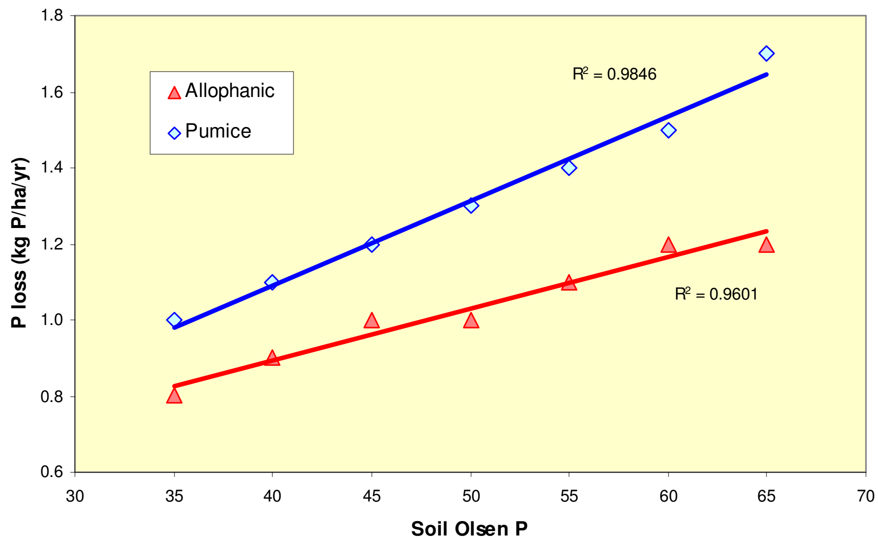
There was no clear trend between amount of imported feed N and amount of N loss on the ICM farms due to the wide range of data points. Bringing in feed supplements onto a farm also brings in nutrients. Some degree of substituting feed nutrients for fertiliser nutrients can occur, as was demonstrated on Farm 2. Pasture typically has a crude protein content of 20-25% while some feed supplements, such as, palm kernel extract (PKE) and maize silage have crude protein contents of 16 and 8% respectively. The higher the crude protein of the feed the more nitrogen it contains, so buying in a lower N feed like maize silage can reduce overall farm N inputs. On one farm where fertiliser inputs were initially 191 kg N/ha/yr and N leaching was 51 kg N/ha/yr, reducing fertiliser N inputs to 150 kg N/ha/yr reduced N leaching to 40 kg N/ha/yr. By comparison, hypothetically substituting all fertiliser N (Urea) with feed N (maize silage) could potentially reduce N leaching to 31 kg N/ha/yr. Clearly feed supplementation is a mitigation tool (as long as feed is grown efficiently off-farm). Secondary considerations from feed supplementation are that, to achieve high conversion efficiencies from expensive feed, farmers have installed feed pads. This allows the animals to be off pasture for typically 2-4 hours per day while urinations are captured and treated in the effluent system. This approach also ensures more efficient cycling of nutrients within the farm.

Currently, as at July 2008, fertiliser N in the form of Urea provides feed DM at a cost of $0.22/kg DM. PKE and maize silage provide feed DM at $0.40 to $0.50/kg DM (includes wastage and feeding out costs). At a $7 kg MS payout, and 13:1 feed conversion efficiency, milk provides a return of $0.54/kg DM.

5.7 Soil Olsen P status

Phosphorus losses in runoff from eroded soils to water are implicated in the accelerated eutrophication of surface waters (McDowell *et al.*, 2001). These soil P losses are influenced by three distinct factors: 1) soil Olsen P concentration, 2) climatic conditions e.g. rainfall, and 3) topographical features e.g. slope. Losses from soil are generally less than 1-2 kg P/ha/yr for most New Zealand pastoral systems. However, for intensive dairying systems, these P losses can be higher due to a build up of soil Olsen P concentrations from previous fertiliser P and effluent applications. The effect of higher soil Olsen P concentrations on increasing soil P losses can be clearly seen (R^2 =0.97) when modelled Olsen P values on an ICM farm block are raised above the economically optimal ranges of 20-30 and 35-40 for allophanic and pumice soils, respectively (Figure 11). Also note, that for pumice soils, soil P loss is greater than for allophanic soils, at the same Olsen P value. Pumice soils are amongst the highest risk soils for P losses due to their looser soil structure. Phosphorus adheres strongly to soil particles and when erosion occurs, these soil particles are transported in the overland flow to waterways.

Figure 11: Correlation between soil Olsen P concentrations and soil P loss from ash and pumice soils on typical Upper Waikato farm block, modelled by OVERSEER.



Limiting soil Olsen P to economically optimum levels is an effective best management practice for improving water quality in other dairying catchments (Monaghan *et al.*, 2007). Other changes in management practices that could be considered are to avoid pugging soils and compacting the soil structure, both of which promote lateral movement of water. It should be noted that very little pugging damage was observed on the ICM farms in the project, which were typically on well drained or porous soils.

6. Financial analysis

6.1 Assumptions modelled

Clearly, when planning mitigations, the financial implications for the business need to be considered. Therefore, financial analyses of the nutrient management mitigations were undertaken for two case study farms, one in each catchment, using the UDDER dairy farm production model. UDDER includes a financial component that allows the cost of system changes to be assessed and compared. The UDDER model analysis focused solely on N mitigations (i.e., not P). The following assumptions were used in the UDDER model based on the best available information as at July 1, 2008:

- Milk solids payout: $5, $6, and $7/kg MS
- Purchased feed (landed in a stack on the buyer's farm): $/t DM
  - Maize silage $380; Grass silage $360; PKE $420; Hay $360
- Winter crop: to sow 10t DM/ha swede crop and sow back into pasture: $2,140
- Nitrogen fertiliser: $2,280/t N
- Pasture DM responses to effluent N same as for fertiliser N (10 kg DM/ha per kg N)
- Marginal cost of running a cow: $510
- Variable costs per hectare of land: $840
- Grazing costs (per head per week):
  - Calves $5.00; Heifers $8.00; Cows $22.00 (winter)
- DCD nitrification inhibitor – annual effect of 6% more pasture DM grown per year (but all between July – December), total cost of recommended two applications: $160/ha

The wintering period of the farming calendar is the crucial time of year for managing nutrient losses as described earlier. Wintering systems that looked at removing stock from pastures were investigated. Grazing the herd off the farm to gauge the effect on nutrient losses was also modelled. However, as also described earlier, this is not a realistic environmental option for the ICM farms. For the wintering systems, as discussed, some financial assumptions for UDDER were made and these are presented in Table 9.

The cost of herd management for the pad options (taking the herd to and from the pad every day and other farm work) has been valued, however, some farmers would put a zero value on this cost on the basis that they are paying for their staff no matter what they are doing, so that the cash cost is less than what we are implying. For the standoff pad for example, we have assigned $100/day to this cow management/stock work. This means the total pad cost per cow figure is $122/year or 60 day season. If the $100 is reduced to zero, $122 becomes $92. At 2.6 cows/ha and say 100ha, this is worth 100 x 2.6 x (122-92) = $7800.

The term Gross Margin (GM) used later in this report is defined in the UDDER model as covering all farm working expenses. In reality, it is similar to Cash Farm Surplus.

Table 9: Wintering financials for ICM case study farms used in UDDER model.

Per 200 cows - consuming 8 kg DM/cow/day	Herd Home	Self-feeding pad	Stand-off pad	Grazing off farm
Construction capital costs ($/cow)	1,350	319	184	0
Effluent management capital costs ($/cow)	0[1]	96	71	0
Total capital costs ($/cow)	1,350	415	255	0
Total operational costs ($/cow	35	88	69	0
Total costs (capital & operating) – wintering for 60 days ($/cow/week)	38	33	27	22

[1] Effluent bunker system for herd home is part of capital construction costs.

NB: 1) This table excludes the fertiliser benefits of returned effluent.

2) Total costs, bottom row, includes the costs of the feed supplied to the herd home and, the self-feeding pad. In the UDDER analyses, these options were modelled by treating the cows as though they were wintered off the farm, at the weekly costs shown in the bottom row

3) For the standoff pad, the model assumed the cows were wintered on the farm, with the additional costs of the pad as shown in the table, added to that model's gross margin calculation

4) The figure for grazing off ($22/cow/week; bottom right hand of table) does not include a credit for time saved by the farmer not having to shift cows while they are grazed off

Case Study Farm A

6.2 Case Study Farm A details

A total of 14 scenarios were modelled through the UDDER model on this ICM farm. Descriptive parameters for the base model of this farm included:

- 3.1 cows wintered/ha at peak, young stock off farm
- Milk production: 1,030 kg MS/ha, 330 kg MS/cow wintered
- Fertiliser N: a total 175 kg N/ha – spread over Jul, Aug, Sep, Oct, Dec, Apr
- Fertiliser N applied in winter: 30 kg N/ha
- Winter crop: 10 ha - swedes
- Effluent management: two-pond system, discharge to water

6.3 Scenarios modelled for Case Study Farm A

The 14 scenarios modelled in UDDER for the ICM Case Study Farm A considered nitrogen fertiliser options, changes in effluent treatment, wintering options and herd size changes. A summary of the key parameters; stocking rate, nitrogen fertiliser rate, farm working expenses (FWE) and milk production from the modeled UDDER analysis is presented in Table 10.

- Where no N fertiliser has been applied, stocking rate was reduced from the original 3.1 to 2.75 cows/ha.
- Where cows have been wintered off pasture, no winter crop has been grown.
- In most cases, land application of effluent has been the effluent treatment system used except for the base farm and for where no N (either fertiliser N or effluent N) had been applied on the farm.
- Winter applications of 30 kg N/ha have been used in most scenarios except where it applies to no N and no winter N situations.
- The savings in effluent, expressed over the whole farm, have been taken into account.

Table 10: Key parameters from the modeled UDDER analysis for Case Study Farm A: stocking rate (SR), fertiliser N, farm working expenses (FWE), and milk solids (MS) production.

Scenario description	SR	Fertiliser N	FWE	Milk solids
	cows/ha	kg/ha/yr	$/kg MS	kg /ha
Base: cows wintered on crop on farm	3.11	175	3.58	1028
Base + land disposal of effluent	3.11	165	3.58	1028
No N applied in winter	3.11	165	3.61	1018
No N at all, ponds with discharge to water	2.75	0	3.42	881
No N except effluent N	2.75	0	3.39	894
No winter N, 200kg N/ha/ year	3.20	190	3.59	1058
Change breed of cow to lighter animals	3.38	165	3.69	1059
Base Farm at Optimum stocking rate	3.20	165	3.62	1041
Herd wintered off-farm 60 days, no forage crop	3.42	167	3.55	1146
Herd wintered off-farm, no crop, more time	3.42	167	3.44	1146
Cows wintered in herd home 60 days, 24/7	3.42	162	4.08	1146
Cows wintered on pad 60 days, 24/7	3.42	162	3.93	1146
DCD, annual effect + 6% extra DM all in Jul-Dec	3.38	165	3.73	1087
Herd wintered on pad 24/7, no winter N, DCD, no forage crop, 200 kg N/ha	3.56	186	4.12	1179

NB: * In this scenario, a $ credit was applied to time freed up as a result of cows wintered off and being shifted by someone else

** 24/7: Cows on wintering pad/herd home 24 hours a day, 7 days a week

6.4 Financial implications of N mitigations for Case Study Farm A

The effect of the nutrient mitigation scenarios on gross margins (GM), at three different payout levels, compared to the amount of N leached are presented in Table 11. Changing from a pond treatment system for treating effluent to land application reduces N leaching by 12% and is a profitable mitigation regardless of level of milk payout. Major reductions in N leaching were achieved through applying no fertiliser N (-46%) or only effluent N (-40%). The financial implication of applying no fertiliser N, however, is a reduced GM, and the penalty increases as the milk payout increases. Applying only effluent N is economic at a $5 milk payout but becomes unprofitable as the payout increases. Carrying more live weight per hectare (i.e., a greater number of lighter animals) could potentially reduce N leaching by 8% but would reduce GMs whatever the milk payout. Running the farm at the optimum stocking rate (3.2 cows/ha) reduces N loss by 2% and GM increases as the payout increases. Having stock grazed off-farm reduces N loss by 17% and is profitable at each level of payout. If the opportunity cost of saved time is included then the grazing off-farm is highly profitable, but as mentioned earlier, this in not an environmental option for ICM farmers.

Table 11: Amount of nitrate-N leached, Gross Margin at $5, $6, and $7 kg MS payout for Case Study Farm A.

Scenario description	N loss	Gross Margin ($/kg MS)		
	kg/ha/yr	$5	$6	$7
Base: cows wintered on crop on farm	52	1460	2488	3516
Base + land disposal of effluent	46	1483	2511	3539
No N applied in winter	49	1434	2452	3470
No N at all, ponds with discharge to water	28	1397	2278	3159
No N except effluent N	31	1466	2360	3254
No winter N, 200kg N/ha/ year	52	1521	2579	3636
Change breed of cow to lighter animals	48	1349	2408	3467
Base Farm at Optimum stocking rate	51	1464	2505	3545
Herd wintered off-farm 60 days, no forage crop	43	1679	2825	3971
Herd wintered off-farm, no crop, more time	43	1814	2960	4106
Cows wintered in herd home 60 days, 24/7	48	1087	2233	3379
Cows wintered on pad 60 days, 24/7	47	1262	2408	3554
DCD, annual effect + 6% extra DM all in Jul-Dec	50	1408	2495	3582
Herd wintered on pad 24/7, no winter N, DCD, no forage crop, 200 kg N/ha	45	1066	2244	3423

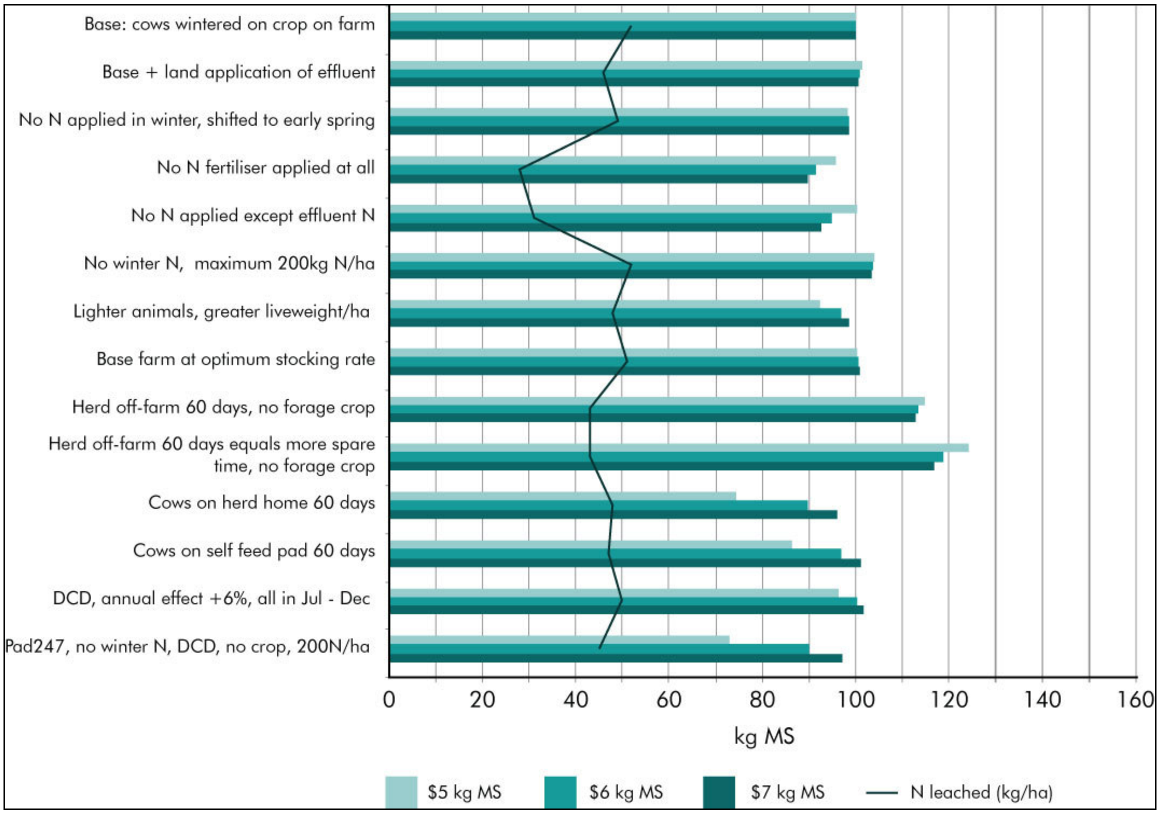
The wintering off options were the most profitable as shown in Table 11 although as described earlier, this is not an acceptable environmental option for the ICM farms because it merely exports the N leaching, due to wintering cows, to another site. It could be argued that wintering off is so profitable because it does not pay the full cost of environmental damage. Needless to say in the real world, at present, this option is still available to farmers, if the grazing area is available.

The self-feeding pad/herd home wintering options could reduce N loss by 8-10% but appears to reduce profitability markedly compared to the base farm (Table 11). These wintering options are sensitive to milk payout level and would require high payouts to be more profitable than the base. It should be noted that these systems (and wintering off) do provide other benefits such as reduced treading damage to pastures and soil compaction caused by stock. The benefits of this in terms of improved soil structure and spring pasture growth have been reported (Ledgard et al., 1996, Longhurst & Luo, 2007) and for some parts of New Zealand can be substantial, but were not included in our models. Using a nitrification inhibitor would reduce N loss by 4% but was less profitable than the base farm model at a $5 payout, as profitable at $6 but more profitable at $7 payout. The last option of a combination of mitigations reduced N loss by 13% but was less profitable than the base model at any level of milk payout.

Figure 12 presents the same data as Table 11 but expressed on a relative basis. (i.e., base farm model profit = 100%). This graph shows that the most profitable option was where the stock were wintered off-farm. The profitability of wintering off-farm was further enhanced if the opportunity cost of the time saved shifting cows was also accounted for.

Some other options were a little more profitable than the base model and were also beneficial from an N leaching perspective. The implication is that farmers could make environmentally favourable changes to these options with out loss of profit and therefore should be encouraged.

Figure 12: Nitrate leached (kg/ha, black line) and Gross Margins at three milk payout levels ($5, $6, and $7 kg MS), expressed relative to base farm scenario for Case Study Farm A. NB, base farm model (cows wintered on crop) = 100%, at top of chart.



The effect of N mitigation scenarios on GMs compared with the amount of N leached is presented in Figure 13. The graph shows that the GM per kg N loss is highest when no fertiliser N is applied and when only effluent N is applied. Wintering stock off-farm also shows high GM per kg N loss. At the low $5 payout all the on-farm wintering options including DCD nitrification inhibitor showed less GM per kg N loss than the current base farm model scenario. As the milk payout price increases so does the GM per kg N loss compared to the base farm model.

Figure 13: Profitability of scenarios expressed as $ GM/kg N leached for Case Study Farm A. NB, base model farm is at bottom of this chart.

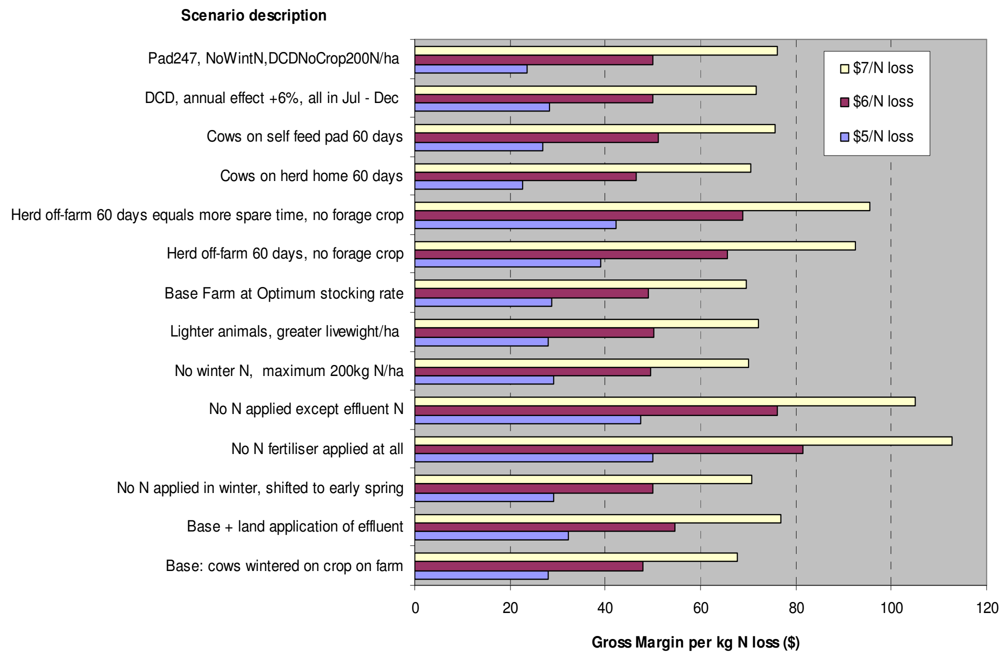


Figure 13 shows that to maximize profit per kg N leached, farmers should stop using N. While this is true, this is also unfortunately less profitable to the farmer on a per hectare basis which is what puts money in his bank account. Wintering off, at first glance, achieves the best of both worlds, but as mentioned several times above, it does this by exporting the winter N leaching problem

Case Study Farm B

6.5 Case Study Farm B details

A total of 12 scenarios were modeled using UDDER for the ICM Case Study Farm B. Descriptive parameters for the base model of this farm included:

- Stocking rate: 2.5 cows wintered/ha at peak, young stock grazed off farm
- Milk production: 920 kg MS/ha, 365 kg MS/cow wintered
- Fertiliser N: a total of 160 kg N/ha – spread over Aug (x 2), Oct, Dec, Mar, Apr
- No fertiliser N applied in winter
- Summer crop: 5 ha - triticale
- Effluent management system: via land application

6.6 Scenarios modelled for Case Study Farm B

The 12 scenarios for Case Study Farm B, modelled in UDDER, are described in Table 12. Herd size for the scenarios varies from 186 cows to 248 cows. For the organic option, stock numbers are lower as all the young stock are all kept on the farm because finding another organic farm on which to rear replacements is usually very difficult. The organic option also differed from the other options as it was the only system that did not apply any fertiliser N. Organic systems rely instead solely on clover N-fixation and a small amount of applied effluent N. Otherwise, pasture growth rates for the base farm and the organic farm were assumed to be the same. Organic farms are permitted to use RPR as a source of P fertiliser and K fertilisers are also allowable. A summary of the key parameters for Case Study Farm B and the modeled scenarios from the UDDER analyses is presented in Table 12.

Table 12: Key parameters from the modeled UDDER analysis for Case Study Farm B, stocking rate (SR), fertiliser N, farm working expenses (FWE), and milk solids production.

Scenario description	SR cows/ha	Fertiliser N kg/ha	FWE $/kg MS	Milk solids kg/ha
Base farm, $6 kg MS payout	2.5	160	3.59	918
Base farm, no summer crop	2.5	160	3.52	899
Nitrification inhibitor - DCD	2.8	160	3.70	982
Self-feeding pad system	2.8	160	4.03	1026
Herd wintered off farm	2.8	160	3.70	1026
Herd wintered off, more time *	2.8	160	3.60	1026
Base farm, optimum SR	2.6	160	3.66	930
Base, winter 12 hrs on-off	2.6	160	3.97	951
Base, + extra 13 ha run-off, - N	2.3	139	3.29	831
Base, + extra 13 ha run-off, + N	2.4	159	3.32	846
Conversion to Organics **	1.9	0	3.13	701
100 ha all-grass system	2.5	160	3.58	921

NB * In this scenario, an extra $100/day was credited to the farm to allow for the time spared not having to shift cows on breaks while they are being wintered off. Some other person is doing the work (the farmer grazing his herd).

** The GM result for the organic model is highly dependent on the assumption about the extra costs of production. These extra costs were set at +$100/ha. This may be incorrect. A full budget exercise, along with examination of the Case Study farms, is required to sort out the cost of milk production on organic farms, but this was beyond the scope of this present study.

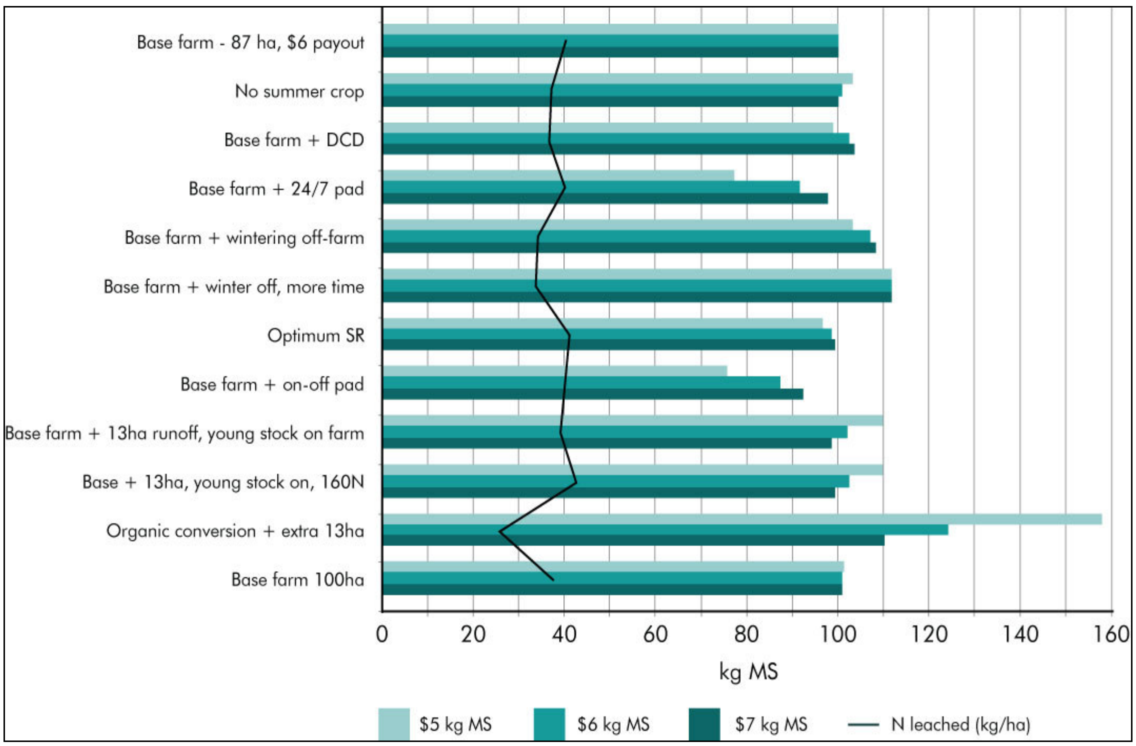
The amount of N leached and the gross margins at three milk payout levels is presented in Table 13. Foregoing a summer crop reduces N loss by 8% and is slightly profitable at $5 and $6 payouts. Using the DCD nitrification inhibitor could reduce N loss by 10%, but is less profitable than the base farm at a low payout but becomes more profitable as the payout increases. The self-feeding system is neutral re N losses because savings in having stock off-pasture are mainly offset by imported feed. The self-feeding system shows less profitable GMs compared to the base farm model at each payout level. The wintering stock off-farm scenario reduces N loss by 15% and is more profitable than the base farm at each payout level. Farming at the optimum stocking rate increases N loss and is more profitable than the base farm at all levels of payout. Wintering stock on a stand-off pad was N loss neutral but less profitable than the base farm at all payout levels. Adding a 13 ha run-off block to the base farm reduces N loss by 2.5% if no fertiliser N is applied on the run-off but increases N loss by 5% if fertiliser N is used. Both of these scenarios are profitable at $5 and $6 payouts but not at a $7 payout. Converting the base farm to organics appears to reduce N loss by 35% and is also much more profitable, more so when milk payout is lower as the premium attracted becomes relatively larger. Having an all-grass system could reduce N loss by 8% and is slightly profitable at each payout level. A hypothetical 100 ha milking platform was slightly more profitable than the base farm at each payout level.

Table 13: Amount of N leached, Gross Margins at $5, $6, and $7 kg milk payout for Case Study Farm B.

Scenario description	N loss	Gross Margin		
	kg/ha/yr	$5/kg MS	$6/kg MS	$7/kg MS
Base farm, $6 kg MS payout	40	1296	2214	3132
Base farm, no summer crop	37	1333	2232	3132
Nitrification inhibitor - DCD	36	1279	2262	3244
Self-feeding pad system	40	1001	2028	3054
Herd wintered off farm	34	1338	2364	3391
Herd wintered off, more time	34	1446	2472	3499
Base farm, optimum SR	41	1251	2181	3110
Base, winter 12 hrs on-off	40	979	1931	2882
Base, + extra 13 ha run-off, - N	39	1421	2252	3083
Base, + extra 13 ha run-off, + N	42	1419	2265	3111
Conversion to Organics	26	2042	2743	3443
100 ha all-grass system	37	1311	2232	3153

Figure 14 presents the same data from Table 13 and expresses the different milk payout levels relative to the base farm model, i.e., base farm model = 100%. This graph shows that scenario of wintering stock off-farm is the second most profitable option compared to the base farm model at all payout levels. This option, however, of exporting the environmental problem was not considered an option for the ICM farms as mentioned for Case Study Farm A. Having an additional 13 ha runoff is equally profitable but only in a low milk payout year. The most promising and profitable scenario is the organic conversion and it appears that as the payout goes lower the profitability of this option increases dramatically. There is still some uncertainty about this result re the costs of production, however, it is an option that deserves more detailed investigation as a separate or additional study.

Figure 14: Nitrate leached (kg/ha, black line) and Gross Margins at three milk payout levels ($5, $6, and $7 kg MS), expressed relative to base farm scenario for Case Study Farm B. NB, base farm model (87 ha) = 100%, at top of chart.

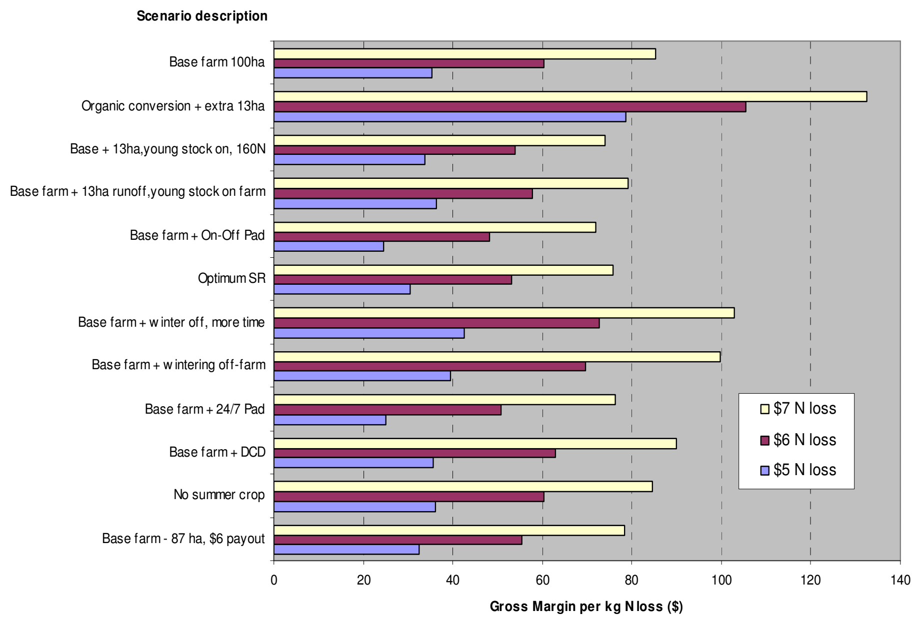


The effect of N mitigation scenarios on Gross Margin/kg of N leached is presented in Figure 15. The graph clearly shows that the GM per kg N leached is highest with the organic conversion option. Wintering stock off-farm also shows high GM per kg N loss. Of the other scenarios using DCD nitrification inhibitor, no summer crop and the 100 ha milking platform are all similar at each payout level. At all payout levels the off-pasture scenarios would affect GM per kg N loss more than the base farm model.

Most mitigations appear to cost the farm, the exact financial penalty depending on the GM and the level of milk solids payout. Nevertheless, in most cases, the monetary reductions are relatively small and while farms might lose some money we should not lose sight of the fact that with a reasonable payout dairying is still very profitable. The biggest unknown, of course, is that we do not know at what level the milk payout will be in the future.

As was the case with Case Study Farm A the most profitable option ($/kg N leached might not be adopted by farmers.

Figure 15: Effect of N loss from scenario descriptions on Gross Margins for Case Study Farm B. NB, base model farm is at bottom of this chart.



7. Comments on sensitivity of mitigations to milk solids payout (both case study farms)

- Wintering off was profitable at all milk payouts but had the unacceptable problem (for the ICM farmers) of exporting the winter N leaching problem
- Land application of effluent was worth about 10 kg fertiliser N/ha/year and appears to be worth doing at all payout levels and is an environmentally desirable practice
- Avoiding N fertiliser application in the winter had a small negative to neutral effect of profitability and reduced N leaching by 1 to 3 kg N/ha/year and therefore, in the authors' opinion, should be adopted by all dairy farmers as part of good practice management
- Generally, the more expensive N mitigation options such as wintering cows on a stand-off pad/herd home, using DCD inhibitor, were less profitable than the base farm at low payouts ($5) and, therefore, would be unlikely to be adopted by most farmers although this study did not adequately assign a value to the impacts of reduced pugging. At high payouts ($7) these options were nearly as profitable as the base farm and in some cases were more profitable although the herd home always seemed to be less profitable, but not by much. The increasing number of herd homes on dairy farms testifies that there are other factors that farmers have observed such as ease of management, reduced pugging, better stock condition (Longhurst *et al*., 2007). Farmer control of animals is one reason stated by the participants in this study.

The analyses in this report are based on the pricing assumptions described. Farmers and others using the information in this report need to adjust the answers in light of changes in the costs of production. Grazing off, wintering systems, and N fertiliser are significant costs items and likely price rises, if they come to fruition, will affect the profit comparison of the scenarios described. As a general rule, if an input costs rises, but payout does not, then our results indicate that stand-off pads, herd homes and grazing off will become less profitable relative to the base farm scenario described. This is not a new phenomena. Previous studies (Jensen *et al*., 2005) involving the use of imported feeds for intensive dairy farming have shown these options to be more profitable than low cost farming systems only at high payouts relative to input costs.

8. On-farm mitigations

8.1 Planning

There are two formal requirements that dairy farmers are required to undertake within EW jurisdiction that would assist in planning nutrient mitigations, these are:

1) Nutrient budget. Undertaking a nutrient budget, as now required of all dairy farmers by the Fonterra Accord. A whole farm nutrient budget identifies all the farm inputs (fertiliser, feed supplements, clover N fixation, animal manures) and farm outputs (milk, meat, fibre or supplements sold) to get an estimate of any particular nutrient surplus. The OVERSEER nutrient budget model has been designed for this purpose, plus the model gives a prediction on the amount of nutrient loss likely to occur through N leaching or surface run-off of P. The model is a useful tool for farmers to identify where savings in nutrients can occur but like all models' the information in the output is only as good as the input data.
2) Nutrient management plan. Any farmer in the EW region applying more than 60 kg fertiliser N/ha/yr must prepare a nutrient management plan. The nutrient management plan is more than a nutrient budget. It must describe practical on-farm steps to be taken to reduce nutrient and sediment losses. The farm management areas that must be covered include; soils, waterways, nutrients, effluent, and environmental hotspots like silage stacks.

8.2 Implementation

From the analysis in the previous sections, there are a number of mitigations that are available for consideration. Some of these mitigations are already being used on some farms, however, not all mitigations are applicable to all farms, and some mitigations will have a larger effect on reducing nutrient losses than others. In summary, these mitigation options are:

1) Nitrogen management. Ensuring that N fertiliser is applied when required (i.e. 4-6 weeks before a feed deficit), and when there is rapid plant N uptake by actively growing pasture. An important consideration to reflect on before any additional use of fertiliser N is applied, is that it is essential to ensure that the feed supply is, in fact, the limiting factor. If feed supply is already sufficient and management is deficient then any addition of extra feed to the system will be uneconomic (Macdonald, 2000). Avoiding N fertiliser applications during high risk months prone to N leaching (May to July inclusive). Consider reducing fertiliser N inputs. Using a DCD nitrification inhibitor where appropriate.

2) Effluent management. Effluent is frequently the problem area of a dairy farm. Two aspects critical to ensuring sound management are:
   a) effluent storage ponds: having the capacity to store effluent before land application is essential in a reasonably high rainfall region (1400^+ mm). To achieve this, the recommended storage ponds' capacity should be sufficient to accommodate at least 3 months volume. Pond sealing is another requirement (DEC manual, 2006). A storm water diversion should be in place to direct clean water away from the pond.
   b) effluent block area: effluent loading rates must not exceed 150 kg N/ha/yr and 25 mm per application. Increasing the effluent block area will spread nutrients further thus reducing fertiliser inputs. Potassium loadings can also be reduced (K concentrations are often higher than N concentrations). David Houlbrooke, AgResearch (pers. comm.), recommends as a "general rule of thumb" an area of 8 ha per 100 cows to allow for the K loading.
3) Stock management. Reducing stocking rate over the high risk months for N leaching (winter). Avoid stock grazing near waterways (especially on sloping ground) during heavy rainfall events.
4) Winter management. Cows can receive most of their daily feed requirements in 6 hours or less. Any longer on pasture during the winter wet can result in environmental problems. Providing stand-off facilities in the form of carbon-based (sawdust, shavings, chips etc) stand-off pads, self-feeding pads (combined stand-off pad and concrete pad containing silage stack which is subsequently break-fed to cows), or animal shelters like herd homes, means that stock can be withheld for an extended time (6-24 hours/day) over a prolonged period (6-8 weeks). The longer the cows are held off pasture the more consideration should be given to feed supplements, to ensure that the stock are receiving sufficient feed. It is important to monitor animal stress when using confined animal systems for prolonged periods (Gwen Verkerk, DairyNZ, pers. comm.).
5) Supplementary feeds. Consider the use feed supplements instead of N fertiliser to over come feed shortages. Use a low N feed supplement such as maize silage instead of a high N feed supplement such as pasture silage or lucerne silage.
6) Phosphate management. Soil P losses can be minimised by avoiding soluble fertiliser P applications during the high-risk months for P surface run-off (May to October inclusive); maintaining Olsen P levels in the optimum range for a particular soil type (allophanic 20-30, pumice 35-45); avoiding winter pugging of

soils, managing timing of stock grazing on steeper slopes and near stream banks to avoid runoff, and considering use of slow release forms of fertiliser P.

7) Riparian management. Both Environment Waikato and Fonterra have been encouraging (and moving to enforcing) farmers to fence off and plant waterway margins, culvert crossing points on races, as well as to reticulate farm water supply. Riparian buffer strips are effective at reducing sediment loss, which contain nutrients and possibly pathogens. Retire riparian areas and fence from stock grazing. Constructed wetlands studies by Sukias et al. (2005) have found that around 40-50% removal of nitrates can be achieved, however, the wetland area needed to cover between 2-5% of the catchment area for the receiving waters. Smaller wetland areas were found to generally remove up to 20% of the nitrate in the drainage water depending on the wetland condition.
8) General farm environmental management. Several sources of nutrient loss can occur around the farm from diffuse sources such as badly maintained tracks and races or from direct point sources such as silage stacks and offal holes. Careful attention to initial planning and design should alleviate most of these nutrient risk areas. Avoid nutrients entering waterways from fertiliser applications.

9. Summary of potential options for reducing N leaching from dairy farms in dairying catchments

A summary of the potential options available for reducing N leaching in dairying catchments such as the Upper Waikato is presented in Table 14. The information draws on results from the ICM study farms and from previous research studies in other similar dairying catchments. The range in profitability as shown in the table is due to the fact that the benefits of the options can be quite highly farm specific, depending mostly on what systems are in place on the farm at the present time

It is unlikely that combining mitigations, listed in Table 14, will result in a N reduction equivalent to adding up the numbers. This is because some of the mitigations, e.g., revolving around winter management, will act on the same pool of N. Running the OVERSEER nutrient budget will model these combined mitigation effects.

Note, that some of the options listed in Table 14 require capital expenditure and / or significant farm system changes.

Table 14: Potential options for reducing N leaching in the Upper Waikato Catchment.

Option	Likely % reduction in N leaching	Likely profitability of option **	Caution…
Don't apply fertiliser N in winter	5 (0-10)	– to O	May need other management changes
Reduce N fertiliser use & reduce milk production	15 (0-35)	–	If current N use is high (>200kg N/ha) reduced N use may increase profit
Changing effluent system from ponds to land application	10 (5-15)	+	Set-up costs, deferred irrigation can be practiced from redundant ponds to minimise capital costs
Apply FDE * over larger area & use less N fertiliser	10 (5-15)	+	Depends on current FDE area
Nitrification inhibitor (DCD)	8 (5–10)	– to O	More research required under high rainfall; more profitable in South Island
Use Wintering Pad/Stand-Off pad/animal shelter (Herd Home)	10 (5-15)	–	Increased work, capital cost including infrastructure, availability, or price, of bark or sawdust could be a problem. Profitable only at high payouts (benefits do not include effects of reduced pugging, stock condition)
Sell off silage in autumn & have a shorter lactation	5 (0-15)	– –	Unprofitable due to foregone milk production
Reduce use of brought-in feed	4 (0-7)	– to +	Depends on quality, use and price of brought-in feed and payout
Change brought-in feed to low protein source (e.g. maize silage)	2 (0-5)	–	Depends on current level of brought-in feed and feed costs
Increase winter grazing off	15 (10-20)	++	Dependent on availability & cost, transfers N loss to other catchments and so may not be acceptable, requires system changes
Replace winter crop with grass-to-grass	5 (0-15)	O to +	Typically only a small area is cropped, profit depends on need for pasture renewal
Reduce stocking rate & increase per-cow production	1 (-5 to 5)	– / +	Profitable on very high stocked farms, change will require increased management skill
Conversion to organics	25 (15-35)	++	Appears highly profitable at lower milk payouts however further research required regarding costs of production and production levels
Put in artificial wetland	? (0-5)	– –	Highly farm specific (contour, soil)

* FDE = farm dairy effluent

** Likely profitability of option

++	Profitable	–	Slightly unprofitable
+	Slightly profitable	– –	Unprofitable
O		Neutral	

10. Conclusions

The range of N leaching values from the eight ICM Farms ranged between 31-52 kg N/ha/yr. These farms were representative of dairy farms in the Upper Waikato region and we expect, therefore, that other farms will show a similar range. Nitrogen losses were generally related to stocking rate (more cows/ha means more urinations per hectare), N surplus and N inputs (i.e. the amount of N entering the farm).

From the above analysis, one simplistic approach to reducing N loss would be to limit fertiliser and other N inputs to a farm. Indeed, this is the legislative approach in Europe. Another approach, however, is to allow farmers to develop management systems that limit leaching losses by building a number of mitigations into their systems (i.e., an emphasis on N outputs rather than N inputs). Our analysis shows that there are a number of mitigation options that could be incorporated into the farming systems without loss of profit in some cases. It should be also be noted, however, that not all mitigations are applicable to every farm (contour, etc).

For example, one farm consistently out performed the other seven ICM farms in terms of N leaching. The main reasons for this were: 1) lower stocking rate (2.5 cows/ha), 2) aiming for high per cow production (550 kg MS/cow), 3) achieving a whole balanced diet using supplementary feed, 4) reduced fertiliser N inputs, 5) sufficient effluent storage capacity, 6) a large effluent block, and 7) a high degree of management skills. This farm shows that by using sound management, high production can be achievable in a sustainable manner and with a low environmental footprint. The environmental footprint of growing all the supplementary feed off-farm and the profitability of this farming operation were not investigated on this particular farm. This would be worth doing to test whether this favourable outlier farming system could be replicated to other farms.

Our analysis shows that there are a number of mitigations that could be built into farm systems. The mitigations offering the most potential for reducing N losses fall into two groupings:

a) Those mitigations that can be achieved through adopting best management practices and do not require major changes to the farming system such as reducing fertiliser N inputs, avoiding winter applications of fertiliser N, increasing the area of the effluent block, not applying fertiliser N on effluent block, and using nitrification inhibitors. These also tend to be cost neutral to slightly profitable depending on payout.

b) Those mitigations that require a large capital expenditure, for example, for constructing standing-off/shelter facilities for stock, especially during the susceptible N leaching period over winter. These tend to reduce farm profitability, again depending on payout.

We tested the option of combining some of the mitigation methods, using OVERSEER and UDDER, for two ICM case study farms. We concluded that some progress in reducing N leaching can be made without loss of profit under the present assumed cost structure models we used. Possible reductions in N loss were in the order of 6% by not applying fertiliser N in winter; 4-10% for using nitrification inhibitors, 12% for switching to land based effluent treatment system; 8-10% for stock wintering systems. Larger reductions in N leaching could be achieved, usually with reduced profit compared to present farm systems through reducing fertiliser N inputs (0-40% depending on the rate of fertiliser N reduction). Conversion to organics deserves serious consideration as it might achieve the win-win situation of both increasing profit and significantly reducing N leaching. Further research on the costs and level of production for organic farming is required to confirm this outcome.

The financial assessment by UDDER on two ICM farms suggested that implementing some of the N loss reduction mitigations did reduce profit relative to the pre-mitigation or base farm scenario.. At high payouts, more scenarios or N mitigation tools were profitable but continued high milk payout levels can not be guaranteed. Gross Margins are affected to a greater or lesser degree depending on the level of milk payout, as might be expected. This is a major consideration in the adoption of any mitigation.

For phosphorus, there was a wide range of modelled surface P losses (0.7-4.3). Runoff P losses were generally related to P high inputs (mainly fertiliser) and having soils on farm blocks with above optimum Olsen P concentrations.

Overall, the ICM project has demonstrated a need for EW and AgResearch to work with farmers on how they can fit mitigations into their dairying systems, and shows that some progress can been made in the management of N leaching without affecting profit. Bigger gains, without affecting profit will be harder to achieve and remain an exciting challenge for research to overcome.

11. Acknowledgements

We wish to thank Dr Mark Shepherd and Ian Power of Climate, Land & Environment, AgResearch Ruakura, Ross Abercrombie and Angela Davies of EW for reviewing this report. Philip Jones, EW, for graphics on Figures 12 & 14. To the participating ICM farmers, and especially to the two farmers who opened their financial accounts to scrutiny.

12. References

Bolan, NS. 2001: Nutrient recycling from farm dairy effluent. *Water and Wastes in New Zealand* 117*:* 32-35.

Cameron, K.C., Di, H.J., Roberts, A.H.C. 2007: reducing nitrate leaching losses from a Taupo pumice soil using a nitrification inhibitor eco-n. *Proceedings of the New Zealand Grassland Association* 69: 131-135.

DEC Manual. 2006: Managing farm dairy effluent. Dairying and the Environment Committee. Fonterra, Hamilton.

Jensen, R.N., Clark, D.A., Macdonald, K.A. 2005. Resource Efficient Dairying trial: measurement criteria for farm systems over a range of resource use. *Proceedings of the New Zealand Grassland Association* 67: 47-52

Ledgard, SF., Thom, ER., Singleton, PL., Thorrold, BS., Edmeades, DC. 1996: Environmental impacts of dairy system. *Proceedings of Ruakura Farmers' Conference* 48: 26-33.

Ledgard, SF., Basset-Mens, C., McLaren, S., Boyes, M. 2007: Energy use, "food miles" and greenhouse gas emissions from New Zealand dairying – how efficient are we? *Proceedings of the New Zealand Grassland Association* 69: 223-228.

Longhurst, RD, O'Connor, MB, Roberts, AHC, Waller, JE. 1999: Farm dairy effluent findings of recent research studies in the Waikato. In *Best soil management practices for production.* (Eds LD Currie, MJ Hedley, DJ Horne, and P Loganathan). Occasional Report No.12. Fertiliser & Lime Research Centre. Massey University, Palmerston North.

Longhurst, B, Luo, J. 2007: On-off farm winter management practices: potential environmental benefits and issues. In *Designing sustainable farms: Critical aspects of soil and water management.* (Eds LD Currie and LJ Yates). Occasional Report No. 20. Fertilizer and Lime Research Centre, Massey University, Palmerston North.

Longhurst, RD., Luo, J., O'Connor, MB., Pow, T. 2007: Herd Homes: nutrient management and farmer perceptions of performance. *Proceedings of the New Zealand Grassland Association* 68: 309-313.

Macdonald, K. 2000: Nitrogen – for thinking farmers only. *SIDE papers – 2000.* South Island Dairy Event. www.side.org.nz

McDowell, RW., Sharpley, AN., Condron, LM., Haygarth, PM., Brookes, PC. 2001: Processes controlling soil phosphorus release to runoff and implications for agricultural management. *Nutrient Cycling in Agroecosystems* 59: 269-284.

Monaghan, RM., Wilcock, RJ., Smith, LC., Tikkisetty, B., Thorrold, BS., Costall, D. Linkages between land management activities and water quality in an intensively farmed catchment in southern New Zealand. *Agriculture, Ecosystems and Environment* 118: 211-222.

Roberts, A., Morton, J. 2004: Fertiliser use on New Zealand dairy farms. New Zealand Fertiliser Manufacters' Research Association, Newmarket, Auckland.

Sukias, J., Tanner, C., McKergow, L. 2005: Management of dairy farm drainage pollution. NIWA Client Report HAM 2005-102 for Dairy InSight. NIWA, Hamilton.

Tillman, RW., Yates, LJ., Horne, DJ., Hedley, MJ., Hanly, JA. 2008: Is "environmental efficiency" a useful concept in improving and regulating the environmental performance of pastoral farming systems. In '*Carbon and nutrient management in agriculture'*. Occasional Report 21. Fertiliser & Lime Research Centre. Massey University, Palmerston North.

Wheeler, D.M., Ledgard, S.F., De Klein, C.A.M., Monaghan, R.M., Carey, P.L., McDowell, R.W., Johns, K.L. 2003: OVERSEER ® nutrient budgets – moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association* 65: 191-194.