Environment Waikato Technical Report 2006/45

Evaluating Strategic Retention of Artificial Drainage Flows for Nitrate-N Reduction Under Waikato Conditions

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

Prepared by:
Greg Barkle, Aqualinc Research Ltd

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

December 2007

Document: #1265566

Disclaimer

Document: #1265566

AQUALINC RESEARCH LIMITED

Evaluating strategic retention of artificial drainage flows for nitrate-N reduction under Waikato conditions

Prepared for Environment Waikato

Report No H06005/1

September 2006

Disclaimer:

This report has been prepared solely for the benefit of Environment Waikato. No liability is accepted by Aqualinc Research Ltd or any employee or sub-consultant of this Company with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the report may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.

Quality Control			
Client:	Environment Waikato		
Report reference:	Title: Evaluating strategic retention of artificial drainage flows for nitrate-N reduction under Waikato conditions		No: H06005/1
Prepared by:	Greg Barkle		
Reviewed by:	C Rajanayaka	Approved for issue by:	G Barkle
Date issued:	20/9/06	Project No:	H06005

Document History								
Version: 1	Status:	Draft	Author:	G Barkle	Reviewer:	C Rajanayaka		
Date: 20/6/06	Doc ID:	H06005_Draft subsurface drainage N reduction.doc	Typist:	G Barkle	Approver:	G Barkle		
Version: 2	Status:	Final	Author:	G Barkle	Reviewer:	C Rajanayaka		
Date: 20/9/06	Doc ID:	H06005_Final subsurface drainage N reduction - GB.doc	Typist:	K Glentworth	Approver:	G Barkle		

www.aqualinc.com

CHRISTCHURCH PO Box 20-462, Bishopdale, Christchurch 8543 ♦ Phone: (03) 964 6521 ♦ Fax: (03) 964 6520

HAMILTON PO Box 14-041, Enderley, Hamilton 3252 ♦ Phone: (07) 858 4851 ♦ Fax: (07) 858 4847

TABLE OF CONTENTS

Page

Page

List of Figures:

List of Tables:

EXECUTIVE SUMMARY

This project investigates a mitigation strategy of retaining drainage flows in the soil profile during the autumn period to reduce nitrate-N leaching from artificial drainage under dairy farming in the Waikato.

A literature review of field drainage experiments in New Zealand confirmed that the highest nitrate-N concentrations occur in early autumn and decline through to spring. This trend in declining nitrate-N concentrations is interrupted if nitrate-N generating process such as fertilizer or grazing occurs. Such processes increase the size of the potential leachable nitrate-N pool.

Based on published data, it is estimated that the maximum potential nitrate-N that could be removed by this mitigation strategy would be 10% of the annual nitrate-N exported through the artificial drainage system. While it is difficult to estimate what fraction of this potential would be realised in the field, it is unlikely to be more than 50%. This would indicate that only about 5% of the nitrate-N exported from artificial drainage would be removed by implementing a strategy of strategic retention of drainage waters. As nitrate-N concentrations in drainage waters are related to fertiliser application, grazing patterns, soil water characteristics, and weather patterns, without field trials this estimate should be treated as an indicative value only.

While this strategy of strategic retention of drainage flow can be implemented relatively easily on-farm, it still requires considerable input of resources for farmer education and promotion before it is likely to be widely adopted. The implementation of the strategy also somewhat increases the risk of short-term flooding but, with good management, this risk should be minimal.

The reduction in nitrate-N exported has been estimated to be limited. It is therefore an unlikely candidate for Environment Waikato to promote as an important drainage management strategy. Regardless, it does have a place amongst the tools that could be considered as best management strategies for farmers wanting to reduce nitrate-N export from artificial drainage systems.

1 INTRODUCTION

Approximately 60% of land used for dairying in New Zealand requires artificial drainage for successful farm operation. Unfortunately, subsurface drainage has been identified as a significant source of contaminants from grazed pastures to waterways (Monaghan et al. 2002, Wilcock *et al*. 1999). Drainage networks accelerate water and associated contaminant flows of nitrogen (N) and phosphorous (P), and bacteria also bypass riparian zones, thus rendering them ineffective as buffers for reducing pollutant concentrations (Nguyen et al. 2002, Tanner *et al.* 2002). The concentration of N, P, sediment and faecal bacteria in drainage from dairying exceeds the recommended guideline values for surface water quality. Monaghan *et al.* (2002) wrote that unfortunately there are few practical management techniques available to reduce these high-background contaminate losses from drainage discharge.

In a review of mitigation strategies to reduce nitrate-N losses from drained agricultural land, Sands (2001) identified five options. The application and ramifications of these five mitigation options with respect to dairy farming systems in New Zealand are summarised in Table 1.

Table 1: Drainage mitigation strategies applied to dairy farming in New Zealand

Strategy	**Water quality objective**	**Example**	**Advantages**	**Disadvantages**
On-farm nitrogen management practices	Minimise nitrate-N available for leaching losses	Stand-off pads, restricted autumn grazing, inhibitors	Reduction in source of nitrate-N	Higher costs, perceived as high risk and cost compared to nitrogen
Drainage design	Minimise nitrate-N reaching drainage system	Shallow drainage	No new management, applicable where ever drainage is installed	Increased cost of drainage system due to narrower spacing
Drainage management	Minimise nitrate-N discharging from the drainage system	Controlled drainage	May provide increase pasture production	Topography limitations, requires new management, risk of yield reduction
Edge of field treatment	Reduce nitrate-N leaving the farm	Riparian buffers, wetlands, bioreactors	Passive, no new management; habitat creation	Topography limitations, land remove from production
Beyond field treatment	Attenuate nitrate-N loads downstream	In-ditch nitrate-N removal	Passive, no new on-farm management	Last line of defence

Some of the mitigation strategies suggested in Table 1 are more attractive and advantageous to farmers than others and are therefore more likely to be implemented. The adoption of a mitigation strategy will depend on a number of factors including cost, expected benefit, confidence in performance, technical feasibility, change in farm management required, legislative or community pressures, and personal preferences.

Overseas, one of the better studies and effective methods implemented for nitrate-N reduction from artificial drainage is controlled drainage. Controlled drainage uses a weir, which is a flow restriction device based on water level height, placed in the drainage outlet. The water table level in the field is controlled to achieve both agronomic and environmental benefits. The reduction in nitrate-N export is achieved via three mechanisms:

- Enhancing nitrate-N removal via denitrification by managing soil water contents to promote this removal mechanism.
- Reduction in the amount of water discharged through the artificial drainage system by higher efficiency of water use by the crop, enhanced deep drainage and higher actual evapotranspiration rates.
- Promoting deeper drainage through soils which have a greater capacity for nitrate-N removal via denitrification.

Overseas published results for effectiveness of controlled drainage are generally for arable cropping systems under different climatic conditions than occur for pastoral dairying farming in New Zealand and as such are not directly comparable. EW has requested Aqualinc Research Ltd (Aqualinc) to undertake a desktop feasibility study to address the potential for using strategic retention of the artificial drainage flow from dairy farms over the autumn period. This mitigation option would involve simply blocking the drainage flows during summer and early autumn when either a single summer drainage event occurs or the initial autumn drainage events for the season are beginning.

This strategy is based on the assumption that the autumn drainage fluxes have the highest nitrate-N concentrations. These higher nitrate-N concentrations are a result of the lower summer pasture uptake rates that occur concomitantly with higher soil temperatures and resulting mineralisation rates. This combination of lower uptake and higher production results in an accumulation of nitrate-N in the soil. These elevated soil nitrogen levels can then be leached out in the autumn wetting events. If this autumn nitrate-N flush can be retained in the soil profile, by preventing soil drainage then either plant uptake or removal via denitrification can occur. This can then provide an overall reduction in the nitrate-N being exported from the farm via the artificial drainage system.

The strategic retention of drainage waters may appear to be somewhat counter intuitive, in that artificial drainage was installed to remove water from the soil profile not to retain it. However, artificial drainage is not in all cases required throughout the year. In summer and autumn for example when isolated drainage events occur, due to high intensity rainfall, the removal of the excess drainage water may not be required or beneficial. This is particularly the case if the pasture is still growing actively and reasonably high levels of evapotranspiration are being maintained. In these cases evapotranspiration may be limited and, if additional water was maintained in the soil profile, benefit to pasture growth could be obtained. It is recognised that if extended periods of drainage are required then this mitigation option is not compatible with farming operations. Strategic retention is not being advocated for drainage over early winter, winter or spring periods.

To evaluate the potential of this mitigation option, the initial question that needs to be answered is what is the total amount of nitrate-N that is being discharged from artificial drainage in the summer/autumn period? This specifies the maximum level of potential savings that could be achieved if all of this nitrate-N was retained in the soil profile and removed by the mitigation strategy. The subsequent question is, of this potential amount, what level of reduction could be realistically achieved by preventing discharge from the drainage system? This study addresses the first question, to estimate the size of the nitrate-N pool being exported from artificial drainage systems in the Waikato over the summer/autumn period.

2 PROJECT OUTLINE

This project has three components:

a) Review and summarise artificial drainage management studies in New Zealand.

b) Review relevant drainage studies in New Zealand to:

- confirm the hypothesis that autumn drainage concentrations are generally the highest
- estimate the nitrogen load that is occurring in the initial autumn flush period that could be potentially reduced through this drainage management option.

c) Assess the accuracy of a simulation model to extend measured drainage data, to allow the longer term viability of autumn drainage management under dairy farming in the Waikato to be ascertained.

One of the difficulties in determining the potential nitrate-N losses that can be captured by this mitigation strategy is that this potential varies from year to year dependent on weather and drainage conditions. If early winter weather conditions occur with the onset of significant drainage in May this could mean that no potential exists for the retention of artificial drainage flow. While recognising this limitation, a starting point for this desktop study has been to initially use Julian days to quantify the potential benefits that could be captured by this mitigation strategy. The year has been divided into the following seasons, based on Waikato climatic conditions:

Summer: December, January, February
Autumn: March, April, May
Winter: June, July, August
Spring: September, October, November.

3 DRAINAGE MANAGEMENT STUDIES IN NEW ZEALAND

There have been two studies in New Zealand where water table management has been tested as a tool to mitigate nitrate-N losses from artificial drainage systems.

The first was a lysimeter study by Singleton et al. (2001) where two levels of controlled drainage and a conventionally drained treatment were investigated. The three year project used very high loadings of dairy farm effluent irrigated onto lysimeters that had pasture managed under a cut and carry system. The three-year average nitrate-N leaching decreased from the equivalent of 26.2 kg NO_3-N/ha/yr under conventional drainage, to 11.2 and 3.7 kg NO_3-N/ha/yr with increasing level of water table height used for the weir condition. This is equivalent to 57 and 86% reduction in nitrate-N respectively being exported from the drainage under conventional drainage. Under the water irrigated treatment, the already low nitrate-N leaching of 6.3 kg NO_3-N/ha/yr was even further reduced to 2.0 and 0.8 kg NO_3-N/ha/yr. This water only treatment shows a similar level of nitrate-N reduction as the effluent irrigated treatment. Unfortunately, the study also found large amounts of organic nitrogen was being leached via bypass flow from the effluent irrigated treatments.

The second study by Fonterra (John Russell, pers. comm.) investigated the option of using controlled drainage for enhanced nitrate-N removal from land applied dairy factory effluent irrigation at Hautapu. The water table was raised by placing weirs in the surface collector drains in the paddocks. No significant difference in the nitrate-N in the drainage water was measured between the controlled and conventional drained treatments. However, the soils on both treatments had high organic matter contents and naturally occurring high water contents. These conditions resulted in very low nitrate-N concentrations in the conventionally drained treatments, generally less than 1.0 g/m^3 of nitrate-N. The remaining potential for further enhancing nitrate-N removal through water table management was accordingly small. It was commented that raising the water table throughout the year made farm management difficult and not conducive to the management of grazing dairy cows.

4 RELEVANT DRAINAGE STUDIES IN NEW ZEALAND

4.1 2002 Review of artificial drainage studies in New Zealand

In 2002 Fonterra commissioned a study to collate and synthesise existing data on the loads of water, sediments, nutrients and faecal bacteria from subsurface drainage systems. Much of this data was on an annualised basis and, as such, is not in a form that could be readily interpolated to investigate the feasibility of strategic retention of drainage flows in the autumn.

Monaghan et al. (2002) concurs with the underlying hypothesis of the mitigation strategy that autumn concentrations of soil nitrate-N can be high due to flushes of mineralisation of soil organic N, especially in the top 200 mm as the soil re-wets after summer. He writes that under urine patches movement of high nitrate-N concentrations to depth which then can be subsequently lost in drainage have also been widely reported (Monaghan et al. 2002).

They report data which shows the first drainage event of the season, occurring in May to June, tends to have the greatest nitrate-N concentration (approx. 20 g N/m^3) but decreases to below approximately 5 g N/m^3 by halfway through the season. This pattern of decreased nitrate-N with winter drainage continues unless some events occur which generate further potential for nitrate-N leaching, such as the application of fertiliser or grazing. This pattern can be readily seen in Figure 1, where in the A Area urea fertiliser was added in June which resulted in an increase in the nitrate-N concentration compared to Area B. When Area B was grazed, in August, this resulted in a rise in the nitrate-N concentration draining from this area.

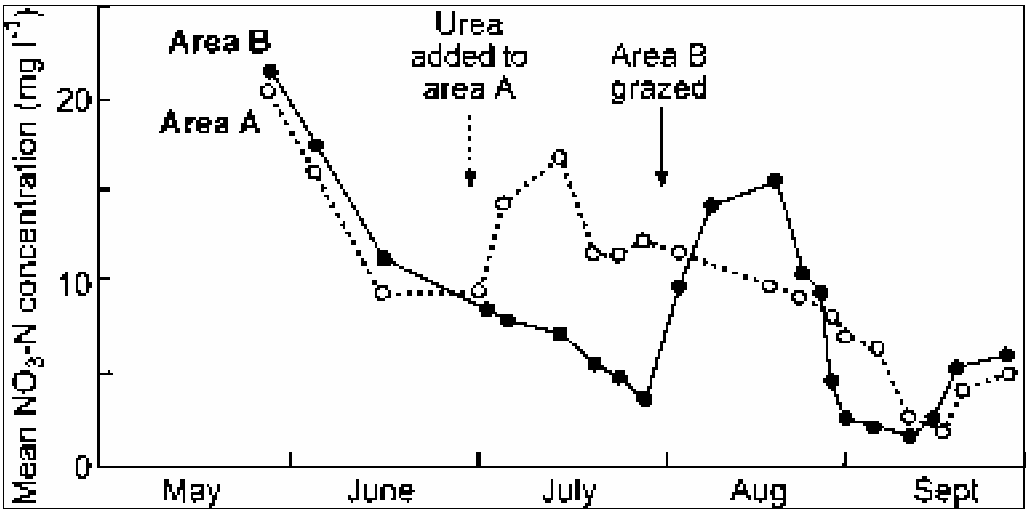


Figure 1: Nitrate-N concentrations in tile drainage discharging from two areas, with either urea fertiliser or grazing treatments (Monaghan et al. 2002)

Nitrate-N drainage data reported from Sharpley (1977) for the Manawatu region and analysed by Monaghan et al. (2002) split the drainage season into three periods: May-June, July and August (Table 2). Using these periods to analyse the potential for reduction in nitrate-N in autumn is somewhat complicated as the autumn period also includes the early winter drainage period of June. As a result, the reported periods from this study over-estimate the nitrate-N reduction in the autumn drainage flow.

Table 2: Summary of drainage volume and nitrate-N load during drainage under dairy pastures in Manawatu, Monaghan et al. (2002)

	May-June		**July**		**August**	
	Area A	**Area B**	**Area A (plus urea)**	**Area B**	**Area A**	**Area B (after grazing)**
Discharge volume (m^3/ha/4 weeks)	110	100	670	740	900	750
Mean nitrate-N concentration (g/m^3)	10.6	12.3	4.3	2.2	4.0	7.5
Load of nitrate-N (kg N/ha/4 weeks)	1.17	1.23	2.85	1.66	3.59	5.65
Percentage of annual loss in this period (%)	15	14	37	19	47	65

The nitrate-N loads drained in autumn and early winter from the two experimental sites reported by Monaghan et al. (2002) are 15 and 14%. While it is difficult to estimate what fraction is in the autumn period it is unlikely to be more than 10% of the annual loss and more likely to be in the 5% range.

4.2 2002/03 Massey University Study

A two-year study by Houlbrooke et al. (2003 and pers. comm.) in 2002/03 was established on an artificially drained Pallic soil profile (Tokomaru silt loam) to measure the impacts of intensive dairying on the quality and quantity of artificial drainage water in the Manawatu. The study had the key objective of evaluating the option of deferred irrigation of farm dairy effluent but the data can also be used to investigate the feasibility of strategic retention of drainage flows in the autumn period.

The site had eight replicated drainage plots that were managed as typical dairy farm units. Each block had its own mole-pipe drain network with an access point that enabled continuous flow monitoring and collection of drainage samples for nutrient analysis. The samplings were scheduled so that representative samples from all parts of the drainage event were sampled.

The winter of 2002 was very wet, particularly the months of June and July. Throughout the season there were 16 drainage events with a mean total drainage of 220 mm of drainage (Figure 2). The drainage which occurred over the autumn period was less than 10 mm, which is only 5% of the total annual cumulative drainage.

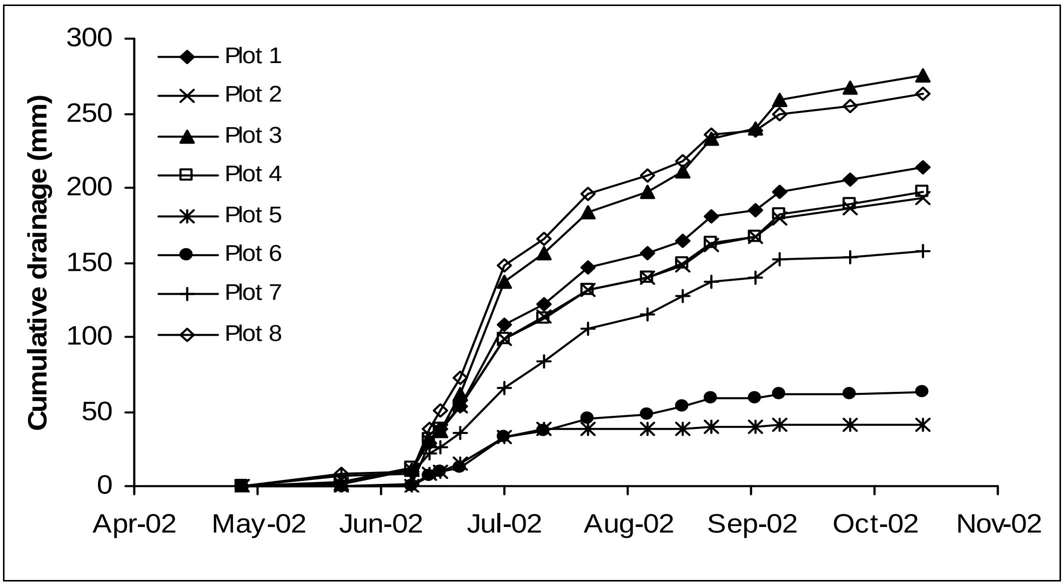


Figure 2: Cumulative drainage from the 8 drainage plots (Houlbrooke et al, 2003)

The autumn nitrate-N concentrations are the highest over the entire drainage season (Figure 3). If it is assumed that the average nitrate-N concentration of the 10 mm of autumn drainage is 22.5 mg/L, then this would equate to a loss of 2.25 kg nitrate-N over the autumn period. The annual average measured nitrate-N loss from the trial in 2002 was approximately 25.5 kg NO_3-N. The autumn fraction would represent a maximum 9% of the total annual drainage loss measured from this trial.

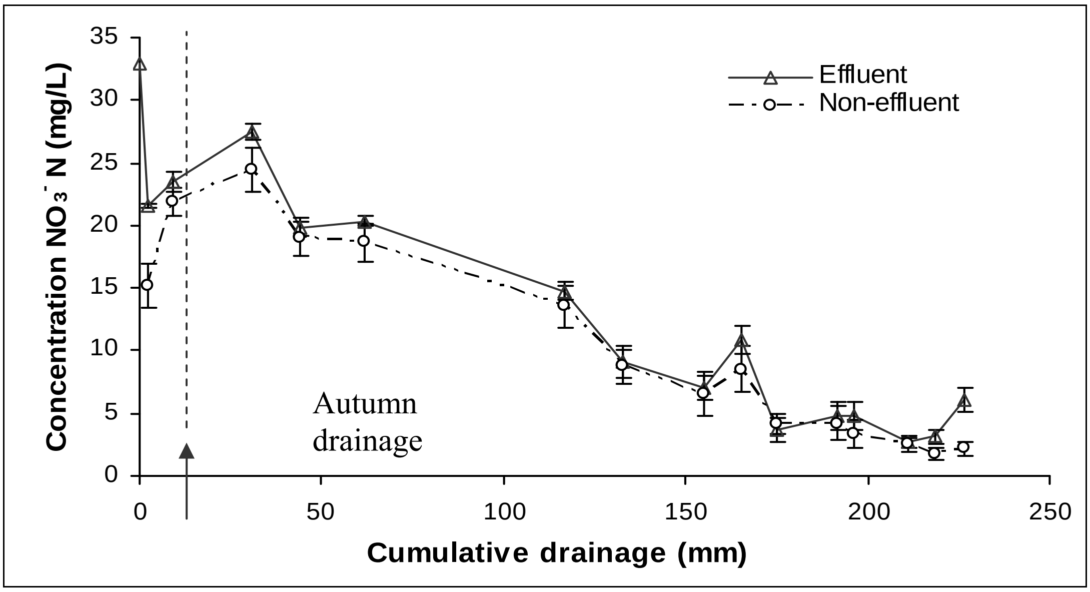


Figure 3: Trend in nitrate-N concentrations with accumulated drainage (Houlbrooke et al, 2003)

The results from the drainage monitoring showed a similar trend in 2003. The cumulative annual mean drainage from the treatments was slightly lower at 200 mm. The mean autumn drainage volume measured was only 5.2 mm or 2.6% of the total drainage volume. The trend with time in the nitrate-N concentration data was very similar to that recorded in 2002 (Figure 3), with the highest concentrations occurring in the early part of the drainage season. The average nitrate-N concentration for the autumn drainage was slightly lower in 2003 at 15 mg/L. The total mean nitrate-N leached from the treatments was close to that recorded in 2002, of 24.5 kg NO_3-N/ha. The resulting average autumn contribution to the total nitrate-N leaching is just over 1 kg NO_3-N/ha or less than 5 % of the total nitrate-N leached from the trial.

4.3 1989/91 Manawatu sheep grazed pasture trial

Magesen et al. (1996) measured nitrate-N leaching from two artificial drained treatments under sheep grazing from 1989 to 1991. They also measured the highest nitrate-N drainage concentrations in autumn with a trend of reducing concentrations as drainage continued through the winter.

In 1990, an early drainage event occurred in March: this produced on average 59 mm of drainage, which represents 19% of the annual drainage volume. Unfortunately samples were not collected from this event for analysis of nitrate-N. From when drainage commenced again on 4-29 May 1990, the drainage volume collected from the two treatments was 33 and 25 mm. This represents 12 and 11% of total annual drainage, respectively. In terms of nitrate-N load, this autumn drainage corresponded to 9 and 6 kg of nitrate-N/ha, which is 18% and 14% respectively of the annual N exported from the drainage system.

In the 1991 drainage year there was a heavy drainage event in February, where an average of 20 mm of drainage was measured from the two treatments. The drainage volume was approximately 6% of the total annual volume of drainage. In this first event an average of 4.4 kg nitrate-N/ha was leached from the treatments which represent about 10% of the total annual nitrate-N exported from the drainage system. By mid May an average of approximately 50 mm of drainage had been measured from the two treatments which represented about 15% of the total annual drainage volume. However, it is not known what fraction of the annual nitrate-N leached this represented.

Magesen et al. (1996) concluded that the nitrate-N concentration in the early drainage waters was much higher than 10 g/m^3, and that early part of the drainage should be collected separately and re-used as ‘liquid fertiliser’ or ‘fertigation’.

4.4 Southland cattle data

Nitrogen losses in artificial drainage were investigated in Southland under cattle grazed pasture by Monaghan et al. (2002a). Due to colder temperatures in Southland and lower daily evapotranspiration amounts, early winter conditions probably start in May under Southland climate conditions, as opposed to June in the Waikato.

The nitrate-N concentrations in the drainage varied considerably throughout the drainage season, although there was a general trend towards higher nitrate-N concentrations in late autumn to early winter. The nitrate-N concentrations in the drainage waters decreased to less than 5.5 mg NO_3-N/litre by spring drainage events. In May 1996 the estimated drainage was 100 mm, which represents about 27% of the annual drainage volume (366 mm/yr). The corresponding nitrate-N export over this period is estimated to be about 20% of the total N exported from the drainage system (25.6 kg N/ha/yr). However, because of climatic conditions this is probably more similar to early winter, rather than autumn conditions in the Waikato.

4.5 Toenepi drainage data

A subsurface drainage system was investigated by NIWA (R Collins, pers. comm.) and Stafford (2002), located within the dairy farm property of George Howie, 10 km southeast of Morrinsville in the Waikato region. As the data collected from this site is from the Waikato and is also used to test the drainage model described in Section 5 of this report, more information about this site is presented than for the previous data sets.

4.5.1 Site data

The layout of the drainage network, collecting drain and open ditch is shown in Appendix A.

Details of the drainage, farming system and catchment area are as follows:

Catchment area	= 3.46 ha
Spacing of the subsurface drains	= 41 m
Average depth of the subsurface drains	= 1.15 m
Size of subsurface drains	= 100 mm
Depth of drainage	= 0.8 to 1.5 m
Stocking rate	= 2.9 cows per ha
Annual mean fertiliser rate	= 100 kg N yr^{-1} (Stafford, 2002)

Drainage flow data was measured where the subsurface drain from the 3.46 ha site discharged into the open ditch. The flow gauging equipment installed was a V-notch weir with stage height monitored behind the weir. The measured drainage volume was divided by the catchment area (3.46 ha) to obtain the average drainage depth (mm). Drainage flow data was available from 8 December 1998 to 14 July 2004. Daily flow data is available for 1797 of the 2046 days in this period, which represent 88% of the potentially available data.

4.5.2 Flow Data

Flow at the site was recorded continuously at a 15-minute frequency, whilst nutrient samples were collected in proportion to flow and bulked. The timescale over which bulked samples were collected was variable, ranging from 1 to 2 hours over a short intense storm, to days during periods of low flow. Some bulked samples reflect both storm and low flows.

Measured drainage flow data is shown in Figure 4 and summarised in Table 3.

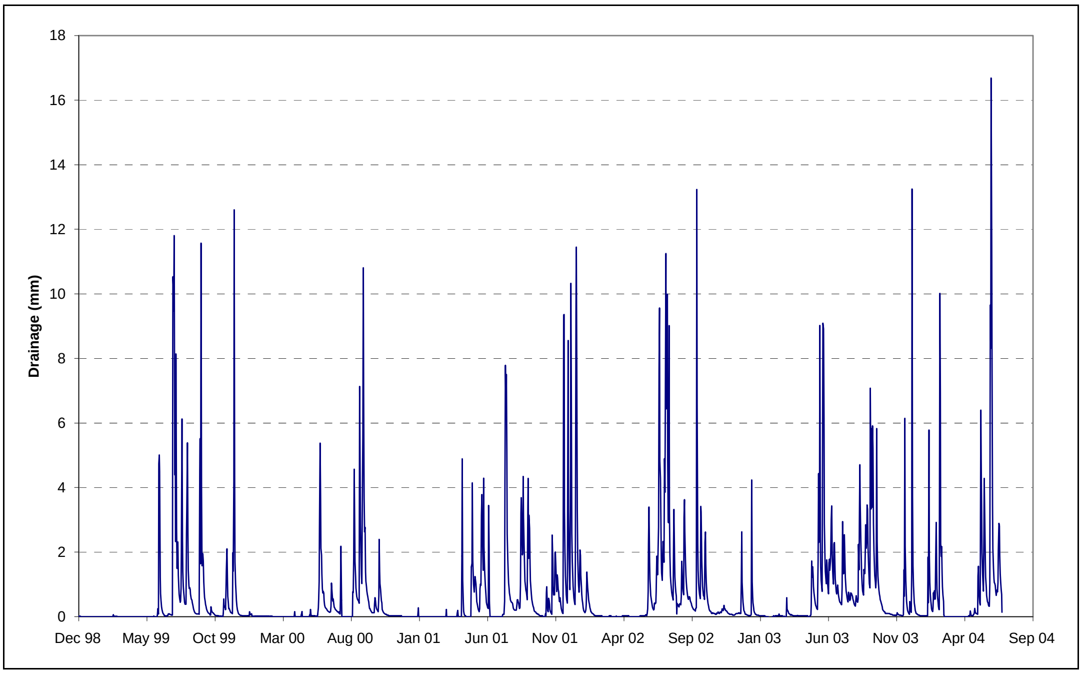


Figure 4: Measured artificial drainage flow from Toenepi from Dec 1998 to Jun 2004

Table 3: Measured drainage volume (mm) and average percentage of annual amount by season from Toenepi site

Year	Summer	Autumn	Winter	Spring	Annual total
1999	1	0	135	78	21
2000	5	1	65	64	136
2001	0	51	89	80	220
2002	106	11	181	61	358
2003	17	13	141	118	288
2004	82	33	104		
Average	**35**	**18**	**119**	**80**	**243**
As percentage of annual average	14	7	49	33	

The average annual drainage over the five years of data from the Toenepi site is 243 mm/yr. Somewhat surprisingly, 21% of the drainage occurs in either the summer or autumn periods, with twice as much (14% compared to 7%) in summer as compared to autumn during this measurement period.

4.5.3 Nitrate-N Measurements

Table 4 summarises the number of observations made in the 4½ year data set, which contains 1361 out of a possible 1642 daily estimates from the proportional bulked samples. This data set represents 83% of the possible daily values.

Table 4: Monthly summary of number of days with nitrate-N export estimates calculated from measurements of the artificial drainage from the Toenepi site

Month	1998	1999	2000	2001	2002	2003	Total
Jan		3	31		31	31	96
Feb		2	29		28	28	87
Mar		18	31	31	31	31	142
Apr		30	30	21	15	30	126
May		31	31	28	23	8	121
Jun		30	30	11	30		101
Jul		31	20	20	31		102
Aug		31	16	31	31		109
Sep		30	30	30	30		120
Oct		31	31	31	31		124
Nov		30	27	30	30		117
Dec	23	31		31	31		116
Total	23	298	306	264	342	128	1361

The nitrate-N concentrations in the flow proportional bulked samples are presented in Figure 5. The nitrate-N concentrations at this site are quite variable, but there is also a reasonable trend of decreasing nitrate-N concentrations from autumn through to winter and spring periods.

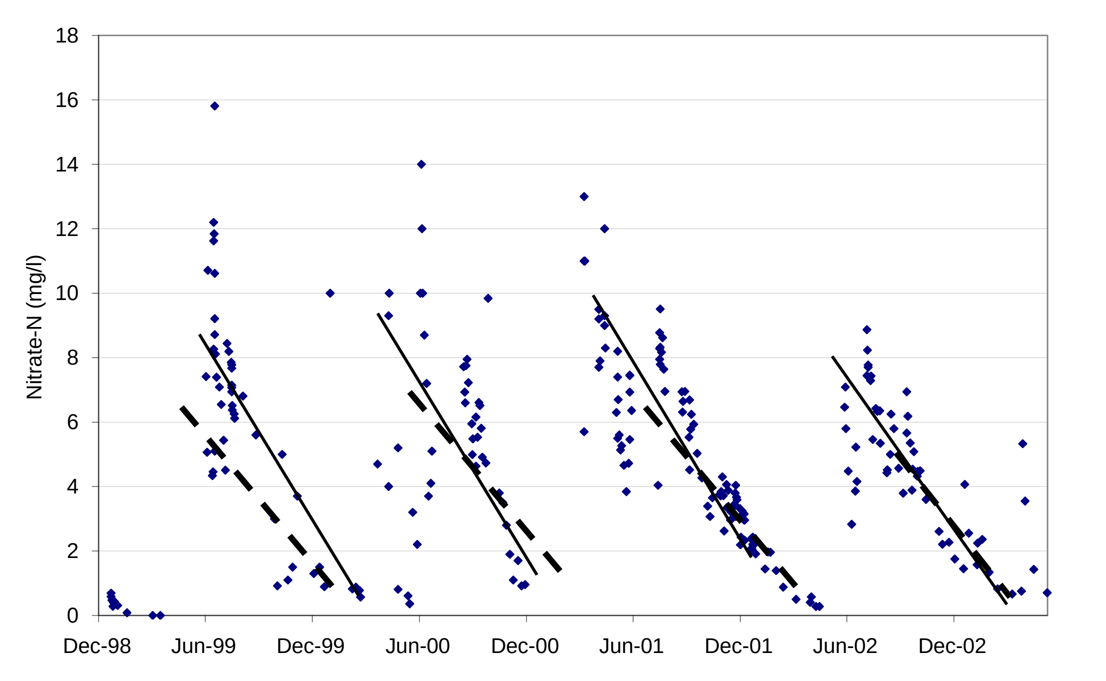


Figure 5: Measured nitrate-N concentrations in artificial drainage from Toenepi drainage site

4.5.4 Nitrate-N export

The nitrate-N export from the drainage system is calculated using the nitrate-N concentrations from the flow proportional samplings combined with the flow data. The resulting calculated loads (Table 5) from the artificial drainage system are relatively low compared to other drainage studies, with the average over the four years of sampling being 12.4 kg NO_3-N/ha/yr. This load, however, represents only the component of leaching that is being intercepted by the artificial drainage system; it has been estimated that a further 42 % of flow is leaving the site via a deeper seepage component below the artificial drain level (Barkle and McGechan, 2006).

Table 5 Nitrate-N load (kg N/ha) calculated by season from artificial drainage at Toenepi

Period	1999	2000	2001	2002	2003	Average by season
Summer	0	0.1	0	2.5	0.4	0.6
Autumn	0	0.1	3.0	0.6	0.1	0.8
Winter	9.0	5.2	6.2	12.1		8.1
Spring	1.7	3.4	3.5	3.0		2.9
Total	10.7	8.8	12.7	18.2		12.4

The estimated average nitrate-N losses via the artificial drainage system over the summer and autumn periods are only 4% and 7% (respectively) of the total annual nitrogen load exported (Table 6).

Table 6: Nitrate-N load as percentage of total load by season from artificial drainage system at Toenepi

Period	Measured seasonal nitrate-N as percentage of total nitrate-N exported in the artificial drainage system(%)				
	1999	2000	2001	2002	Average by season
Summer	0	1	0	14	4
Autumn	0	1	24	3	7
Winter	84	59	49	66	64
Spring	16	39	28	16.5	25

5 MODELLING STUDY

The COUP model was considered the most appropriate tool to use to extend the five year measured data set of nitrate-N leaching at Toenepi to a longer time series. Aqualinc is currently developing and testing this model as part of an on-going project looking at estimating nitrate-N export from artificial drainage at a catchment scale.

For the model to be considered as suitable it needed to accurately describe the onset of autumn drainage and the leaching losses at this crucial shoulder time. The previous work (Barkle et al., 2006) of extending the COUP crop growth model to represent a grass/clover pasture grown under New Zealand conditions is briefly summarised below.

The simulated nitrate-N losses from the drainage system have then been compared to measured data to ascertain if the COUP model has the required accuracy to extrapolating the measured drainage data over a longer 25-year period.

5.1 Model input parameters used

Required weather data for the COUP model are mean air temperature, rainfall, evapotranspiration (PET) and global radiation. The data for the validation period was predominately obtained from NIWA and Lincoln Environmental Research meteorological stations within the Toenepi catchment. However, where these data were not available, and for the 25-year extended simulation, data from Ruakura climate station was used. Soil data used was reported by Stafford (2002) and/or Singleton and Addison (1996).

The soil chemistry data was either estimated from data contained in Singleton andand Addison (1996) or literature values. Other biological parameters or rates for N fixation, denitrification, nitrification, mineralisation and so on are based on literature data or values suggested in the COUP documentation.

Representation of N additions to the soil surface from dairy cows, both inorganic ammonium N from urination and organic N from defaecation, was based on assumptions for dairy cows used in previous simulation study (McGechan and Topp, 2004). Inorganic fertiliser was added in the quantities and on the dates specified by the farm manager.

5.2 Predicted Versus Measured Pasture Production

Above ground pasture biomass production rates and herbage composition on the Howie farm have been measured by AgResearch from 10 July 2002 until 1 August 2005 (A McGowan, pers. comm.). Standard field methods for measuring pasture biomass growth rates using two exclusion cages in two replicated paddocks (Paddock 2 and 11 – see Appendix A) were used. Herbage samples have been analysed for nitrogen content, from which an estimate of the pasture N removal could be made. Biomass growth rate measurements and herbage analyses had been carried out approximately 12 times per year.

Results comparing simulated and measured N yields for the measurement dates are shown in Figure 6. In general, the simulations slightly overestimate pasture biomass (kg DM/ha) removal and slightly underestimate the N removal.

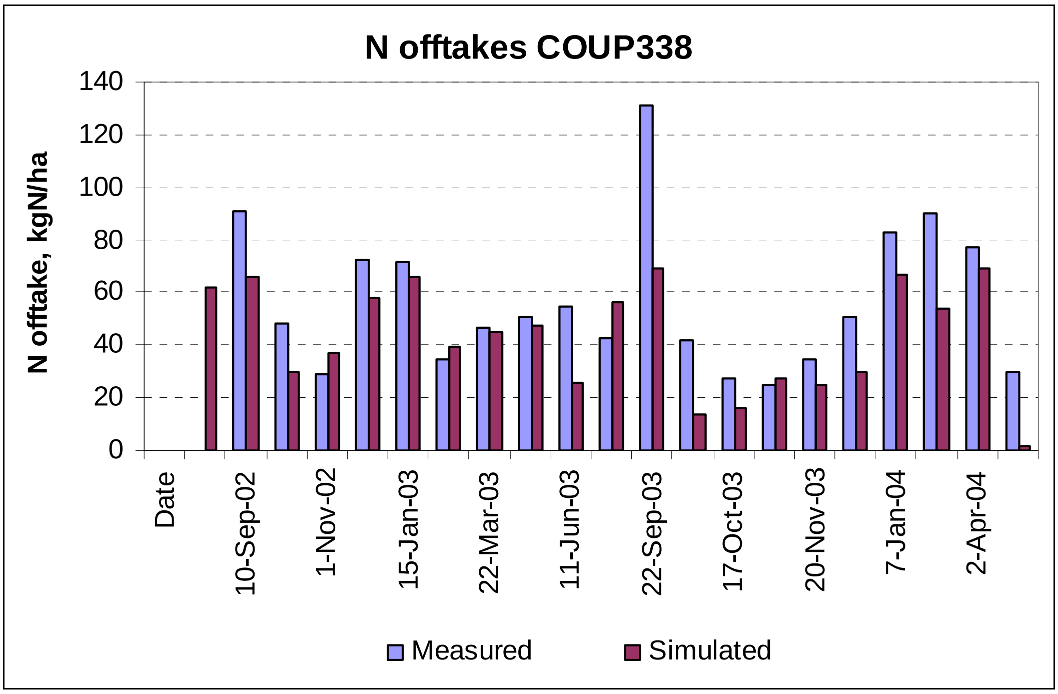


Figure 6: Simulated and measured dry matter removal in grazed pasture

5.3 Predicted versus measured artificial drainage flows

A dual soil hydraulic conductivity scheme has been modelled for the drainage system. One component represents the soil matrix flow. A second component, which is a higher value of hydraulic conductivity, is used to specify the saturated flow conditions that occur through macro-pores in the soil profile. The matrix conductivity is based on the rather low, clay like, hydraulic conductivity data measured by Stafford (2002). The macro-pore flow, which represents the installed mole drains as described by Monaghan et al. (2001) is based on the higher hydraulic conductivity data reported by Singleton and Addison (1996).

The simulated subsurface drainage is compared against the measured daily flow data, as shown in Figure 7. The statistics of the simulated versus the measured drainage fluxes, for the period from December 1998 to July 2004, are summarised in Table 7. Only where measurements of the daily drainage rate exist is the comparison made between simulated and measured values.

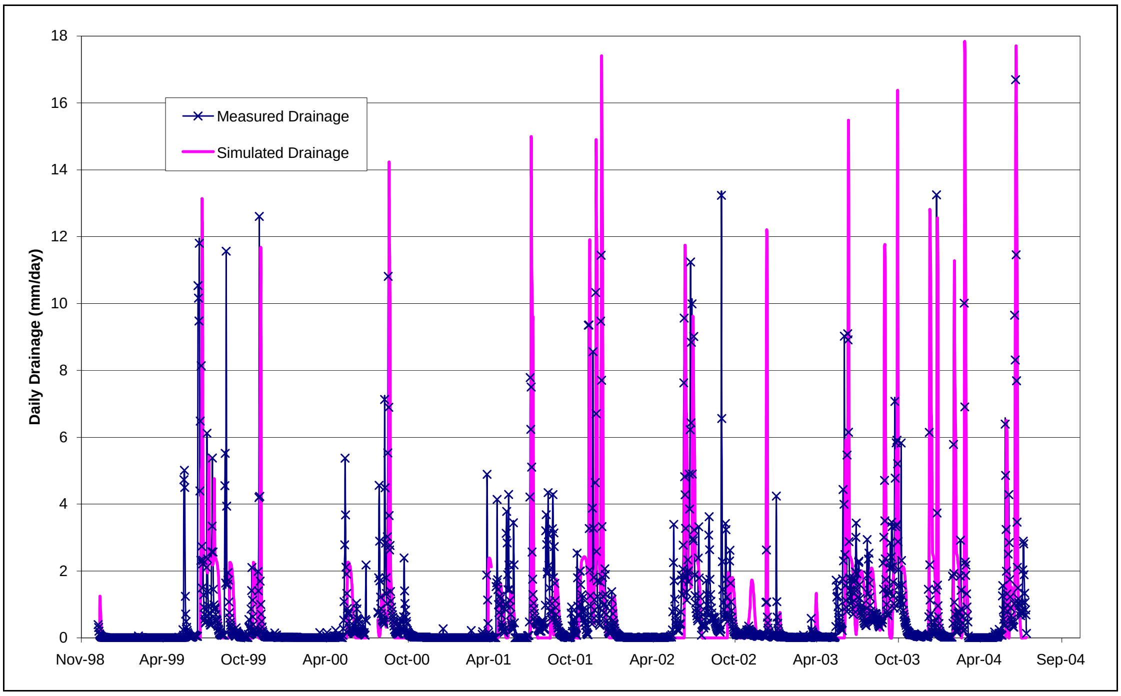


Figure 7: Simulated subsurface drainage compared to the measured data (on an event basis for the Howie artificial drainage system)

Table 7: Statistics of measured and simulated flows from the subsurface drainage system

Parameter	Measured	Simulated
Maximum daily drainage (mm/day)	16.7	17.7
Mean daily drainage (mm/day)	0.80	0.85
Standard deviation (mm/day)	1.71	2.20
Total drainage (mm)	1,434	1,522
Average deviation (mm/day)	0.05	
Standard error (mm/day)	2.21	

The simulated cumulative volume of subsurface drainage over the 5½ years agrees very well with the measured data (Table 7). The ratio of the cumulative measured to predicted drainage of 0.94 is very close to the range for simulation studies of this type, which vary between 0.95 to 1.28 (Barkle et al., 1998). The predicted and measured drainage components from individual events can also be seen to be in good agreement (Figure 7). The daily maximum simulated value (17.7 mm) is very close to the measured maximum (16.7 mm). The average daily deviation between measured and simulated drainage was only 0.05 mm/day, which is extremely good. The temporal dynamics of the simulated drainage processes are also reasonably accurate, indicated by the good correlation of the simulated and measured drainage events shown in Figure 7.

5.4 Simulated Nitrate-N Export in Artificial Drainage Fluxes

Using the grass growth model as described in Section 5.2 of this report and the flow predictions (Section 5.3), COUP simulated the nitrate-N export, via the subsurface drainage system for the period from December 1998 through to May 2003 (Figure 8). It should be noted that only where measured data is available is the comparison made between the measured and simulated values.

Very little calibration of the carbon and nitrogen parameters which describe these processes in the COUP model has been attempted. Parameter values used are largely based on literature or suggested values in the model documentation.

The model was able to predict the relatively low level of leaching that was measured via the subsurface drainage system at this site. The dynamics of the simulated and measured data are similar between the two sets of data and the predicted amount leached on an event basis in reasonable agreement (Figure 8; note for conversion 10 x 1g N/m^2 is 1 kg N/ha).

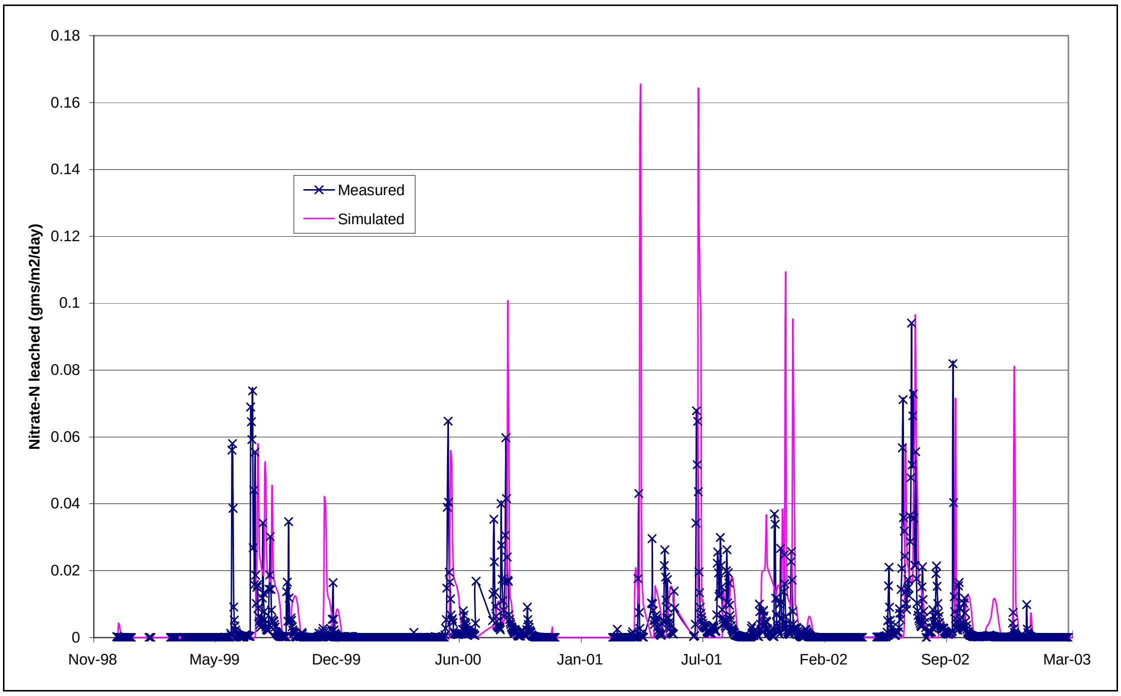


Figure 8: Simulated daily nitrate-N export (g/m^2/day) compared to measured daily amounts from December 1998 through to May 2003 (note, only where measured data was available is the comparison made with the daily simulated data)

On a seasonal basis, the measured and simulated nitrate-N export (kg nitrate-N/ha) data are shown in Table 8. In general, the simulated nitrate-N leached in the subsurface drainage system is greater than that measured, with the average three monthly deviation between simulated and measured nitrate-N being 1.7 kg N/ha. The bias in over estimation in nitrate-N export can be seen in Figure 8 with, unfortunately, the greatest errors in individual events associated with the prediction of autumn export of nitrate-N from the drainage system. The greatest deviation over any three-month period was in summer 2002 of 6.4 kg nitrate-N/ha.

Table 8: Measured and simulated nitrate-N (kg NO_3-N/ha) exported from artificial drainage on a seasonal basis over five years

Period	Measured annual nitrate-N (kg NO_3-N/ha)						
	1999	**2000**	**2001**	**2002**	**2003**	**Seasonal average**	**Percentage of annual**
Summer	0.0	0.1	0.0	2.5	0.4	0.6	4.8
Autumn	0.0	0.1	3.0	0.6	0.1	0.8	6.1
Winter	9.0	5.2	6.2	12.1		8.1	65.6
Spring	1.7	3.4	3.5	3.0		2.9	23.4

Period	Simulated annual nitrate-N (kg NO_3-N/ha)						
	1999	**2000**	**2001**	**2002**	**2003**	**Seasonal average**	**Percentage of annual**
Summer	0.2	0.7	0.0	8.9	2.8	2.5	13.9
Autumn	0.0	0.0	7.8	0.0	1.0	1.8	9.7
Winter	9.4	5.4	8.7	10.6		8.5	46.9
Spring	4.6	4.0	8.1	4.8		5.4	29.6

The predicted average summer nitrate-N leaching from the model was 2.5 kg NO_3-N/ha, while the measured amount was only 0.6 NO_3-N/ha. In autumn, a better agreement was obtained where the predicted nitrate-N leaching was 1.8 kg NO_3-N/ha compared to the measured amount of 0.8 kg NO_3-N/ha. As a percentage of the annual amounts the measured summer/autumn leaching represented 11.0%, whereas the predicted amount was over twice this amount of 23.6%. This would indicate that while on an annual basis the nitrate-N losses from the model are reasonable, the model predictions are not reliable enough during the critical summer and autumn periods to extrapolate the measured data out for extended periods. For these reasons it is recommended that the COUP model should not be used to ascertain the longer term viability of strategic retention of drainage flows as a mitigation option.

6 SUMMARY

A mitigation strategy of retaining any drainage flows in the soil profile during autumn has been suggested as a possible option for reducing nitrate-N leaching from artificial drainage under dairy farming in the Waikato.

In most drainage studies the highest nitrate-N concentrations occur in the early drainage events in autumn and then decline through to spring. This, however, is not the case if nitrate-N generating processes such as fertilizer or grazing occur, which increases the size of the potential leachable nitrate-N pool.

The maximum potential nitrate-N that could be removed via strategic autumn retention is estimated to be 10% of the annual nitrate-N that is exported through the artificial drainage system (Table 9).

Table 9: Summary of potential nitrate-N exported in autumn drainage from artificial drainage systems (various literature sources)

Data source	**Trial period**	**Reported as**	**Estimated maximum potential for Waikato in autumn period (%)**
Manawatu dairy 1977	2 trial year	For May and Jun, 14 and 15%	7.5
Manawatu dairy 2002-03	2 years	For May, 9 and 5%	7
Manawatu sheep 1989 - 91	6 trial years	For May, 18 and 14%	15
Southland cattle 1996	1 year	For May, 20%	10
Waikato dairy 1999 - 2003	4.5 years	Jan to May, 0, 2, 24, 17%	10

While it is difficult to estimate what fraction of this potential would be realised in the field using this strategy, it is unlikely to be more than 50%. This would indicate that only about 5% of the nitrate-N exported from artificial drainage would be removed by implementing a strategy of strategic retention of drainage waters.

However, as nitrate-N concentrations in drainage waters are related to fertiliser application, grazing patterns, soil water characteristics, and weather patterns, without field trials this estimate should be treated as an indicative value only.

Due to the complex interactions between soil, plant, animal and fertiliser, existing modelling tools are not at this stage considered accurate enough to be able to improve on this estimate.

While this strategy of strategic retention of drainage flow can be implemented relatively easily on-farm, it still requires a reasonable input of resources for farmer education and promotion before it is likely to be widely adopted. The implementation of the strategy also somewhat increases the risk of short-term flooding, but with good management this risk should be minimal. However, as the benefit in nitrate-N reduction is limited, Environment Waikato should not invest significant resources in its promotion as a high profile drainage management strategy. Regardless, it does have a place amongst the possible management strategies that could be considered as best management strategies for farmers wanting to reduce nitrate export from artificial drainage systems.

7 REFERENCES

Barkle, GF; Brown, TN; Singleton, PL; Painter, DJ (1998): Hydrology models DRAINMOD and SWIM applied to large soil lysimeters with artificial drainage. *Australian Journal of Soil Research* **36:**783-97.

Barkle, GF; McGechan M (2006): Quantification of nitrate-N export from subsurface drainage in the Toenepi catchment – Phase 2: Development and testing of a grazed pasture model. Report No H06001/1. Aqualinc Research Ltd.

Houlbrooke DJ; Horne, D; Hedley, MJ; Hanley, JA; Snow, VO (2003): The impact of intensive dairy farming on the leaching losses of nitrogen and phosphorous from a mole and pipe drained soil. Dairy[3] Conference, Massey University, held in Rotorua April 2003.

McGechan, MB and Topp, CFE (2004): Modeling environmental impacts of disposition of excreted nitrogen by grazing dairy cows. *Agriculture, Ecosystems and Environment* **103:**149-164.

Magesan, GN; White, RE; Scotter, D (1996); Nitrate leaching from a drained, sheep-grazed pasture, I-Experimental results and environmental implications. *Australian Journal of Soil Research* **34**:55-67.

Monaghan, RM; Paton, RJ; Drewey, JJ (2002a): Nitrogen and phosphorus losses in mole and tile drainage from a cattle-grazed pasture in eastern Southland. *NZ Journal of Agricultural Research* **45**:197-205.

Monaghan, RM Horne, D; Hedley, M; Nguyen, L (2002b); Subsurface drainage review - Water and contaminant loads from artificial subsurface drainage system in New Zealand. Prepared for Fonterra Research Centre. AgResearch Ltd.

Monaghan, RM; Drewey, JJ; Thorrold, BS; McGowan, A; Smith, LC; Roach, C (2001): Best practices dairying catchments for sustainable growth. NZ Pastoral Agricultural Research Institute Ltd.

Nguyen, ML, Eynon-Richards, N; Barnett, J (2002): Nitrogen removal by a seepage wetland intercepting surface and subsurface flows from a diary catchment in Waikato. *In: Dairy farm soil management* (Eds L Currie and P Loganathan), Occasional Report No 15. Fertilizer and Lime Research Centre. Massey University. Palmerston North.

Sands, GR (2001): Feasibility of controlled drainage for mitigating nutrient loss from tile drainage systems in South Central Minnesota. WRC Research.

Sharpley, AN (1977): Sources and transport of phosphorus and nitrogen in a stream draining a dominantly pasture catchment. PhD thesis. Massey University.

Singleton, PL and Addison, B (1996): Water quality in a dairy farming catchment – Distribution and hydraulic characteristics of the Topehaehae soil. AgResearch Ltd.

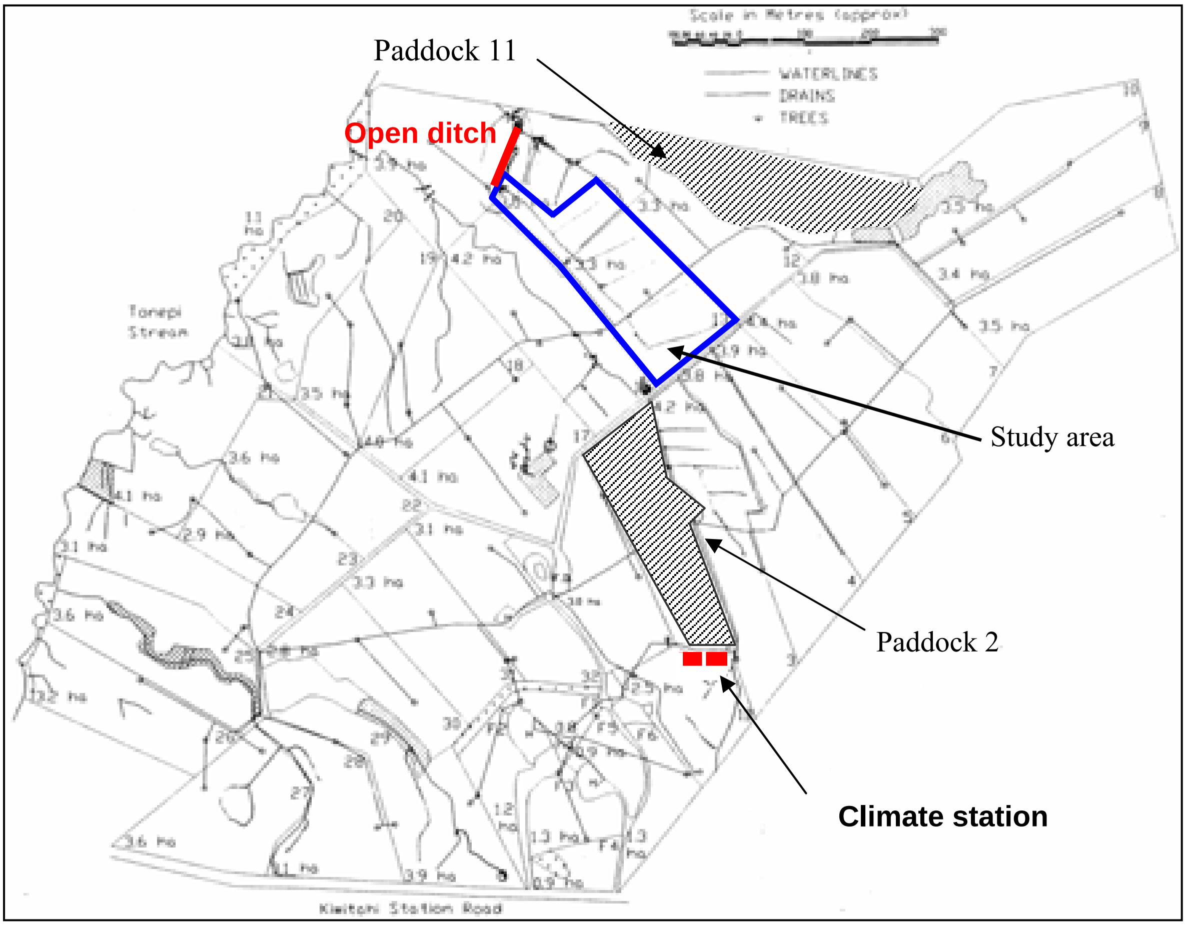
Singleton, PL; McLay, CDA; Barkle, GF (2001): Nitrogen leaching from soil lysimeters irrigated with dairy shed effluent and with managed drainage. *Australian Journal of Soil Research* **39**:385-396.

Stafford, AD (2002): Drainage water and nutrient losses from a Waikato dairy farm. MSc (Earth Sciences) Thesis, University of Waikato.

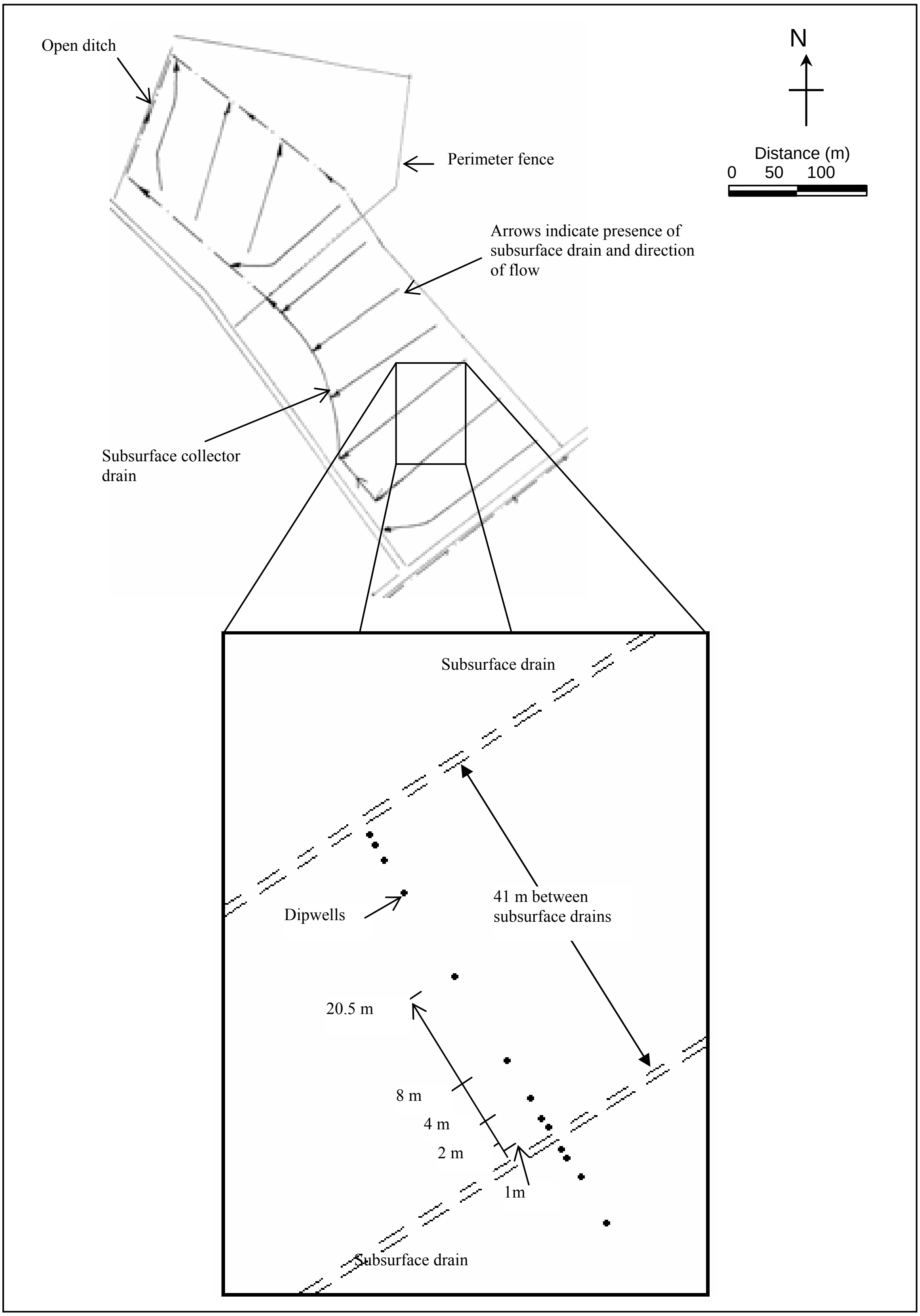
Tanner, CC Nguyen, ML; Sukias, JPS (2002): Last ditch effort to reduce nutrient export from drained pastures using constructed wetlands. In *Dairy farm soil management* (Eds L Currie and P Loganathan), Occasional Report No 15. Fertilizer and Lime Research Centre. Massey University. Palmeston North.

Wilcock, RJ; Nagels, JW; Rodda HJE; O'Conner MB; Thorrold BS; Barnett, JW (1999): Water quality of a lowland stream in a New Zealand dairy farming catchment. *New Zealand Journal of Marine and Freshwater Research* **33**:683-696.

Appendix A: Layout of Toenepi study area



Location of the catchment and study area (modified from Stafford, 2002)



Layout of subsurface drainage, collector drains and open ditch (Stafford, 2002).