Current research related to dairy farm effluent management in New Zealand[1]

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Within the last two decades milk production in New Zealand has increased by 65%, yielding 8603 million litres (excluding town milk supply) during the 1993-94 season (Dairy Statistics 1993-1994). This may not be surprising because a similar increase occurred in average herd size (112.2 to 187.5). However, herd numbers have declined by 21% (18540 to 14597) which means that dairy farming in New Zealand is becoming more intensive through an increase in effective grazing area and stocking rates (currently 77 ha and 2.5 cows ha^{-1} respectively). From an economical viewpoint these figures are very encouraging considering our farmers do not rely on farm subsidies unlike their European or American counterparts. However, in order to continue to compete with the overseas farmers for market access and to develop dairying as a sustainable farming industry our farmers must adopt environmentally sound farming practices.

There are many aspects of New Zealand dairy farming practices that require environmental evaluation. To some extent this has been acknowledged by our dairy industry and hence the recent formation of the **Dairying and Environment Committee (DEC)**. This committee currently comprises members from the **NZ Dairy Research Institute (NZDRI)**, **Livestock Improvement Corporation**, **Dairy Research Corporation (DRC)** and **Federated Farmers** and is facilitated by **NZDRI**. One of the objectives of the DEC is to improve dairy farm effluent management. This objective is also shared by the wider scientific community as reflected by the number of proposals on the amount of dairy farm effluent management related research during the last Foundation for Research, Science and Technology (FRST) bidding. Regional councils are also concerned about dairy farm effluent mainly as a potential contaminant of water environment. Since there are several parties interested in sustainable dairy farm effluent management it is difficult to know the extent and the type of research carried out in New Zealand. This article is an attempt to present the current dairy farm effluent related research to New Zealand scientists. I invite other researchers or research facilitators to take the opportunity to report any dairy farm effluent research that has not been presented here.

I. DAIRY FARM PONDS

Although there is a general trend towards dairy farm effluent irrigation systems, many dairy farms in New Zealand still use dairy farm ponds as a preferred treatment system. For example, despite the rapid conversion from dairy farm ponds to irrigation systems in the Waikato region (> 1000 farms within the last two years) about 50% of dairy farmers (approximately 3000 farms) are still using dairy farm ponds as treatment systems. Operational inconvenience, poor technological transfer and high capital cost related to effluent irrigation management and unsuitable soil or climatic conditions explain the relatively greater use of dairy pond systems in New Zealand. Moreover, a recent review on dairy farm ponds by MAF Agriculture Policy (1994) concluded that dairy farm ponds were the best practical option as a 'waste' treatment

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system for New Zealand dairy farmers whilst recommending further dairy farm pond research. Consequently, research related to the performance of dairy farm ponds or the impact of dairy ponds on the environment is considered very useful.

1. Primary/secondary treatment systems

1. Dairy farm pond performance survey

There have been several dairy farm pond surveys conducted by certain regional authorities in New Zealand (e.g. Grogan, 1990 and TRC Technical Report, 1990). Hickey *et al.* (1989) collated pond survey data from Southland and Manawatu and concluded that there was considerable variation in pond effluent characteristics with time and among different ponds. They recommended that for most surface water uses a dilution of at least 250 fold is required to discharge dairy farm pond effluent into waterways. Since a similar pond survey has never been conducted in the Waikato region, it has been decided to undertake a long-term pond survey. The objectives of the survey are: (a) to assess the quality of anaerobic and aerobic pond discharges; (b) compare different pond treatment systems (e.g. barrier ditches, two pond systems and three pond systems); (c) assess seasonal variation in pond performance (d) examine the effect of dairy shed management on pond performance; and (e) assess the extent of nitrification (ammonium-N $\rightarrow$ nitrate-N) in aerobic pond systems.

Currently, a total of 20 pond systems are surveyed by **Environment Waikato** in the Waikato region on a bimonthly basis during each milking season. The survey was started during the 1993-94 milking season. The project is funded and run by Environment Waikato.

2. Mechanical aeration of dairy farm ponds

It is well known that aerators are widely used to treat sewage and certain industrial waste waters. There is no reason why aerators should not enhance dairy farm pond performance. Data obtained from DRC dairy farm pond systems installed with aerators (to minimise odour) indicated that nutrient polishing could be performed effectively using aerators. For example, contaminants such as BOD_5 (Biochemical Oxygen Demand during a 5 day incubation) and ammoniacal-N were reduced to low levels in aerated ponds (20-30 g m^{-3}). In contrast, Environment Waikato's regional pond survey indicated that a conventional dairy farm pond discharge has more than 100 g m^{-3} of BOD_5 and ammoniacal-N. Moreover, a similar pond survey also showed that both anaerobic (first pond) and aerobic (second pond) pond discharges did not contain any nitrate-N. The reason for the absence of nitrate in dairy farm ponds could be either: (a) the ponds are anaerobic and hence the pond environment is not conducive for generating nitrate, or (b) nitrate may be produced in the second pond, but denitrified rapidly. Environment Waikato's preliminary work with AgResearch microbiologists showed that nitrifiers are present in the second pond. Further tests have to be carried out to confirm this finding.

A mechanical aeration study is being carried out by the **National Institute of Water & Atmospheric Research Ltd (NIWA)** in the Waikato region. A second dairy farm pond (aerobic pond receiving effluent from a 400 cow herd) has been divided into two halves using a polyethylene barrier. One half is mechanically aerated, and nutrient, BOD_5 and bacterial levels are monitored from both halves on a regular basis. Preliminary results obtained over the last 6 months have been very promising. For example, BOD_5 levels were reduced below 40 g m^{-3} and high nitrification was achieved dropping ammoniacal-N levels to < 5 g m^{-3}. Detailed monitoring of pond processes in the untreated pond suggests that the presence of algae could strongly influence pond performance. Further aeration studies are planned to investigate the use of intermittent aeration. Intermittent aeration should be performed mainly during the night, taking advantage of the oxidation by algae during the day time. Intermittent aeration is also believed to increase denitrification potential and hence removal of nitrate from the system. The study is funded by the **DEC** and facilitated by the **NZDRI**.

3. Extended aeration activated sludge system
Traditional activated sludge systems require a treatment plant and systematic operation. Obviously such a system is not appropriate for dairy farm effluent treatment. However, **Waste Solutions Ltd** scientists propose that activated sludge designed with intermittent cycle operation could be used to treat dairy farm effluent effectively. The system designed to treat dairy farm effluent comprises a mechanically aerated pond (controlled by a timer), settling periods, and decant and discharge. The study will investigate the treatment efficiency of the proposed system to treat both raw dairy farm effluent and discharge from an anaerobic pond.

2. Tertiary treatment systems

Tertiary dairy farm effluent treatment systems aim to improve the quality of a dairy farm pond discharge where major contaminants are BOD_5, suspended solids (SS), N, P and bacteria. High BOD_5 is caused by the presence of high levels of organic-C and ammoniacal-N. If water quality is to be improved all these contaminants should be reduced substantially before discharging into waterways.

1. Use of zeolite as an effluent treatment material
Zeolite has many fold greater capacity to adsorb ammoniacal-N than clay and organic matter found in soil. **NIWA** (FRST 94-NIW-29-081) is investigating the possibility of using zeolite beds to reduce ammoniacal-N in dairy pond discharges. If the ammoniacal-N binding capacity of the zeolite beds could be 'regenerated' by stimulating microbial processes then such a system could provide sustainable ammoniacal-N removal. The use of effluent level fluctuations to promote sequential aerobic and anaerobic conditions to stimulate nitrification and denitrification respectively is being investigated.

2. Constructed wetland systems
The main objective of the study is to provide dairy farmers with another tertiary treatment system that is easy to manage without involving substantial capital and running cost. Several constructed wetland trials (at Ruakura and several dairy farms in the Waikato region) have been studied by **NIWA** (FRST 94-NIW-03-105) intensively in the past 3 years. Some of these studies have been funded by **Environment Waikato** and **NZ Dairy Board**. Results to date suggest that constructed wetlands can significantly reduce the BOD_5 and SS levels of pond discharges. High levels of ammoniacal-N removal will require either relatively large wetland areas or improved pretreatments in ponds. As wetlands are effective environments for denitrification they may be ideal for use in combination with mechanical aeration of oxidation ponds. A key problem encountered during the study was the slow plant establishment in constructed wetlands due to the continuous interference by pukekos (*Porphyrio melanotus*) to growing plants. Plants are often either uprooted or regenerating tips are grazed by these birds. Effective means are required to prevent pukekos from damaging newly planted wetlands.

3. Recyclable nutrient traps to improve dairy farm effluent quality
A trial at Massey University indicated that ammonia released from poultry manure was readily absorbed by bark materials (Mahimairaja *et al.*, 1993). Recyclable nutrient traps will be used to investigate a method to further polish nitrogen (ammonium-N) and reactive-P from a dairy farm pond discharge. Materials with high CEC such as finely ground pine bark will be used to absorb ammoniacal-N whilst materials with high P fixing capacity (naturally available materials with high P fixing capacity are still being investigated) will be used to remove reactive-P. A major proportion of this study is also funded by **Environment Waikato** through the **Massey University Agricultural Research Foundation (MUARF)** and conducted by the **Department of Soil Science**, **Massey University**.

3. Dairy ponds and the environment

1. Dairy farm pond seepage study
Through Environment Waikato's pond performance survey it has been found that many dairy farm pond systems in the Waikato region do not discharge. Most systems that discharge effluent during most of the milking season do not discharge during dry periods. Although non-discharging pond systems are preferable because of reduced effluent loading into waterways during low flow periods, the impact of pond seepage on ground water quality cannot be ignored.

A long-term step by step study is being performed by **Lincoln Ventures** on ponds constructed in the Hinuera area where pond seepage is common. The objectives of the study are to (a) assess the quantity and quality of effluent seeping into ground water, (b) assess the effect of seepage on ground water quality; and (c) examine the role of sludge accumulation on the extent of seepage. The research is fully funded by **Environment Waikato**.

II. EFFLUENT IRRIGATION

Effluent irrigation is one of the best options available for dairy farmers to effectively manage dairy farm effluent. This option not only encourages the concept of efficient nutrient cycling, but also effectively removes the adverse effects of direct discharges on waterways. Even in the worst case of effluent irrigation, a substantial amount of BOD_5, SS, P, N and bacteria is filtered by soil. Effluent irrigation may minimise requirements for effects monitoring. Consequently, some regional councils have allowed dairy farm effluent irrigation as a permitted activity whilst still maintaining dairy farm ponds as discretionary activity. Permitted activities do not require either resource consents or annual payment of administration fees. However, permitted activities still have to comply certain conditions. For example two of the several conditions for dairy farm irrigation imposed by Environment Waikato require that effluent application should not exceed a total-N loading of 150 kg ha^{-1} y^{-1} and a hydraulic loading of 25 mm per application (Environment Waikato, 1994).

It is predicted that New Zealand may develop different sets of regulations in different regions. For example, Environment Waikato has prescribed an annual loading rate of 150 kg N ha^{-1} for dairy farm effluent irrigation Canterbury and Auckland Regional Councils support 200 kg N ha^{-1}. The main reasons could be different geographical and political differences, and the extent of information available on environmental issues to regional councils. The latter could be resolved by effective communication with other regional councils and research agencies and by acquisition of quality information.

1. Effluent characterisation

1. Characterisation of untreated effluent

Until now most N loading rate estimates for dairy farm effluent irrigation have been based on the information obtained from the *Agricultural Waste Manual* (Vanderholm, 1984) (i.e. 10.4 g N cow^{-1} d^{-1}). The quality and quantity of dairy farm effluent could be significantly different from that studied a decade ago. Policy makers who are desperately in need of information may be willing to use limited or poor information. A recent example is where MAF Agriculture Policy (1994) used 49.3 g cow^{-1} d^{-1} as the amount of N excreted in the dairy shed. This figure was calculated from the herbage, animal, milk production and herd management data (Southland Regional Council, 1993) rather than obtained through chemical analyses of the effluent.

A project was started during the last milking season (1993-94) to assess raw effluent quality on a monthly basis from 10 dairy farms in the Waikato region. The project will estimate the volume of effluent and nutrients such as N (cow^{-1} d^{-1}) produced during milking operation. One of the problems encountered with such a study is obtaining a representative raw effluent sample. This has been overcome by effluent sampling from farms that use tankers to collect raw effluent for land application. The study will recommend to farmers the average area required for raw dairy farm effluent irrigation. The study will also examine the variation in quality and quantity of effluent produced among farms and among seasons (e.g. spring vs summer) and the reasons for such variation. The project is funded and run by **Environment Waikato**.

2. Characterisation of untreated and treated (anaerobically) effluent

This study has already been completed by **AgResearch**. An effluent survey was carried out during summer 1993. More than 40 sites were sampled to characterise the effluent quality from anaerobic ponds (first pond after thorough mixing) and from dairy sheds. The objective of the study was to determine the fertiliser value of treated and untreated effluent. The results showed that the land area required for dairy shed effluent irrigation is approximately 8 ha for a 200 cow herd farm @ 150 kg N ha^{-1} y^{-1} and the average nitrogen excreted in the Waikato as 20 g N cow^{-1} d^{-1}. The survey also shows that if dairy farm effluent is irrigated @ 150 kg N ha^{-1} y^{-1}, the fertiliser value of the effluent will be approximately \$300 ha^{-1}. This estimate considers N, P and K.

2. Effluent irrigation and the environment

1. Mineralisation of effluent organic nitrogen

A major proportion of nitrogen in dairy farm effluent is in organic form (e.g. urea, protein). Urine-N (mainly urea) rapidly hydrolyses and volatilises as ammonia leaving some ammoniacal-N in the effluent. This process is generally complete within few hours of urination. However, the formation of ammoniacal-N from dung-N is a slow process which requires microbial decomposition (mainly ammonification). Urea-N transformation in soil has been studied extensively in New Zealand and overseas. However, there is little information available on dung-N transformation in soils irrigated with effluent. The long-term pot trial by **Lincoln**

Ventures (FRST No. 94-AEI-29-433) examines organic-^{15}N transformations under pasture at two soil moisture levels for three soil horizons under controlled conditions.

2. Land treatment of dairy farm effluent using short rotation tree crops
The objective of the study is to irrigate dairy farm effluent onto short rotation tree crops such as *Eucalyptus spp* and *Salix spp* and examine the economic returns. The study is already underway and performed at **Massey University** by a masterate student under the supervision of the **Agricultural Engineering Department**. Evapotranspiration rates, soil nutrient levels, soil infiltration rates and plant yields will be monitored in the field at two N loading rates (i.e. 75 and 150 kg N ha^{-1}). Pot trials will also be carried out to examine nutrient removal efficiency under four different hydraulic loading rates (i.e. 0, 15, 30 and 45 mm per fortnight). The study is funded mostly by **Environment Waikato** through the **MUARF**.

3. Nitrogen removal through denitrification from land application of effluent
Landcare Research NZ Ltd (FRST 94-LCR-29-149) in collaboration with **Lincoln Ventures** (FRST No. 94-AEI-29-433) and **AgResearch** is investigating denitrification and N cycling in soils irrigated with dairy farm effluent. The effect of controlling water table height in soil is being investigated. More recently Lincoln Ventures (in collaboration with Landcare Research NZ Ltd) is developing a N model which could be used to predict N transformation processes. The current work is partially funded by **Environment Waikato**.

The initial results from this project indicate that when dairy farm effluent is applied (weekly application) to a poorly drained soil (Te Kowhai) with a perched water table, substantial amounts of organic-C are leached beneath the water table. Although the soil has the potential to produce a large amount of nitrate, there was little or no nitrate found in ground water. The work also shows that effluent applied can enter ground water via preferential flow pathways present in this soil type. The work demonstrates that under controlled drainage conditions poorly drained soils can receive substantial amounts of effluent without causing nitrate pollution.

4. Use of nitrification inhibitors to minimise nitrate leaching from dairy farm effluent applied onto pasture
Nitrification inhibitors are biodegradable chemicals which are used to minimise nitrate production in soil. These chemicals will enhance the build-up of ammonium-N, which can be used by pasture and soil bacteria. These processes enable not only the retention of applied N to soil in immobile forms and thus minimise nitrate leaching, but may also improve the soil physical properties. The study which is carried out by **Landcare Research NZ Ltd** (FRST 94-LCR-03-122) aims to irrigate a nitrification inhibitor (DCD) with dairy farm effluent and assess the environmental and agronomical benefits derived from the use of nitrification inhibitors.

5. Pathogen movement in soils irrigated with effluent
Dairy farm effluent contains a substantial amount of bacteria. When effluent is irrigated onto pasture most bacteria and viruses are filtered by soil. In certain cases, due to the presence of cracks or earthworm casts, these pathogens and other effluent pollutants such as N, P and organic-C can migrate to a greater depth. If the water table is high this can affect the water quality adversely. The study by **Landcare Research NZ Ltd** (FRST Appl. No. 95-LCR-S17-3762) will use different effluent application rates and assess nutrient and bacteria movement in soils and determine environmentally sustainable hydraulic loading rates. Management practices which reduce soil cracks will be tested so that direct pollution of ground water can be avoided.

6. The fate of dairy farm pond sludge injected into and applied onto soil

This research programme investigates the fate of nutrients and bacteria in dairy farm pond sludge injected and surface applied onto soil using field and lysimeter (undisturbed soil) studies under Canterbury conditions. Initial results indicate that ammonia volatilisation was substantially lower when sludge was injected. Although the loss of ammonia was greater from surface applied sludge it was only 1% of total N applied. The preliminary results of the study also indicate that nitrate leaching occurred in the sludge injected soil. However, in general there were few or no sludge microbes found in the leachate in both types of sludge application. Sludge injection (and soil loosening) was found to reduce soil bulk density and increase porosity in subsoil. Both types of sludge application significantly increased pasture yield. The study by **Lincoln University** (FRST LIN 302) is still in progress.

7. Effluent and N fertilisers: Effects on soil and water quality

This study by **Lincoln University** (FRST Appl. No. 95-LIN-S05-4251) will examine the factors and processes which influence the fate of N and pathogens in dairy farm effluent and N fertiliser applied to free-draining pasture soil. The following trials will be conducted for the next three years: (a) dairy farm effluent (with labelled and unlabelled N) will be flood and spray irrigated and leaching losses of nitrate and microbes will be monitored using lysimeters; (b) dairy farm effluent-N and fertiliser-N will be surface applied at 3 rates (0, 200 and 400 kg N/ha/year) and the amount of N and P leached will be measured using lysimeters; and (c) evaluating the accuracy of mathematical models to predict N and microbial losses from soil. These trials will be complimentary to the **AgResearch** programme (FRST Appl. No. 95-AGR-S02-4408) whereby the Lincoln University lysimeter results will be compared.

8 Managing dairy farm effluent as a nutrient input for pasture

This three year study by **AgResearch** (FRST Appl. No. 95-AGR-S02-4408) will be examining (a) a simple method (a method that can be used by dairy farmers, i.e. use of hydrometers) to measure total-N in dairy farm effluent; and (b) the effect of effluent application on pasture production, animal performance and the environment (e.g. aerosols or spray drift, nitrate leaching, and detergent effects). It has been proposed to apply effluent @ 150 and 300 kg N/ha/year.

9. Dairy farming and water quality

NIWA in collaboration with **AgResearch** is investigating the impact of dairy farming on water quality in the Toenepi catchment (Morrinsville area). This work is funded by the **DEC** and facilitated by the **NZDRI**. The Fertiliser Manufacturers Research Association (FMRA) has also granted considerable funding for the same purpose. It is likely that the FMRA programme will be undertaken on a national basis. Both AgResearch and NIWA will be involved in this programme.

III. TECHNOLOGICAL TRANSFER

1. Dairy farm effluent manual

Since the publication of the *Agricultural Waste Manual* in 1984 there have been several research projects carried out on farm effluent treatment. We believe it is timely and urgent to produce an updated manual due to the rapid changes in farm effluent treatment technology and the interest shown by dairy farmers in general.

A comprehensive manual (in loose leaf form) and an ‘easy to read’ farm booklet will be produced by the **NZDRI** before the end of 1995. The NZDRI will compile the existing information on all dairy farm effluent treatment methods available to farmers. The manual which may also contain information on environmentally sustainable farming practices will be sent to all dairy farmers in New Zealand. The project is funded by the **DEC**.

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