ENVIRONMENTAL RTDI PROGRAMME 2000–2006

EUTROPHICATION FROM AGRICULTURAL SOURCES -

Effects of Agricultural Practices on Nitrate Leaching

(2000-LS-2.3c-M2)

Synthesis Report

Main Report available for download on
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Prepared for the Environmental Protection Agency

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DISCLAIMER

WATER QUALITY

The Water Quality Section of the Environmental RTDI Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on water quality and the environment.

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Table of Contents

Preface

Overview of LS-2 Projects - Eutrophication from Agricultural Sources

This report synthesizes the results and outputs from three research projects that contributed to the LS-2.3 project – Effects of Agricultural Practices on Nitrate Leaching. The aim of the project was to measure nitrate leaching from an intensively managed dairy farm on a soil type typical of a nitrate vulnerable zone. The project was one of three that formed the large scale research project LS-2 – Eutrophication from Agricultural Sources (Figure 1).

The objective of this large-scale integrated research project, commissioned in 2000, was to supply scientific data to underpin appropriate actions or measures that might be used in the implementation of national policy for reducing nutrient losses to waters from agricultural sources. The research, including desk, laboratory, field plot, farm and catchment studies, was conducted by teams in Teagasc, the National Universities of Dublin, Cork and Galway; Trinity College Dublin; University of Limerick and the University of Ulster at Coleraine.

The LS-2.1 project - Pathways of Nutrient Loss to Water with Emphasis on Phosphorus Losses - aimed at quantifying and ranking the magnitude of phosphorus loss from soil, grazed pastures and the application of slurry and fertiliser to water so as to identify effective mitigation strategies.

The LS-2.2 project - Models and Risk Assessment Schemes for Predicting Phosphorus Loss to Water - aimed at developing three modelling approaches which explored the sources of phosphorus and the hydrology that transports it from land to water.

Integrated synthesis for LS-2, LS-2.1 and LS-2.2 projects and the individual reports from each of the sub-projects are available for download on the EPA website.

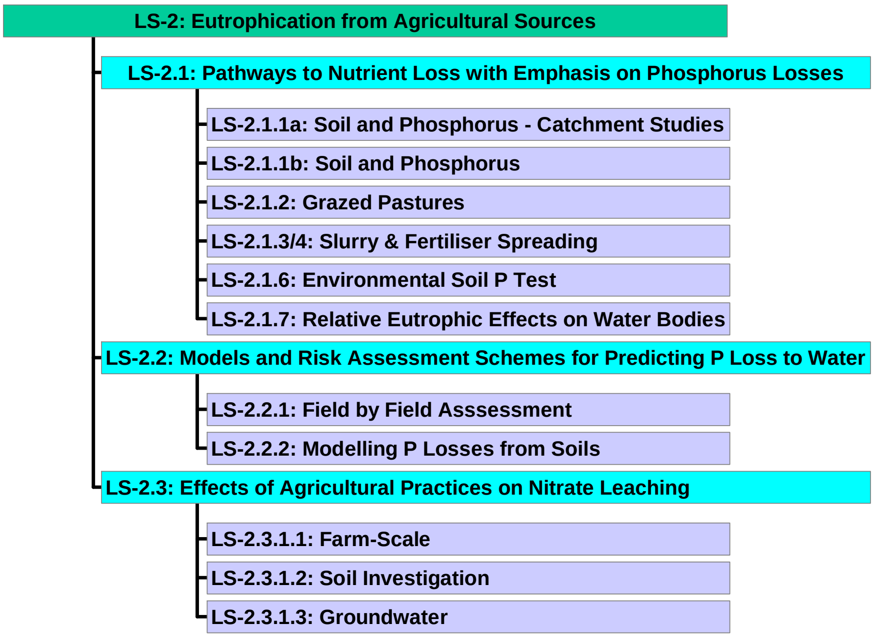

Figure 1: Overview of LS-2 projects

1 MAIN MESSAGE

The objective of this integrated research project was to measure nitrate leaching from an intensively managed dairy farm in a vulnerable area.

Mean concentrations of nitrate nitrogen in the groundwater beneath Curtin's farm during the first and second monitoring years were 15.2 mg/l and 11.9 mg/l, respectively, and exceeded the Maximum Admissible Concentrations (MAC) set in the Nitrates Directive and drinking water legislation. The average nitrate nitrogen concentrations in the soil pore water were less than the drinking water MAC in the three measurement years. However, there was a trend for increased nitrogen loadings to result in elevated concentrations of nitrate nitrogen in soil pore water and groundwater. The results indicated that lower concentrations of nitrate nitrogen in groundwater can be expected where management practices reduce the nitrogen and hydrological loads.

Questions remain as to the specific suite of management practices required to achieve compliance with water quality targets on an intensively managed grassland dairy farm on a vulnerable soil type:

- Will the implementation of the identified management practices which reduce the nitrogen and hydraulic loads achieve compliance with current water quality targets?
- Can models be expanded to provide an evaluation of the relevance of the present results and the possible mitigation strategies required in other less vulnerable circumstances?
- What are the implications of extrapolating these farm scale results to larger catchment scales where the intensity of farming can vary quite considerably?

A number of national research projects have been initiated to address some of these questions.

2 SYNTHESIS

The objective of the research was to measure nitrate leaching from an intensively managed dairy farm on a subsoil thickness and permeability which are considered to create conditions of groundwater vulnerability. Nitrate leaching is a consequence of water percolating down through the soil pushing the nitrate nitrogen-enriched soil pore water down to the groundwater. Three studies contributed to this integrated project: Groundwater, Farm Scale and Soil Investigation. The individual reports are available on the EPA website:

- M. Ryan *et al., (*2006): Nitrate Leaching – Farm-Scale (2000-LS-2.3.1.1-M2)
- P. Gibbons *et al.,* (2006): Nitrate Leaching – Soil Investigation (2000-LS-2.3.1.2-M2)
- P. Bartley and P. Johnston (2006): Nitrate Leaching – Groundwater (2000-LS-2.3.1.3-M2)

The research was conducted on Curtin's Farm (50 ha) which forms part of the Teagasc, Moorepark Dairy Research Centre. Curtin's Farm was being used to experimentally evaluate three dairy cow breeds. The farm management was generally representative of the top 10% of Irish grassland farms in terms of intensity. The farm site is characterised by a shallow, free draining sandy loam soil/subsoil overlying a karstified-limestone bedrock aquifer. The conceptual model for the complex hydrogeology under Curtin's Farm evolves as a 0.3 to 0.4 m rich brown topsoil in the upper layer sitting on 0.4 m of a very gravely silty/sandy layer, followed by a thick sandy layer soil and subsoil overlying a fractured/fissured karstic reef limestone. The subsoil is a well-drained permeable sandy till, from 0 – 4 m thick, which rests on an uneven weathered limestone bulk rock mass, also of high permeability and less than 2 m thick. This blanket weathered zone (epikarst) focuses the drainage from the subsoil into the fissures and fractures of the more solid rock immediately beneath. A substantial area of Curtin's Farm is located within the source protection zone for a public water supply and is therefore also classified as extremely vulnerable by the Geological Survey of Ireland. These site characteristics represent about 4.6% of the country's land area.

The groundwater beneath Curtin's farm sits on a plateau between the Blackwater and Funshion rivers. Therefore, the concentrations of nitrate nitrogen measured in the groundwater reflect the Curtin's farm practice and generally exclude the potential for incoming supplementation or dilution.

2.1 Groundwater and Soil Pore-water

The **Groundwater study** reported the concentrations of nitrate nitrogen in groundwater ranged from 3 to 31 mg/l and from 4 to 23 mg/l for the first and second monitoring years, respectively. Mean annual concentrations were 15.2 mg/l in year 1 and 11.9 mg/l in year 2. These exceed the MAC of 11.3 mg/l for drinking water.

Responses in the nitrate nitrogen concentrations in groundwater were discernable for the four management areas on the farm. For example, the highest concentrations were observed under the 'grazed dirty water irrigation' area, probably reflecting the higher total nitrogen and hydrological loading for this management area compared with the '1 cut silage', '2 cut silage' and 'grazed' areas on the farm. This suggests that the nitrate nitrogen concentrations in the groundwater were responsive to management practices which influence the nitrogen and hydrological loading.

A positive correlation was found between the number of days during which the herd grazed a particular plot, in one grazing season, and the average groundwater concentration of nitrate nitrogen in the associated borehole in the following recharge period.

The **Farm scale study** reported mean nitrate nitrogen concentrations in the soil pore water, extracted from 1 m below ground level, during the three consecutive years of the monitoring programme were 7.9, 4.2 and 9.1 mg/l, respectively. These values are less than MAC. The three-year mean concentration was 7.0 mg/l.

The lower concentrations of nitrate nitrogen reported for the 1 m soil pore water from the **Farm scale** study compared with those measured in the **Groundwater** study may be a consequence of different sampling methods used in the two studies. The groundwater sample reflects an integrated value from the area contributing to the borehole. However, the number of ceramic cup used in the **Farm scale** study may not have been sufficient to capture the full impact of the high N point sources associated with the urine patches in grazed pastures thereby giving a lower estimate of the nitrate nitrogen levels than those measured in the groundwater.

There was considerable within and between treatment variability in the concentrations of nitrate nitrogen in soil pore water measured in the **Farm scale** study. However, significant differences in the concentrations of nitrate nitrogen were found among the four management areas in the first and second years but not in the third year. The 'grazed dirty water irrigation' and the '2 cut silage' areas had significantly higher mean concentrations compared with the 'grazed' and '1 cut silage' areas. No relationships were found between the nitrate nitrogen concentration and either grazing days or total nitrogen applied within each management area. There was some suggestion that increased release of soil nitrogen as a consequence of the long term applications (10 years +) of dirty water to these plots combined with the additional hydraulic load might also be contributing to the observed higher concentrations in that management area.

In the small plot cutting experiments of the **Soil Investigation study**, the highest annual rate of nitrogen fertiliser (387 kg /ha) resulted in concentrations of nitrate nitrogen in the soil pore water exceeding MAC. Generally, nitrogen fertiliser applications of less than 300 kg/ha/annum did not result in MAC being exceeded. However, nitrogen applications in late September and excessive nitrogen fertiliser in early spring tended to result in the drinking water quality target being exceeded especially when the fertiliser application was followed by heavy rainfall.

High (50 mm) and medium (25 mm) rates of dirty water applied to small plots in *winter*, without antecedent nitrogen fertiliser inputs, resulted in the concentrations of nitrate nitrogen in the soil pore water exceeding the drinking water MAC. However, the same rates of dirty water irrigation in *summer* did not have this effect. Low dirty water irrigation (10 mm) rates at any time of year did not result in elevated soil pore nitrate nitrogen concentrations.

These results from the three studies suggest that the concentrations of nitrate nitrogen in both groundwater and soil pore water will be reduced by combinations of the following changes: lowering the fertiliser nitrogen loading; avoidance of excessive nitrogen applications in mid-late September and mid- January/early February; lower dirty water irrigation rates in winter; reducing the number of grazing days. It can be reasonably expected that the implementation of a suite of management changes will have a cumulative effect. In addition, the greater the extent to which they individually reduce the nitrogen load, the higher the probability of reducing the concentrations of nitrate nitrogen in groundwater.

2.2 Recharge and Soil Hydrology

Recharge was 707, 503, and 547 mm for the three measurement periods August 2000 to July 2001, August 2001 to July 2002 and August 2002 to July 2003, respectively. Winter recharge generally began in October of each year and continued until May or June.

The decline in groundwater and soil pore water concentrations in the second monitoring year is most probably a result of higher winter recharge in the second year (303 mm) compared with the first year (191 mm), which resulted in a dilution of nitrate nitrogen. Thus winter rainfall is a major, but uncontrollable, driver of nitrate nitrogen concentrations in vulnerable receiving waters.

Recharge flow rate was estimated at 4.5 mm/day, varying in the approximate range, 7 to 1 mm/day, in the winter and summer seasons, respectively. The mean travel time to 900 and 3,000 mm using 4.5 mm/day is 200 and 667 days. In winter, the mean travel time to 900 mm is about

130 days, but this depends on the rainfall amount, taking longer in dry winters. An implication is that additional hydrological loadings from dirty water irrigation in winter will increase the potential for an impact on groundwater. An additional dirty water irrigation of 10, 25 and 50 mm will increase the recharge rate by approximately 4%, 8% and 16%, respectively.

In the **Groundwater study** a peak bromide concentration of 5.9 mg/l was found in the groundwater 44 days following the surface application of a bromide tracer with a concentration of 70,000 mg/l. This result and an analysis of the groundwater nitrate nitrogen response to recharge suggested that a secondary preferential flow pathway existed in addition to the soil matrix flow. The **Soil Investigation study** only found matrix flow and no evidence of preferential flow pathways in any of their many analyses. The conflicting result requires further investigation because if secondary preferential flow pathways exist it has important implications for phosphorus and pathogen transfer to groundwater.

2.3 Nitrogen and Hydrological Loadings

In the **Groundwater study,** the calculated total nitrogen loading on the entire Curtin's farm in 2001 and 2002 was 512 kg/ha and 538 kg/ha, respectively. Of this 60% and 54% was fertiliser nitrogen in 2001 and 2002, respectively. The average stocking rate in both years was 2.4 cows/ha which is equivalent to a return of 204 kg/ha of organic nitrogen in the dung and urine. Total nitrogen loadings differed among the management areas. The highest loading was associated with the 'grazed dirty water irrigation' area (668-719 kg/ha) followed by the '2 cut silage' (534 – 573 kg/ha) and '1 cut silage' (515-554 kg/ha) areas. The 'grazed' area had the lowest total nitrogen loading (455 – 474 kg/ha).

For the **Farm Scale study,** the total nitrogen loadings for 2001, 2002 and 2003 on the area of the farm monitored were 465, 474 and 509 kg/ha, respectively. Between 55% and 60% of the loading was derived from fertilizer nitrogen. The overall total nitrogen loadings in this study were lower and the differences in the nitrogen inputs to the four management areas were not as great as those in the **Groundwater study**.

Estimated annual nitrogen losses, based on the weighted annual mean nitrate nitrogen concentrations and recharge plus irrigated dirty water were 35, 23 and 36 kg/ha, for years 1, 2 and 3, respectively. This represented 11%, 7% and 11% of the nitrogen inputs from the fertiliser, slurry and dirty water applied in the three consecutive years, respectively. The percentage losses tended to be lower than previously published Irish estimates which were in the region of 13 to 14%.

In the **Soil Investigation study** the fertiliser nitrogen applications ranged from 174 to 286 to 387 kg/ha. The nitrogen loadings from the winter application of dirty water varied from 31 to 215 kg/ha with associated hydraulic loadings ranging from

10 to 50 mm. The nitrogen loading for the summer dirty water application ranged from 31 to 155 kg/ha with a hydraulic loading of between 10 and 50 mm.

2.4 Models

A model, NCYCLE_IRL, was developed and demonstrated potential for use at farm level to assess the impact of soil type, cutting or grazing management, dairy or beef enterprise and fertiliser nitrogen inputs on nitrate leaching. Progress was also made with the risk assessment concept for groundwater by the successful testing of the hydrological risk assessment model (RAM) for the karstified hydrogeological system at Curtin's farm. The LEACHN model was parameterised for the site and gave fair agreement with the field data for the dirty water treatments and could be used on similar sites to estimate nitrate nitrogen fluxes through the soil. However, further field data are required before the models can provide more accurate estimations of nitrate leaching following nitrogen inputs from other sources.

2.5 Context for Synthesis

The studies reported were generally not replicated, conducted at a single geographic location with a limited number of sampling points and on a site with a complex hydrological pathway. This limits the potential for quantitative statements on cause and effect. Also, care is required with the extrapolation of the results to other less vulnerable areas of Ireland. In these areas, represented by heavier less well drained to impeded soils, the potential for denitrification, *i.e.* the conversion of nitrate to the benign dinitrogen gas or nitrous oxide which is a potent greenhouse gas, is greater thereby reducing nitrate leaching losses. This is supported by previous international and Irish research findings which indicate on less vulnerable soils there would be reduced soil pore and groundwater impacts from managements similar to those which applied in the current study.

The monitoring programme was established in the context of the highest leaching risk or vulnerability scenario where the nitrogen loadings, drainage water, soil hydrology and the sensitivity of the groundwater all combined to create a probable worst case scenario in an Irish context.

The farm management of Curtin's farm was primarily designed to support the experimental evaluation of three dairy cow breeds. However, some farm management practices to meet the specific requirement of the experiment may be at variance with typical farm practice. For example, the volumes of dirty water generated are greater than most typical farms, due to yard cleaning associated with the high numbers of visitors received annually on the farm. The fertiliser nitrogen inputs were above those generally advised to ensure that grass supply was not a limiting factor in the experiment.

This study has raised a number of interesting questions. These have given rise to a number of new research projects initiated in 2005 and 2006. These studies will examine management effects (stocking rate and extended grazing) on nitrate leaching, preferential flow in a range of soil types and denitrification potential in a range of sub-soils and aquifers. The output will provide additional knowledge which will contribute to a better understanding of the processes involved and more quantitative answers to the questions.

3 RELEVANCE TO POLICY

The aims of the study were (i) to measure and evaluate the impact of the an intensive dairy farm in a vulnerable environment on the nitrate nitrogen concentrations in soil pore water and groundwater (ii) to provide data on nitrate leaching following the application of chemical nitrogen fertilisers, farm slurries and dirty water (dairy wastewaters) to the soil surface at various rates and times of the year, and (iii) to provide inputs for modelling nitrogen fluxes in a dairy farming situation in order to estimate their effects on nitrate leaching.

3.1 Policy Issues

The primary policy drivers for this research were three European Union (EU) water quality directives – Nitrates, Drinking Water and Water Framework. The issues of concern were nitrate nitrogen concentrations in groundwater and surface water and the farming practices that contribute to these. Initially, the EU focus for limiting nitrate nitrogen in drinking water was related to human health. However, more recently the policy concern relates to the sustainable use of our natural resources. Groundwater containing high concentrations of nitrate nitrogen discharging to freshwater or marine habitats, can contribute to algal blooms and eutrophication. The EPA report, *Ireland's Environment 2004* concluded, based on the national monitoring surveys carried out in 2001-2002, that there was no widespread contamination of individual aquifers. However, the results did show intermittent and localised pollution in an appreciable number of instances and 23% of the samples with nitrate-nitrogen concentrations equal to or greater than the EU guideline value of 25 mg/l for drinking waters.

Groundwater and agriculture are connected because the soil and subsoil on which farming takes place acts as the pathway for the leaching of contaminants such as nitrate nitrogen. Shallow (< 3 m) free draining soils overlying aquifers used for public water supplies have been identified as being most vulnerable and represent the greatest risk to groundwater quality when combined with a significant pressure or source of nitrate.

In 2000, knowledge regarding the scale, timing and distribution of nitrate leaching from Irish farmland was limited. Irish and indeed international studies of nitrate leaching from grass had been generally conducted at component (grazed plots, cut plots) or lysimeter scales. It was clear that the greater the nitrogen loading or pressure, particularly during periods of recharge in autumn and winter on vulnerable soils, the greater the potential for elevated concentrations of nitrate nitrogen in soil pore water and groundwater. However, no Irish study had measured, contemporaneously, the integrating effects of intensive farming systems on the leaching of nitrate nitrogen to soil pore water or its ultimate receptor - groundwater in an area considered to be vulnerable.

In summary, the research found that the average concentrations of nitrate nitrogen in the groundwater beneath Curtin's farm during the two years of monitoring exceeded the MAC for drinking water. There was a trend for increased nitrogen loadings to result in elevated concentrations of nitrate nitrogen in soil pore water and groundwater. These results are consistent with the international literature and the source-pathway-impact model which identifies the greatest impact when the source and pathway coincide and the receiving water is sensitive to change. However, they are specific to the present soil and management conditions.

3.2 Implications

The potential limitations associated with the present study noted above are relevant when considering the policy implications of the results.

The results suggest that changes in the management practices on Curtin's farm during the monitoring period are required to achieve compliance with water quality targets at this site. The observed chemical and hydraulic response of the site indicate that the concentrations of nitrate nitrogen in the groundwater would be expected to decline when management changes which reduce the nitrogen and hydraulic load, especially during the winter drainage season, are implemented.

The research team indicated the need to review and adapt the fertiliser and dirty water regimes on Curtin's Farm and monitor the groundwater response over a longer time than the present studies. There may also be a need to consider similar monitoring programmes in less vulnerable areas.

There is a requirement to develop a focused educational programme for farmers in vulnerable areas to inform them of the risk. This should include the development of a guidance document which will assist them to implement and integrate the management practices which will reduce the nitrogen and hydraulic loadings. These include:

- reducing the production of dirty water by improvements in dairy parlour washing routines, clean water control and reduction in farmyard dirty areas;
- ensuring an adequate area of the farm is available for dirty water applications;
- adjusting the fertiliser nitrogen applications to take account of the nitrogen contribution from dirty water;
- splitting first spring nitrogen applications to take account of the soil nitrogen supply and
- not exceeding the nitrogen advice for grassland.

There is a requirement to develop these modelling capacities to assess and validate the new knowledge at farm and catchment scales. The model evaluation and development in the present project should be considered as a starting point for any such initiative. The potential of NCYCLE_IRL and RAM should be further developed to provide assessment tools at the farm level for the effective evaluation of proposed management changes required to achieve current or future water quality targets.

The models should consider the extrapolation of the farm scale results to the larger catchment scales. This raises questions regarding the capacity of an aquifer to accommodate elevated concentrations emanating from a proportion of farms in a catchment. The focus of this research has been on intensive grassland. However, in a catchment management context, and particularly for those in the south and east of the country there is need to take cognisance of the potential impact of tillage operations.

The results of this study raised further research questions which led to the initiation of a number of new research projects. These are either ongoing at present or will commence shortly and they should provide greater clarity in relation to the effect of management factors on nitrate leaching and on the mechanisms involved. The model development could provide an integrating platform for these new research projects.

4 ACRONYMS AND NOTATION

EPA	**Environmental Protection Agency (of Ireland)**
ERTDI	**Environmental Research, Technological Development and Innovation**
EU	**European Union**
LS	**Large Scale**
MAC	**Maximum Admissible Concentrations**
NUI	**National University of Ireland**
RAM	**Risk Assessment Model**
RTDI	**Research, Technological Development and Innovation**