Environmental RTDI Programme 2000–2006

EUTROPHICATION FROM AGRICULTURAL SOURCES – Soil and Phosphorus: Catchment Studies (2000-LS-2.1.1a-M1)

Synthesis Report

(Final Report available for download on http://www.epa.ie/downloads/pubs/research/water/)

Prepared for the Environmental Protection Agency

by

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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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Preface

1 Overview of LS-2 Projects – Eutrophication from Agricultural Sources

This report summarises the aims, methods, results, conclusions and recommendations of the sub-project LS-2.1.1a (Soil and Phosphorus: Catchment Studies). The aim of the project was to investigate the processes responsible for phosphorus (P) transfer from fertilised grassland soils to streams and to investigate the patterns of such transfers in three catchments (Dripsey, County Cork; Clarianna, County Tipperary; Oona, County Tyrone). This sub-project was one of six that formed the LS-2.1 project, which aimed to investigate the absolute and relative losses of phosphorus from soil, grazed pastures, slurry and fertiliser spreading and farmyards. The LS-2.1 project is part of the large-scale research project LS-2 – *Eutrophication from Agricultural Sources* (Fig. 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-2.2 project – *Models and Risk Assessment Schemes for Predicting Phosphorus Loss to Water* – aimed to develop three modelling approaches that explored the sources of phosphorus and the hydrology that transports it from land to water.

The LS-2.3 project – *Effects of Agricultural Practices on Nitrate Leaching* – aimed at measuring nitrate leaching from an intensively managed dairy farm on a soil type typical of a Nitrate Vulnerable Zone.

Integrated synthesis reports 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.

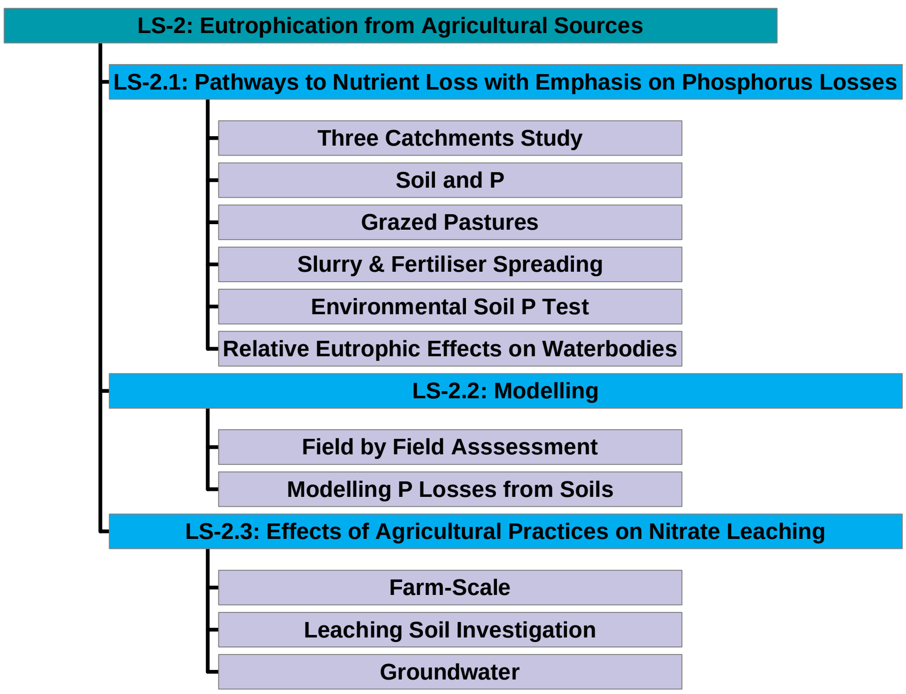

Figure 1. Overview of LS-2 projects.

Abstract

This project examined, over the 12-month period January–December 2002, the phosphorus (P) in stream run-off from three grassland catchments in Ireland: the Dripsey in County Cork, the Oona Water in County Tyrone, and the Clarianna in County Tipperary. In each catchment, three or four river monitoring stations for flow and P fraction concentrations were set up in a nested catchment arrangement at scales of 0.15–85 km^2. The objectives were to investigate the processes responsible for P transfer from fertilised grassland soils to streams and to investigate the patterns of such transfers. The P sorption and desorption characteristics of soil samples from each catchment were also determined (and are reported separately as part of LS2.1.1b). The catchments were characterised by similar land use (grassland) and a gradient of soil P fertility. The differences were mainly soil type (and associated chemistry affecting P retention) and soil hydrology (affecting P run-off).

The distribution of rainfall across the three catchments during 2002 was very similar and most storms were recorded concurrently (±1 to 2 days) in all three catchments despite the distance between them. However, the hydrological responses of the three catchments were different. In the two catchments with soil types of moderate to impeded drainage (Dripsey and Oona) and intensive grassland agriculture, the P losses to surface water were three to five times higher than required for good stream water quality. In the well-drained calcareous soils of the Clarianna catchment, the P losses to surface water were approximately ten times lower than in the Dripsey or Oona. In the three catchments, the greatest P losses were associated with storm events and high stream flows particularly in autumn and early winter. Soil type through its influence on P chemistry and flow pathways was identified as a major determinant of potential P loss. Catchment scale was also important. As scale increases, factors such as increased variability in land use, hydrological difference and in-stream processes determine the catchment response. For example, in both the Dripsey and Clarianna, the export of P decreased with increasing size of catchment. In contrast, in the Oona Water catchment, P export increased with increasing catchment size. The timing of chemical fertiliser and slurry applications influences the P export to streams. Phosphorus loss to groundwater was also found in the Clarianna.

Specifically, it was found that agriculture was a major source of P loss to water in the three rural catchments studied. In all three catchments the average soil test phosphorus (as Morgan's P) was between 10 and 12 mg/l (STP Index 4). The magnitude of P loss (kg/ha) depends on the soil type and timing of fertilisation. Highly fertilised soils transfer soluble or particulate P depending on the adsorptive capacity of the soil (soluble P) and the permeability of the soil (particulate P). The timing of fertilisation particularly with slurry spread in wet months is susceptible to transfer to watercourses when rainfall occurs after the application.

Approximately 80% of P export was in the October to February period. In the Oona catchment, the high particulate P loss was associated with the most severe storms. In all three catchments, high P concentrations were associated with peak stream discharges. The Clarianna calcareous soils, in addition to providing chemical sites for P precipitation, have deep Quaternary sediments that provide a significant P sink. However, the capacity of this sink to store additional P is unknown. Particulate P was re-mobilised during dredging of the Clarianna. Agricultural catchments with non-calcareous fertilised soils that are low in aluminium, high in organic matter and have a flashy hydrological response to rainfall are at risk of P transfer via desorption and detachment.

1 Introduction

Eutrophication is one of the most pervasive water quality problems in Europe. It is widely recognised that phosphorus (P) is the limiting plant nutrient in freshwaters. The extent of this limiting factor for plant growth depends on a number of physical, chemical, biological and land-use management factors. Research in agricultural, environmental science and environmental engineering has shown that soils (particularly fertilised arable and grassland) are a source of nutrient transfer to freshwaters. The extent of this transfer is dependent on factors including soil type and soil P status, land-use type and intensity, fertilisation practices, climate, hydrological regime and catchment scale. This project examined the risk of P transfer from fertilised grassland soils to water. In this three-catchment study, land-use type and intensity and geographical scale were similar while soil type, climate and hydrological regime were dissimilar. The overall aim of the study was to quantify the P loss from soil to watercourses.

The objectives of the study were:

1. Quantify the water balance in three catchments (Dripsey, Clarianna and Oona)
2. Compare the river P concentrations and P export loads in these catchments and examine how these are affected by soil chemistry, climate, hydrology and geographical scale
3. Examine the significance of the amount and timing of chemical fertiliser and slurry on P export to streams (Dripsey only)
4. Investigate the significance of the groundwater pathway for P transfer (Clarianna only).

2 Partners and Study Areas

This was a collaborative project between University College Cork (UCC), University of Ulster (UU), University of Limerick (UL) and Teagasc. Three agricultural river catchments were used as field sites and associated water chemistry was determined in the participants' laboratory facilities. Teagasc at the Johnstown Castle research laboratory in Wexford undertook soil studies. The locations of the three catchments are shown in Fig. 2.1 and were assigned for field studies as follows: the Dripsey in Co. Cork (UCC), the Oona Water in Co. Tyrone (UU), and the Clarianna in Co. Tipperary (UL).

Grassland agriculture was the predominant land use in each of the three catchments, which were managed for beef and dairy cattle and for sheep. Additionally, some tillage was undertaken in the Clarianna catchment. Nutrient input figures were not available prior to the study to compare land-use intensity although crop rotation and husbandry were regarded as similar and typical of intensive agriculture in each region. Fertiliser and slurry quantities were recorded during the study period for the 2 km^2 mini-catchment of the Dripsey.

Figure 2.1. Location of project partners and river catchments in study.

The soil types were dissimilar in the three catchments and characterised as:

- *Dripsey*: neutral soils, mostly Brown Podzolic with some Gleys, impeded to free draining
- *Oona Water*: drumlin soils, mostly surface and groundwater Gleys of moderately acidic nature, impeded drainage
- *Clarianna*: calcareous soils of neutral to alkaline pH representing a mix of Grey Brown Podzols, Gleys, Peats and Brown Earths, free draining.

These soil types, in terms of chemistry and hydrology, provided two environmental gradients. The first was characterised by how well P was bound to soil (sorption binding energy) and the second by how rainfall was partitioned into surface and subsurface run-off. This combination of soil-type factors was considered a key element in determining the P transfer risk from soils.

The Dripsey and Oona catchments have soils with moderate to impeded drainage while the Clarianna has well-drained calcareous soils. The Dripsey soils were characterised in laboratory studies as having a higher potential for P desorption and for soil P saturation per unit soil P test when compared with Oona Water soils. Both the Dripsey and Oona soil types were non-calcareous and the major differences appeared to be aluminium (Al) concentration, which was higher in Oona Water soils, and higher iron–organic matter (Fe–OM) complexes in the Dripsey. Calcareous soils in the Clarianna did not exhibit the same magnitude of P transfers. Chemically, this was attributed to calcium (Ca)-dominated P precipitation.

3 Methods

In each of the Dripsey, Oona Water and Clarianna catchments, three or four nested sub-catchments were monitored for flow and P fraction concentrations in water, at scales from 0.15 to 88.5 km^2 over a 12-month period (see catchment plans of Figs 3.1–3.3) so that the full agricultural cycles of grazing, stock housing, silage cutting, fertilising and wet and dry periods of the hydrological cycles were included.

The infrastructure at each site consisted of:

- Continuous water level (flow) monitoring (90° V notches, rectangular weirs, etc.)
- Semi-continuous automatic water chemistry sampling for total P (TP), total dissolved P (TDP), soluble reactive P (SRP), suspended solids (SS), etc., and
- A meteorological station monitoring wind speed, air temperature and relative humidity, soil temperature, soil moisture, etc.

Water samples were analysed for SRP, TP and TDP fractions. The particulate P (PP) fraction was calculated as the difference between TP and TDP. Suspended solids concentrations were also measured.

All stream and river stations in the study used a combination of rated control structures and pre-calibrated flumes or weirs and water-level recorders to monitor discharge. Storm water samples were taken by automatic sampler and, in the Dripsey and the Oona Water, a flow-proportional composite sampling method was employed that concentrated the monitoring on storm events without generating prohibitively large numbers of samples in

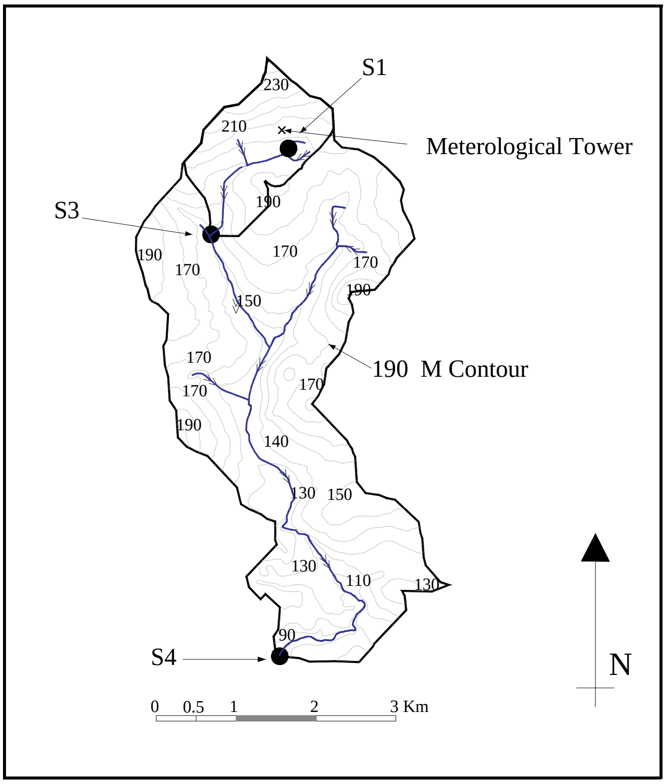

Figure 3.1. The Dripsey sub-catchment showing flow and water chemistry sites, S1, S3 and S4. Delineation of catchment is for catchments S3 (211 ha) and S4 (1,524 ha). The stream is shown in blue running from north to south. The stream rises at an elevation of *c.* 200 m asl and flows to station S4 at an elevation of *c.* 90 masl. The stream gradient to station S4 was *c.* 10.3 m/km.

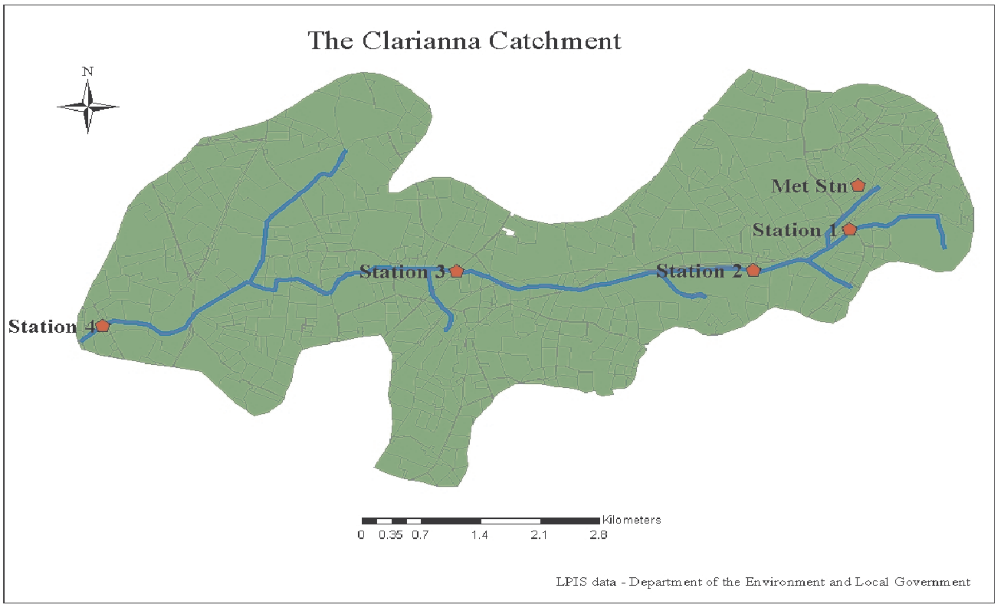

Figure 3.2. The Clarianna catchment. The streams flow east to west.

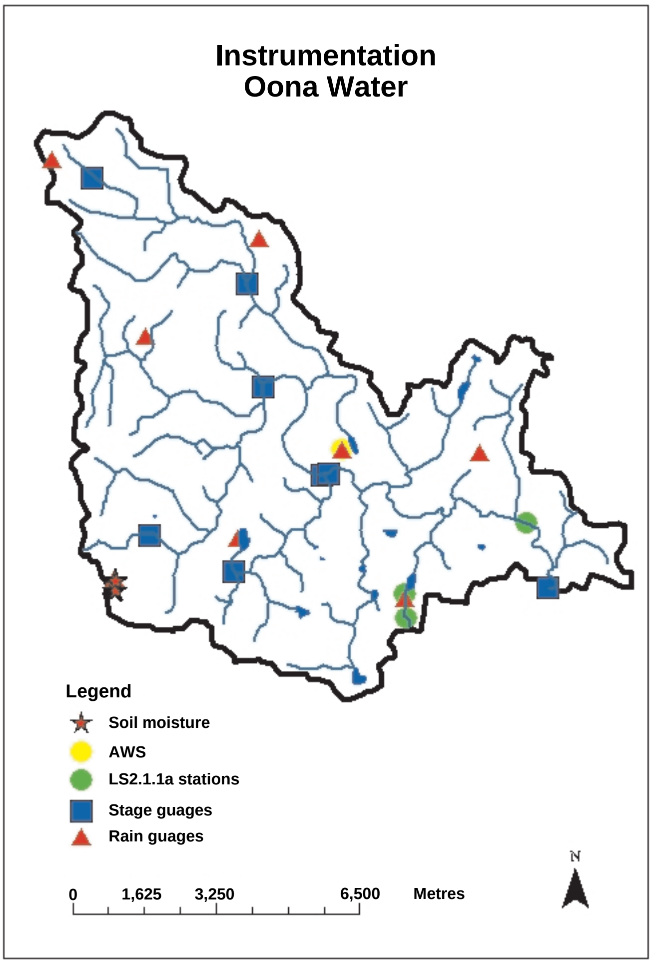

Figure 3.3. The Oona Water catchment. The outlet is in the south-east.

these flashy streams. As the Clarianna was considered to be a less flashy river, a flow-proportional discrete method was chosen whereby a sample was taken and stored in isolation from the others over storm periods. A method of grab sampling between storms was also undertaken at least once weekly to isolate nutrient and sediment concentrations during low flow periods.

The dimensionless ratio (Q5/Q95) summarises the magnitudes of the infrequent 5th percentile (high flow) and the frequent 95th percentile (low flow) and was used to compare the run-off response between gauged catchments. Catchments with a higher ratio have flashier responses to rainfall due primarily to a predominance of faster run-off flow paths.

Tipping bucket rain gauges, situated close to the smallest sub-catchments, monitored rainfall. In the Oona Water and Clarianna catchments evapotranspiration was calculated by the Penman–Monteith equation using data generated from the automatic weather stations. In the Dripsey, actual evapotranspiration was measured directly by the eddy-covariance method.

Small field scale monitoring was undertaken to measure the P losses from land in the absence of farmyard inputs of P and those from any extra-agricultural activities such as industrial or municipal waste-water point sources. Monitoring at the larger catchment scales included (the potential for) all of the latter.

A study of the seasonal P applications of fertiliser and slurry was also undertaken in the Dripsey within the 2 km^2 catchment. Phosphorus exports were calculated using the data set gathered at each of the fully instrumented river monitoring stations.

The P sorption and desorption characteristics of soil types from each catchment were determined across a soil P gradient in the sub-project LS-2.1.1b (Daly and Styles, 2005)[1]. Composite soil samples (0–10 cm soil depth) were collected from seven to 12 fields in each catchment that covered a Morgan soil P index of 1–4. The concentrations of P, Fe, Al, Ca and OM in the sampled soils as well as their pH and P sorption and desorption characteristics were also determined.

1. Daly, K. and Styles, D., 2005. *Eutrophication from Agricultural Sources – Phosphorus Chemistry of Mineral and Peat Soils in Ireland.* EPA, Johnstown Castle Estate, Wexford, Ireland.

4 Results

The concentrations of P, Fe, Al, Ca and OM in the sampled soils as well as their pH and P sorption and desorption characteristics are presented in Table 4.1. The range of pH was 4.8–7.3 and %OM was 5.3–14.2%, excluding the two peat samples in the Clarianna. Acidic–neutral soils were represented by the Oona catchment, neutral soils in the Dripsey and neutral–alkaline soils were typical of soils sampled from the Clarianna catchment.

In Table 4.2, the annual hydrological and hydrochemistry results for the three catchments are shown. The Dripsey was the wettest catchment with 1,833 mm in 2002, while

Table 4.1. Soil chemistry results from sample soils in the three catchments with Langmuir parameters: X_m, P sorption maximum; b, binding energy; MBC, maximum buffer capacity (X_m × b). P_M is Morgan soil P test. P_{M3}, Fe, Al and Ca are all Mehlich-3 extracts. P_{feo} is the P desorption by iron-oxide paper strips. OM is % soil organic matter as estimated by loss-on-ignition.

Catchment	Soil type	X_m (mg/kg)	b (l/mg P)	MBC (l/kg)	P_M (mg/l)	P_{M3} (mg/kg)	P_{feo} (mg/kg)	pH	OM (%)	Ca (mg/kg)	Fe (mg/kg)	Al (mg/kg)
Clarianna	Gley	323	0.66	213	11.8	56.1	38	6.8	12.7	4,635	399	69
Clarianna	Gley	333	1.25	417	3.2	24.3	24	6.8	8.7	3,737	305	379
Clarianna	Gley	263	0.93	244	6.8	50.2	32.8	6.4	8.7	2,925	362	471
Clarianna	Peat	**		**	3.6	11.3	34.8	7.3	30.5	23,008	177	***
Clarianna	GBP	323	1.19	385	3.9	45.2	31	6	6.4	2,430	323	686
Clarianna	GBP	263	0.81	213	4.5	47.4	35.4	6	10.7	2,391	252	778
Clarianna	Peat	**		**	2.5	3.9	27	7.2	21.8	32,104	75	***
Clarianna	BE	323	1.48	476	2.4	25.6	21.6	6.6	6.9	3,543	222	435
Clarianna	BE	333	1.15	385	13	51.4	37.2	6.7	7.5	3,185	215	548
Oona	Gley	588	2.13	1,250	25.8	285	113	6.3	10.9	3,566	422	931
Oona	Gley	476	4.2	2,000	8.4	96.9	41.8	4.9	7.9	913	411	1,265
Oona	Gley	455	2.2	1,000	7.9	71	34.2	5	7.5	681	468	1,075
Oona	Gley	385	1.86	714	4.8	64.3	31	5.1	6.5	1,136	407	971
Oona	Gley	417	6	2,500	4	40.7	18.4	5.2	5.3	953	446	1,225
Oona	Gley	500	1.43	714	22.3	204.8	128	5.2	7.8	1,127	537	925
Oona	Gley	417	4.8	2,000	2.8	46.1	15.4	4.9	6.6	427	390	1,102
Oona	Gley	417	4.8	2,000	1.8	18.4	16.2	4.8	6.2	781	419	1,070
Oona	Gley	455	3.14	1,429	10.4	70.2	51.2	4.9	7.8	1,041	571	901
Oona	Gley	435	2.56	1,111	8.6	90	47.2	5.1	7.4	1,468	473	1,042
Oona	Gley	435	7.67	3,333	5.7	49.9	23.6	4.8	6.9	465	464	1,231
Oona	Gley	556	4.5	2,500	2.9	38.1	18.8	4.8	7.9	284	397	1,330
Dripsey	BP	500	2.5	1,250	8.9	99.5	39.8	5.1	8.9	894	619	880
Dripsey	Gley	270	0.54	147	13.7	102.6	53.6	5.4	8.9	1,656	454	612
Dripsey	BP–Gley	500	1.82	909	10.2	141.4	64.8	5.5	10.1	1,974	527	940
Dripsey	BP	476	1.75	833	8.6	133.4	57.2	5.7	8.3	1,858	498	901
Dripsey	BP	526	2.71	1,429	6.6	101.8	71.6	5.3	8.6	1,187	524	1,068
Dripsey	BP	556	2.57	1,429	14.6	211.7	70.4	5.2	9.3	1,021	612	***
Dripsey	BP	625	2	1,250	13.5	192	83.2	5.6	14.2	1,666	561	1,054

**No fit to Langmuir model.
***Not enough sample for analysis.
BE, Brown Earth; BP, Brown Podzolic; GBP, Grey Brown Podzolic.

Table 4.2. Annual hydrochemistry results from the three catchments from 1 January 2002 to 31 December 2002 (rain, evapotranspiration (ET), run-off, Q5/Q95, TP, PP, SRP, SS). The flow weighted mean concentration for TP, PP SRP and SS is given in mg/l and the annual export for TP, PP and SRP is given in kg/ha. The very high (dimensionless) Q5/Q95 ratio from the 0.80 km^2 Clarianna was due to a stream diversion during summer 2002 and so does not reflect the wider catchment flow.

Catchment	Sub-catchment area (km^2)	Rain (mm)	ET (mm)	Run-off (mm)	Q5/Q95	TP[1] (mg/l)	TP[2] (kg/ha)	PP[1] (mg/l)	PP[2] (kg/ha)	SRP[1] (mg/l)	SRP[2] (kg/ha)	SS[1] (mg/l)
Dripsey	0.15	1,833		1,206	51.85	0.220	2.658	0.049	0.596	0.153	1.847	6.053
	2.00		362	1,080	77.53	0.230	2.480	0.099	1.071	0.105	1.138	13.241
	15.0			1,037	40.75	0.154	1.599	0.057	0.591	0.078	0.812	13.115
Oona Water	0.15	1,366		611	95.80	0.393	2.403	0.239	1.461	0.083	0.506	73.682
	0.62		352	894	48.85	0.269	2.408	0.157	1.404	0.060	0.536	34.933
	88.5			817	67.43	0.382	3.125	0.203	1.656	0.111	0.904	50.184
Clarianna	0.80	1,091		603	410.84	0.114	0.685	0.078	0.472	0.024	0.146	67.024
	7.30		493	435	12.72	0.069	0.298	0.049	0.212	0.013	0.058	7.126
	13.60			416	20.92	0.040	0.165	0.021	0.089	0.014	0.057	12.163
	29.80			434	13.67	0.053	0.232	0.021	0.089	0.025	0.109	19.355

[1]Flow weighted mean concentration (mg/l).
[2]Annual export (kg/ha).

the Oona Water had 1,366 mm and the Clarianna had 1,091 mm. Evapotranspiration in the Dripsey and Oona Water was estimated at 362 mm and 352 mm, respectively. Evapotranspiration in Ireland does not change much from year to year, meaning that in wet years more precipitation finds its way to rivers as higher flows. Wet years have the potential to flush more P from the soil than dry years if the soil has high quantities of P in them as measured by a soil P test.

The Dripsey (impeded to free draining) and Oona Water (impeded drainage) soils were most prone to P transfer to surface water. Up to 2.5 kg/ha/year were measured as TP export at the field scale (~15 ha). Concentrations of TP were as high as 5.1 mg/l (during an exceptionally high flood event) and as low as ~0.015 mg/l during low flows. Surface water P loads measured in the Clarianna were approximately ten times lower, at all spatial scales. Significant P concentrations were, however, measured in the Clarianna groundwater boreholes.

The TP export from the Dripsey and Oona Water catchments was similar, with loads of approximately 2.5 kg/ha/year at the two catchment scales smaller than 2 km^2. The exports from the Clarianna were much lower at approximately 0.7 and 0.3 kg/ha/year for the 0.8 and 7.3 km^2 catchments, respectively. At the larger catchment scales in both the Dripsey and Clarianna, the TP export loads were reduced by nearly a half. This suggests the importance of the dilution mechanism as the catchment scales increase. However, in the Oona Water, the reverse was found.

Suspended solids concentrations were positively correlated with the PP fraction in samples from all catchments and sub-catchments (Fig. 4.1) although higher concentrations in the Dripsey were infrequent and associated with low storm SS concentrations of less than 150 mg/l. These concentrations were less than storm SS concentrations in the Oona Water and Clarianna of over 300 mg/l. This difference in PP and SS concentration relationship may be related to the sediment coarseness as other workers have noted decreasing PP concentrations with increasing grain size.

The intensity of agriculture was recorded in the Dripsey catchment at 2.2 livestock units per hectare (LU/ha) compared to the national average of ~1.4 LU/ha. The P input of chemical fertiliser in the 2 km^2 mini-catchment was estimated at 17.5 kg P/ha/year in 2002. The corresponding P input from slurry (accrued while animals were fed indoors during the winter period) was estimated at 7 kg/ha. For comparison, the national average annual fertiliser P input for grassland pastures was estimated as

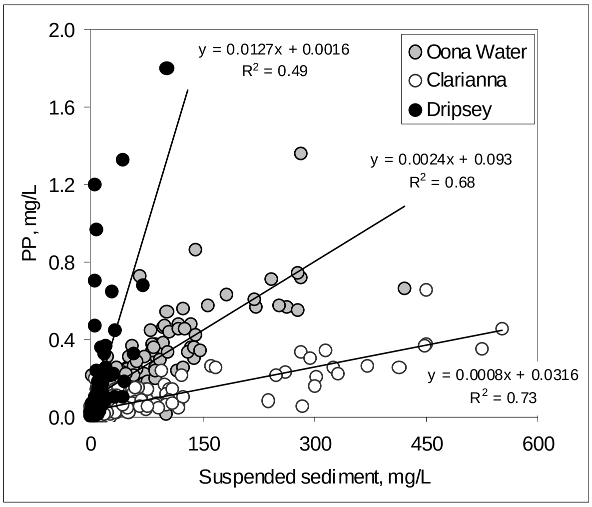

Figure 4.1. Suspended sediment and PP concentrations (mg/l) in the headwaters of the three catchments. The differences between the rivers are probably due to grain size differences in the SS (not measured). The Dripsey recorded higher PP concentrations although these were infrequent and the Oona Water recorded the higher flow-weighted PP concentration for 2002 (0.239 mg/l). The higher SS concentrations in the Clarianna were probably caused by a short period of bed disturbance (dredging) along the whole channel.

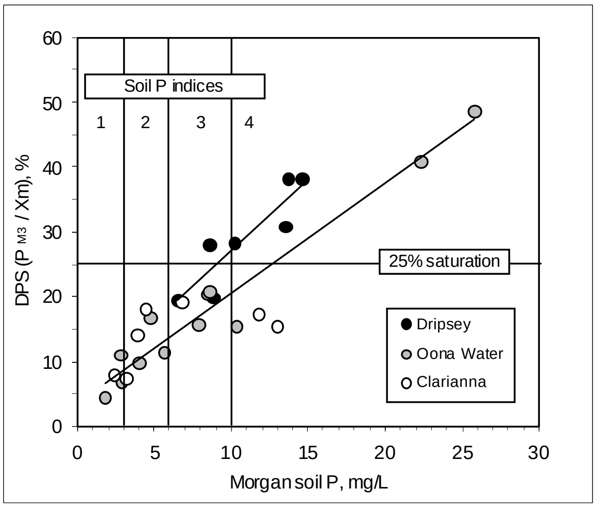

Figure 4.2. Degree of phosphorus saturation (DPS) and soil P test (Morgan) for the three soils using the Langmuir X_m as the denominator and shows that the Dripsey soils were more P saturated for a given soil P test concentration compared with the Oona Water soils. The relationship is less clear with the Clarianna soils as P retention is probably dominated by precipitation/dissolution processes rather than adsorption/desorption processes.

9 kg/ha/year. The measured P loss was 2.48 kg/ha in 2002. This was equivalent to 10.1% of P applied at the 2 km^2 mini-catchment level. In this mini-catchment, 42% of the fields had a soil test P level (Morgan's) greater than 10 mg/l. Some of the highest and some of the lowest soil test P fields were located close to the stream. Approximately 80% of P was exported between October and February in the Dripsey catchment. Data were not collected on fertiliser use or slurry use in the Clarianna and Oona Water catchments.

The Dripsey soils transferred more soluble P than the Oona Water at the small field scale. This agreed with the laboratory assessment that showed the Dripsey soils to have lower P sorption capacities and binding energies, and higher P desorption to solution, compared to Oona soils (Fig. 4.2). Soil types in the Dripsey and Oona Water catchments were characterised as non-calcareous. The Oona Water soils transferred more PP at the small field scale, even though these soils were exposed to much less annual run-off.

A comparison of flow regimes showed that the Oona Water soils produced a flashier and potentially more erosive run-off and this might account for the transfer of higher PP loads. The relationship between flashiness (characterised as the ratio between the Q5 and Q95 flows) and PP transfer was log linear when all catchments were compared (Fig. 4.3a and b).

An increase in catchment size in the Dripsey and Clarianna showed a reduction in overall P load when expressed on a unit area basis. This was not observed in the Oona where there was an increase in TP export of 0.7 kg/ha at the most downstream end of the catchment due to chronically enhanced P transfers between storm events, mainly in soluble form. In the absence of hydrological connectivity from soils to streams between storm events, the sources of these small, non-storm P transfers is an issue for future research. A working hypothesis is that it is accounted for by the cumulative and combined transfers from domestic rural septic systems, farmyards and internal stream-bed loading. This suggests that future research should examine municipal waste-water treatment plants (WWTPs) also, as during flood times WWTPs (which overflow some of the untreated

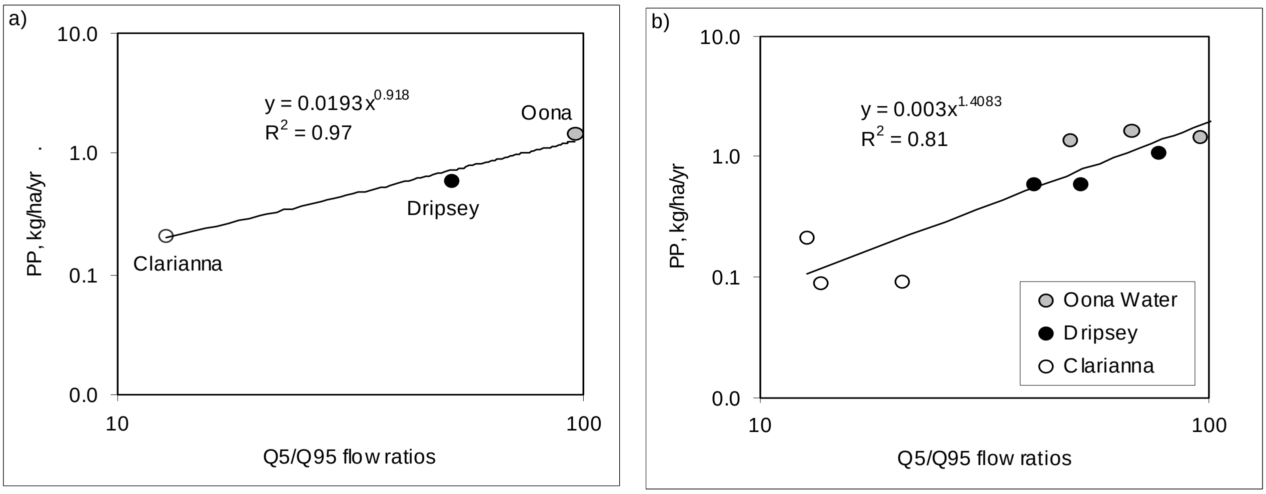

Figure 4.3. Flow statistics using the ratio of high, infrequent flows (Q5) to low, frequent flows (Q95) in the three headwater catchments compared with PP (TP >0.45) load. (a) The relationship shows that, despite less run-off, the potential for the PP fraction to be transferred from fertilised soils in the Oona Water is greater due to run-off flashiness. (b) The relationship is less certain as catchment area increases.

discharge) are known to contribute to sediment, nutrient and pathogenic stream loads.

Surface water P transfers in the Clarianna appeared to be attenuated by highly permeable soils. Whilst the Clarianna soils exhibited similar desorption properties to soils from the Dripsey and Oona Water catchments, it is speculated that some downward retention of P may have occurred in the Clarianna.

5 Conclusions

5.1 Overall Conclusions

- The distribution of rainfall across the three catchments during 2002 was very similar and most storms were recorded concurrently (±1 to 2 days) despite their spatial separation. However, the hydrological responses of the three catchments were different.
- The P losses measured to surface water were three to five times higher than required for good water quality in the two intensive grassland catchments with soil types of moderate to impeded drainage (Dripsey and Oona). The P loss was approximately ten times lower in the well-drained calcareous soils of the Clarianna catchment compared with the Dripsey or Oona.
- The largest P losses were associated with storm events and high-river flows particularly in autumn and early winter in the three catchments.
- Soil type was identified as a major determinant of potential P loss through its influence on P chemistry and flow pathways.
- Catchment scale was important. As scale increases factors such as increased variability in land use, hydrological difference and in-stream processes determine the catchment response. For example, in both the Dripsey and Clarianna, P export decreased with increasing size of catchment. In contrast, in the Oona Water catchment, P export increased as catchment size increased.
- The timing of chemical fertiliser and slurry applications influenced the P export.
- Phosphorus loss to groundwater was found in the Clarianna.

5.2 Specific Conclusions

- Agriculture was the major source of P loss to water in the three rural catchments studied.
- The average soil test P (Morgan's P) was between 10 and 12 mg/l (Index 4) in the three catchments.
- The magnitude of P export (kg/ha) was influenced by:
  - Soil type: Highly fertilised soils transferred soluble or PP depending on the sorption and desorption properties of the soil (soluble P) and the permeability of the soil (PP).
  - Timing of fertilisation particularly with slurry: Slurry spread in wet months is susceptible to transfer to watercourses when rainfall occurs following application.
- Approximately 80% of P export was in the October–February period.
- In the Oona catchment, the high PP loss was associated with the most severe storms.
- Phosphorus export decreased with increasing size of catchment in the Dripsey and Clarianna. In contrast, in the Oona Water catchment, P increased with increasing catchment size.
- High P concentrations were associated with peak stream flows in all three catchments.
- Particulate P was re-mobilised during dredging of the Clarianna.
- Agricultural catchments with non-calcareous fertilised soils with high soil test P levels (Morgan's P), low in Al and high in OM and have a flashy hydrological response to rainfall present a high risk of P via desorption and detachment.

6 General Recommendations

6.1 Preamble

Phosphorus export from two of the three catchments was high (>2.0 kg/ha in 2002). For example, this is equivalent to approximately 10% of the chemical fertiliser P applied at the 2 km^2 Dripsey catchment.

6.2 Action Recommendations

- Phosphorus losses from agriculture must be reduced to achieve water quality targets.
- The soil test P levels of agricultural grasslands should be maintained such that losses to the water environment are minimal and create no threat to water quality. This will normally mean a soil test P level of between 4 and 10 mg/l. Phosphorus applications to grassland soils above this soil test P level should be avoided.
- The completion of a detailed national soil survey is required to provide the information necessary for catchment-specific risk assessment.
- Advice on P management should be at farm scale and should take account of risk at individual field scale.
- The design of water quality monitoring programmes should take account of catchment-scale effects and dynamic hydrological responses.
- Adequate slurry storage must be provided to ensure that slurry is not applied during periods of high risk. The timing of slurry applications should coincide with crop P uptake requirements.
- In catchments similar to the Clarianna, consideration should be given to groundwater in catchment management plans.
- River dredging should be avoided unless demonstrably necessary as it mobilises P-rich sediment.
- In the context of nutrient management plans a new initiative is required to re-emphasise the importance of slurry as a P (and N) source that must have its nutrient value considered and integrated into the farm nutrient management plan.
- It is recommended that a system of farm nutrient balances be extended to all farms and implemented in tandem with a P awareness campaign for farmers.
- It is recommended that a national programme of soil P testing at field level should be implemented.

6.3 Research Recommendations

- Catchment-scale studies should be developed as a means of monitoring the impact of measures to address nutrient loss such as the Nitrates Directive Action Plan (AP) and the Rural Environment Protection Scheme. These should employ farm advisers to collect the agronomic data (stocking rates, fertiliser inputs, spreading dates, etc.) for correlation with water quality. In addition, these catchment studies will perform an important technology transfer function between the stakeholders in rural water quality.
- The Dripsey, Clarianna and Oona Water catchments should be considered as demonstration/monitoring catchments for monitoring the effectiveness of the AP based on their high P and/or N transfer rates and the established infrastructure (including baseline data).
- A pilot-scale (approximately ten farms) real-time web-based meteorological and hydrological forecasting system (including soil moisture status) should be developed to aid farmers with the timing of spreading fertiliser and slurry. This should include the development and testing of a decision support system based on antecedent rainfall, soil moisture and rain forecast.
- The possibility of a real-time weather station for installation at approximately 1,000 km^2 catchment scale should be investigated in consultation with Met Éireann and the EPA (Hydrometric Section).
- Future monitoring should investigate the use of real-time bank-side water-quality analysers so that cause and effect can be properly linked. The intensive

storm-based sampling used in the project to monitor nutrient transfers meant that 'capturing' process-to-pattern data (such as slurry transfers) was opportunistic even with the automatic sampling equipment used.

- A review of P loss control (e.g. buffer strips, wetlands, reed beds) at both farm and catchment scales should be undertaken for Irish conditions. Potential viable systems should be evaluated in flashy (rapid stream flow response to heavy rainfall) catchments to reduce soil erosion.
- Research should be undertaken on the fate of agricultural P in the Clarianna catchment, with connectivity to groundwater, to develop an Irish calcareous soils P (conceptual) model as this soil type accounts for approximately 40% of soil types.
- A P export coefficient-type model should be developed based on land use, soil P chemistry and hydrological regime to differentiate between the same land use in different regions.
- Future research should examine municipal WWTPs also, as during flood times WWTPs (which overflow some of the untreated discharge) are known to contribute to sediment, nutrient and pathogenic stream loads.

Acronyms and Notations

AP	Action Plan
m asl	metres above sea level
MBC	Maximum Buffer Capacity
PP	Particulate Phosphorus
SRP	Soluble Reactive Phosphorus
SS	Suspended Solids
TDP	Total Dissolved Phosphorus
TP	Total Phosphorus
WWTP	Waste-Water Treatment Plants