Soil management and stream water quality at the agricultural catchment scale in Ireland

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Abstract
The effectiveness of the EU Nitrates Directive regulations is being measured in five agricultural catchments in Ireland. The catchments represent a range of typical soil type, geology and climate conditions. A comparison of spatial variation in water chemistry and indicative soil hydrological properties was undertaken to inform phosphorus and nitrogen transport behaviour in the catchments. Morgan soil P was measured for samples collected at 2 ha resolution across three of the catchments. Stream water chemistry was analysed monthly at 8-11 subcatchment locations in four of the catchments. Initial data from the four catchments are presented and indicate that the link between compliant soil nutrient sources and water chemistry is uncertain with flow heterogeneity, source connectivity and sample resolution requiring further investigation at the catchment scale.

Key Words
Phosphorus, nitrate, nutrient source, baseflow, event flow, nitrates directive.

Introduction
To evaluate the effectiveness of new Irish farm soil and nutrient management regulations on water quality, an agricultural catchment monitoring program is being undertaken (Fealy *et al.* 2009). Agricultural catchments ranging in size from 7.5 to 12.1 km^2 were selected to represent a range of soil type, geology and landuses in Ireland. Two catchments are more than 30% cropped with wheat and barley (Tillage A and B) and two are grassland (Grassland A and B) sustaining more than 1.6 livestock units per ha on average with between 3 and 5 months of over-winter housing of stock. Average long-term annual rainfall ranges from 900 to 1200 mm. To quantify stream water chemistry relative to statutory guideline levels and to better understand the spatial and temporal links between soil chemical and physical properties and agricultural management on stream water quality, a series of reconnaissance water chemistry surveys and soil sampling surveys were conducted. Longitudinal water chemistry surveys under both baseflow and stormflow conditions can reveal relative inputs of surface and subsurface-derived water, and spatial variations in soil type, geology, diffuse and point sources of phosphorus (P) and nitrogen (N) (Shand *et al.* 2005; Withers and Hodgkinson 2009). These surveys are part of a wider research programme that includes high resolution time-series sampling of water quality at each catchment outlet and demonstrative studies of surface and subsurface nutrient flux pathways.

Methods
Water sampling and analysis
Grab water samples were collected from 8-11 stream locations in each of two grassland and two tillage catchments on a monthly basis and extra samples were collected opportunistically during storm flow events. Other than a deliberate sampling immediately downstream of a small sewage outfall (75 PE) in catchment Tillage A, observed farm and urban point sources were avoided. Sampling began in either February (Tillage A) or March (other three catchments) 2009. Samples were stored at 4°C prior to chemical analysis. Total molybdate-reactive P (TRP), total oxidised N and nitrite-N were analysed within 32 hours of sample collection. Nitrate-N (NO_3-N) was calculated as the difference between total oxidised N and nitrite-N.

Soil sampling and analysis
Each field within a catchment was sampled according to the standard agronomic soil sampling protocol in Ireland; fields were subdivided into approximately 2 ha sampling areas that accounted for topography, nutrient and crop management history. A composite of twenty 10 cm deep soil cores were taken randomly within each sampling area, dried and ground to <2 mm before chemical analysis for Morgan P.

Results and discussion

Table 1 shows that mean TRP concentrations in all catchments exceeded the 0.035 mg/L chemical standard set in Ireland, for concentrations measured over a 12 month period, for 'Good Status' river water quality. Higher P concentrations in the two less well drained catchments (Grassland B and Tillage B) may reflect higher proportions of surface and near-surface runoff in stream flow where storm events were sampled and/or a significant influence of urban or rural point sources on baseflow water quality. There are currently no standards for NO_3-N for rivers in Ireland apart from the 11.3 mg/L maximum EU limit for water abstracted for drinking purposes, which was not exceeded on any of the sampling occasions in any catchment. The gradient of increase in mean NO_3-N concentrations across catchments broadly matched the relative abundance of well drained soils, probably reflecting contributions from deeper flows. The influence of subsurface flows is supported by stream hydrograph data that are not presented here. Mean and median soil P concentrations (where measured to date) were lower in the Grassland B catchment than the two tillage catchments and were within or below recommended optimum ranges of 5.1-8 mg/L for grassland soils and 6-10 mg/L for tillage soils. Application of off-farm nutrients to soils above these ranges is prohibited. Data so far indicate that catchments are within the 170 kg organic N/ha regulation for equivalent stocking density.

Table 1. Catchment descriptions and mean and median concentrations of selected analytes of field soil and stream outlet water chemistry.

Catchment	Tillage A	Grassland A	Tillage B	Grassland B
Land Use (%)				
Tillage	54	20	33	6
Grassland	39	77	49	84
Geology	Ordovician Metasediments	Ordovician volcanics	Silurian metasediments & volcanics	Old red sandstone and mudstone
Soil				
Description	Acid deep brown earths and podzols	Basic deep brown earths and gleys	Acid deep brown earths and gleys	Acid deep brown earths
Drainage	Well drained uplands and lowlands. Poorly drained alluvial soils.	Poorly drained lowlands, well drained uplands	Moderately drained lowlands and uplands	Well drained uplands, moderately drained lowlands
No. areas sampled	469	389	299	0
P Morgan (mg/L)	5.9, 4.4	4.5, 4.1	6.7, 4.2	Not available
Water				
No. baseflow or intermediate flow samples	6	6	6	6
No. event flow samples	4	3	0	2
TRP (mg/L)	0.040, 0.028	0.063, 0.040	0.071, 0.086	0.037, 0.036
NO_3^--N (mg/L)	6.24, 6.59	2.92, 2.87	5.25, 4.99	6.04, 6.13

Figures 1 and 2 show trends from headwaters to catchment outlets for mean TRP and NO_3-N concentrations during baseflow and event flow samplings for the two tillage catchments and two grassland catchments respectively. A complex pattern of NO_3-N concentration trends occurred across and within each catchment. In all catchments, mean event or intermediate flow concentrations were equal to or less than corresponding baseflow concentrations. In Grassland A marked dilution might have been expected due to the propensity for surface flows, however event NO_3-N dynamics varied seasonally (data not shown); NO_3-N concentrations were high during a spring flush and very low under storm flow in late summer. Higher NO_3-N concentration occurred during baseflow in the Tillage catchments. Within each catchment, downstream trends in NO_3-N concentrations were generally consistent regardless of flow type; all catchments except Grassland B and the north arm of Tillage A exhibited decreasing NO_3-N concentrations downstream. These decreasing trends indicated additions of NO_3-poor tributary flows and lower nutrient inputs on downstream farms in Tillage B, a possible direct influence of NO_3-poor deep groundwater or lower land-use intensity downstream in Tillage A and denitrification of soil NO_3 sources in the heavy lowland soils in Grassland A. In Grassland B, similarity between intermediate and baseflow NO_3-N was probably due to the small range of flow types measured. Nitrate-N in the headwater of the main stream in Grassland B was low, reflecting the buffering effect of ungrazed riparian boglands. Thereafter, concentrations were consistent throughout the catchment, indicating uniformly well-drained soils.

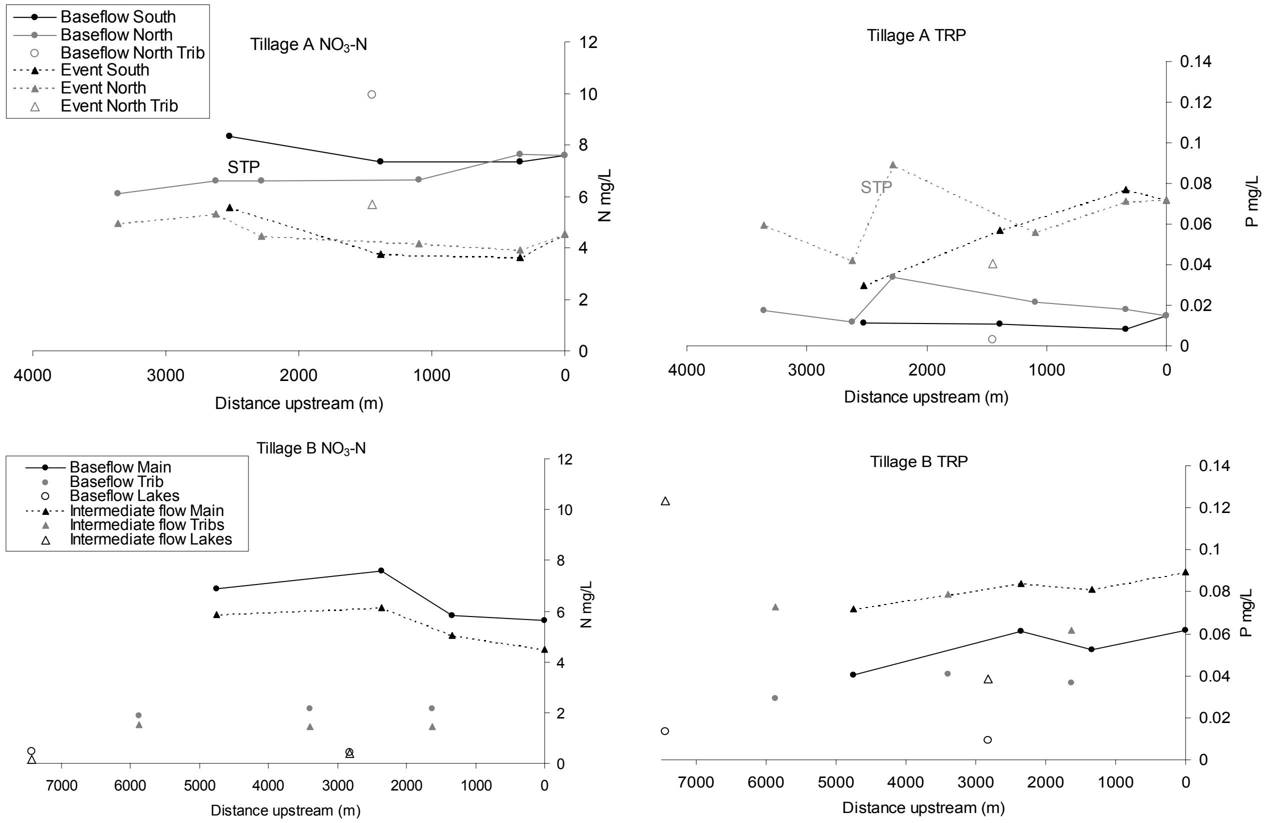

Figure 1. Trends in TRP and nitrate-N concentrations from headwater to outlet in two tillage catchments under baseflow, intermediate or event flow conditions.

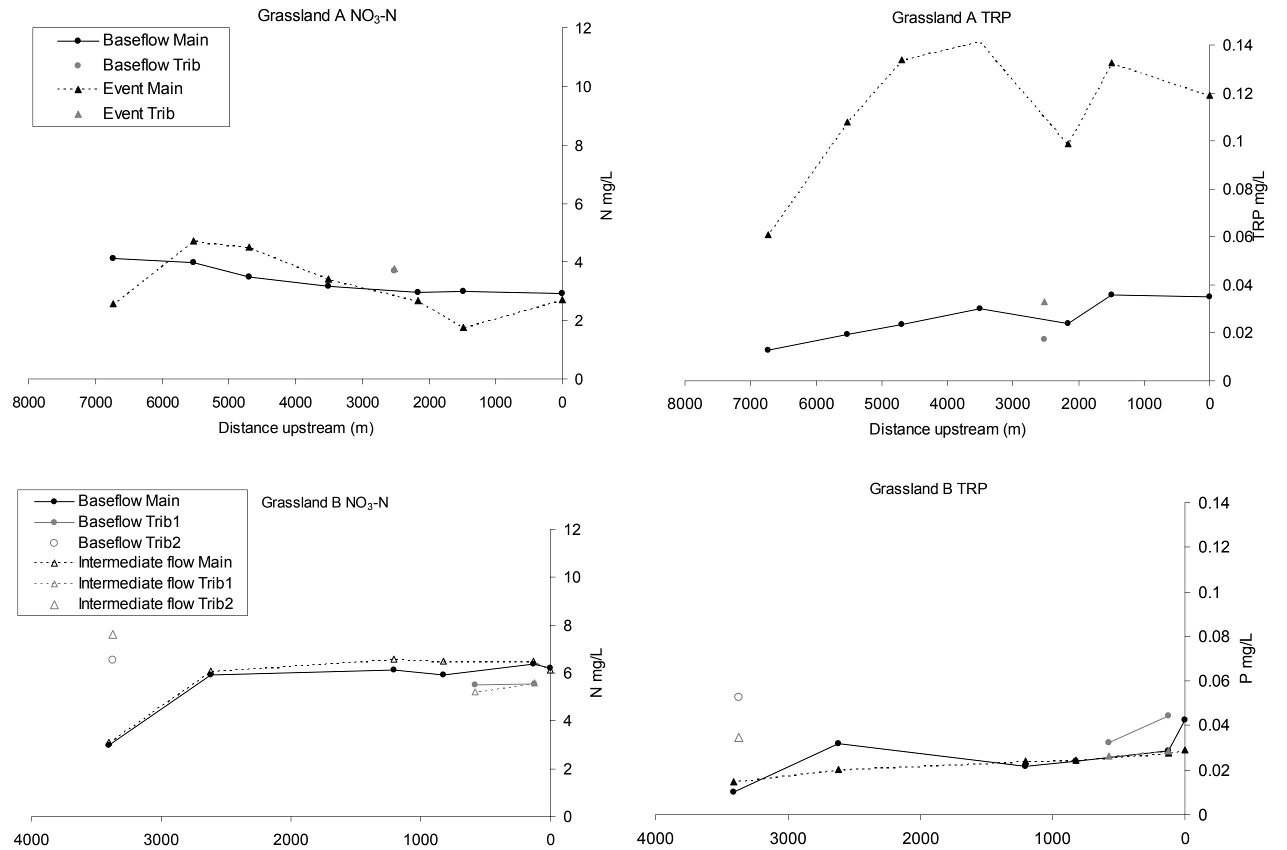

Figure 2. Trends from in TRP and nitrate-N concentrations headwater to outlet in two grassland catchments under baseflow, intermediate or event flow conditions.

In all catchments, TRP concentrations during intermediate, or event flow were equal to, or higher, than during baseflow which reflects mobilisation of surface P sources (dissolved and particulate) from hydrological source areas in fields, and direct wash-off from hard surfaces during storms. During events or intermediate flow, TRP concentrations also increased from headwater to catchment outlet in all catchments suggesting a concomitant increase in intensity of diffuse or point P sources. Source contributions may increase with either; increased density and connectivity to the stream network (critical source areas), or increased frequency of stream disturbance activities such as cattle access and earth works. In all but the south arm of Tillage A, point sources and disturbance activities are likely to play an important role given that the trend for a downstream increase in TRP concentrations was also evident during baseflow. Phosphorus inputs from a small sewage outfall probably explain the marked spike at about 2700 km in Tillage A. In both the well drained catchments, a step change decrease in TRP concentration indicated dilution of stream waters by nutrient-poor tributaries. In Tillage B the low TRP concentrations in the tributaries were likely related to lower intensity land use; however, in Grassland A the tributary and stream headwater were fed by P-depleted spring water.

The study demonstrated that flow type has variable influences on stream nutrient chemistry; intermediate flows and baseflows reflected the integrated diffuse inputs of nutrients, particularly NO_3-N, from soil drainage and discharges from highly connected point-sources whereas event flows revealed the integrated impacts of surface-derived diffuse sources, and rarely-connected or active point sources such as hard surfaces and intermittent earth works. To better qualify and quantify the relative influence of these multiple soil and nutrient sources on stream water quality, baseflow, intermediate and event flows will continue to be sampled at multiple scales. The role of in-stream attenuation and/or mobilisation processes will also be assessed.

Conclusions
This study demonstrated that a combination of soil chemistry, agronomic management practice records, soil and catchment hydrological properties as well as point source distribution, connectivity and activity are required to explain trends in stream nutrient concentrations. The study also demonstrates that flow type and frequency of monitoring has variable influences on stream nutrient chemistry and that stream sampling strategies therefore need to be fit for their purpose. This has implications for comparisons of compliance of soil nutrient status (data show these catchments to be satisfactory) with compliance of stream water chemistry (unsatisfactory with regard to P here even at times of disconnection). Guideline water body concentrations should be accompanied by standardised sampling strategies in order for compliance to be monitored in a comparable way across Ireland.

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References
Fealy RM, Shortle G, Melland AR, Mellander P-E, Mechan S, Buckley C, Wall D, Jordan P (2009) A catchment approach to evaluate the Nitrates Directive National Action Programme in Ireland. In '16th Nitrogen Workshop: Connecting different scales of nitrogen use in agriculture'. (Eds C Grignani, M Acutis, L Zavattaro, L Bechini, C Bertora, P. Marino Gallina, D Sacco) pp. 475-476 (Turin, Italy).

Shand P, Haria AH, Neal C, Griffiths KJ, Gooddy DC, Dixon AJ, Hill T, Buckley DK, Cunningham JE (2005) Hydrochemical heterogeneity in an upland catchment: further characterisation of the spatial, temporal and depth variations in soils, streams and groundwaters of the Plynlimon forested catchments, Wales. *Hydrology and Earth System Sciences* **9**, 621-644.

Withers PJA, Hodgkinson RA (2009) The effect of farming practices on phosphorus transfer to a headwater stream in England. *Agriculture, Ecosystems and Environment* **131**, 347-355.