Agriculture, Ecosystems and Environment 135 (2010) 238–252

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Streamwater phosphorus and nitrogen across a gradient in rural–agricultural land use intensity

H.P. Jarvie [a,*], P.J.A. Withers [b], M.J. Bowes [a], E.J. Palmer-Felgate [a], D.M. Harper [c], K. Wasiak [c], P. Wasiak [c], R.A. Hodgkinson [b], A. Bates [b], C. Stoate [d], M. Neal [a], H.D. Wickham [a], S.A. Harman [a], L.K. Armstrong [a]

[a] Centre for Ecology and Hydrology, Wallingford, Oxfordshire OX10 8BB, UK
[b] ADAS Environment Group, ADAS Gleadthorpe, Meden Vale, Mansfield, Notts NG20 9PF, UK
[c] Department of Biology, University of Leicester, UK
[d] The Game & Wildlife Trust, Allerton Project, Loddington, Leics LE7 9XE, UK

ARTICLE INFO

Article history:
Received 27 February 2009
Received in revised form 27 September 2009
Accepted 2 October 2009
Available online 27 November 2009

Keywords:
Rural population
Nitrogen
Phosphorus
Agriculture
Stream
River
Septic tank
Sewage
Load apportionment model

ABSTRACT

This paper provides an overview of the impacts of rural land use on lowland streamwater phosphorus (P) and nitrogen (N) concentrations and P loads and sources in lowland streams. Based on weekly water quality monitoring, the impacts of agriculture on streamwater P and N hydrochemistry were examined along a gradient of rural–agricultural land use, by monitoring three sets of 'paired' (near-adjacent) rural headwater streams, draining catchments which are representative of the major geology, soil types and rural/agricultural land use types of large areas of lowland Britain. The magnitude and timing of P and N inputs were assessed and the load apportionment model (LAM) was applied to quantify 'continuous' (point) source and 'flow-dependent' (diffuse) source contributions of P to these headwater streams. The results show that intensive arable farming had only a comparatively small impact on streamwater total phosphorus (TP loads), with highly consistent stream diffuse-source TP yields of ca. 0.5 kg-P ha^{-1} $year^{-1}$ for the predominantly arable catchments with both clay and loam soils, compared with 0.4 kg-P ha^{-1} $year^{-1}$ for low agricultural intensity grassland/woodland on similar soil types. In contrast, intensive livestock farming on heavy clay soils resulted in dramatically higher stream diffuse-source TP yields of 2 kg-P ha^{-1} $year^{-1}$. The streamwater hydrochemistry of the livestock-dominated catchment was characterised by high concentrations of organic P, C and N fractions, associated with manure and slurry sources. Across the study sites, the impacts of human settlement were clearly identifiable with effluent inputs from septic tanks and sewage treatment works resulting in large-scale increases in soluble reactive phosphorus (SRP) loads and concentrations. At sites heavily impacted by rural settlements, SRP concentrations under baseflow conditions reached several hundred μg-P L^{-1}. Load apportionment modelling demonstrated significant 'point-source' P inputs to the streams even where there were no sewage treatment works within the upstream catchment. This indicates that, even in sparsely populated rural headwater catchments, small settlements and even isolated groups of houses are sufficient to cause significant nutrient pollution and that septic tank systems serving these rural communities are actually operating as multiple point sources, rather than a diffuse input.

1. Introduction

River eutrophication resulting from phosphorus (P) and nitrogen (N) enrichment is an issue of global significance, leading to deterioration of water quality for potable supply and amenity, as well as reduced aquatic biodiversity (Carpenter et al., 1998a; Cheng and Chi, 2003; Smith, 2003; Neal and Jarvie, 2005). Across the world, intensive agricultural practices, such as cereal production, forage maize, potatoes, intensive dairy and outdoor pigs are generally regarded as 'high risk' for P and N loss to rivers, because they are either regularly over-fertilised, recycle large amounts of manure, or are highly vulnerable to soil erosion (Carpenter et al., 1998b; Chambers et al., 2000; Wilcock et al., 2006). These effects may be exacerbated where 'high-risk' agricultural practices are located in close proximity to watercourses, on steep slopes or on under-drained land, which increase hydrological connectivity, resulting in greater efficiency of delivery of P and N to surface waters (Gburek and Sharpley, 1998; Sharpley et al., 2008). Increasingly, other rural sources, such as sewage treatment works (STW), septic tank overflows and runoff from impervious surfaces (roads and farm-

* Corresponding author at: Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK.
Tel.: +44 01491692260; fax: +44 01491692424.
E-mail address: hpj@ceh.ac.uk (H.P. Jarvie).

0167-8809/$ – see front matter
doi:10.1016/j.agee.2009.10.002

yards) have also been identified as significant sources of P and N to streams draining rural watersheds (Edwards and Withers, 2008; Withers et al., 2009). The synchronicity between P and N delivery and periods of biological nutrient demand is of key importance for eutrophication impacts of P and N sources, which contribute at different times of year and under varying flow conditions (Jarvie et al., 2006; Edwards and Withers, 2007). Appropriate understanding of the relative contributions and timing of P and N inputs to rivers and streams is therefore of central importance for targeting mitigation options most effectively.

In this study, the impacts of agriculture on streamwater P and N hydrochemistry were examined along a gradient of rural–agricultural land use intensities, by means of three sets of 'paired' rural headwater streams. This formed part of a wider study, PARIS (Phosphorus from Agriculture: Riverine Impacts Study; Palmer-Felgate et al., 2009; Withers et al., 2009) and a companion paper examines streambed sediments and the impact of agricultural land use and other geochemical controls on bed-sediment P concentrations (Palmer-Felgate et al., 2009). In this study, we focus on the streamwater component: we examine the magnitude and timing of P and N inputs and quantify the 'point' and 'diffuse' source inputs of P to these headwater streams, using the load apportionment modelling approach (Bowes et al., 2008, 2009). Load apportionment modelling was undertaken for P, which is often the key limiting nutrient in flowing freshwaters and therefore the main target for remediation to reduce eutrophication in rivers and streams (Reynolds and Davies, 2001; Bowes et al., 2007). A full description of the 'paired catchment' approach is provided in Palmer-Felgate et al. (2009): in essence, each set of 'paired' streams included both a stream draining low agricultural intensity rural land use and one or more streams draining higher intensity agricultural land use. 'Paired' streams were chosen with similar baseline catchment characteristics, including catchment area, soils, underlying geology and rainfall patterns. Headwater streams were chosen because they provide a clearer hydrochemical 'fingerprint' of the land use and background geology, whereas the water quality signals in larger rivers are integrated from multiple land use and effluent discharges, which tends to obscure the impacts from individual agricultural land use types.

2. Study sites

The three sets of paired catchments were located in three lowland river basins: the Herefordshire Wye, Hampshire Avon and Leicestershire Welland (Palmer-Felgate et al., 2009). These three river basins were chosen because they are representative of the major geology, soil types and agricultural and rural land use of large areas of lowland Britain. The paired low agricultural intensity and high agricultural intensity streams within each of the catchments were as follows:

Table 1
Summary of catchment characteristics for each of the streamwater monitoring sites in the Wye, Welland and Avon river basins; for more detailed information, see Palmer-Felgate et al. (2009). L denotes low agricultural intensity catchments; H denotes high agricultural intensity catchments.

Basin	Catchment	Area (km^2)	General soils description	Dominant land use	Population and point sources
Wye	Whitchurch (L)	6.4	Sandy silt loam and silty clay loam on variably sloping terrain; soils are highly dispersive and erosive	Low intensity beef and sheep farming and grass and ley-arable crops on the perimeter plateau land	No major wastewater discharges; ca. 90 residents (24% of the rural population of 375) rely on septic tanks
	Dinedor (H)	8.7		Mixed beef/sheep and cereal/potato farms	No major wastewater discharges; the rural population of 290 residents relies on septic tanks, including a village hall
	Kivernoll (H)	9.9		Intensive arable cultivation (winter cereal, oilseed rape, sugar beet, potato); also poultry farming	Small village sewage treatment works (discharges directly to the stream). 190 residents (ca. 27% of the population of 709) rely on septic tanks
Welland	Digby Farm (L)	0.44	Chalky boulder clay soils; seasonally waterlogged clayey and fine loamy over clayey soils; most fields have under-drainage and ditches are common	Permanent pasture (beef, sheep, silage production)	No major wastewater discharges; all 4 residents (1 farm) are served by a septic tank which is not in direct connectivity with stream
	Belton Bridge (H)	1.5		Intensive arable production (cereals, oilseed rape and beans) and mixed agriculture (ley grassland grazed by sheep, spring cereals, stubble turnips)	No major wastewater discharges; ca. 15 residents within 6 houses are served by septic tanks. Septic tank effluent discharges to a network of ditches which ultimately drain into the stream
	Lone Pine (H)	1.2		Sheep and spring cereals and stubble turnips	Sampling site is dominated by direct discharge of effluent from septic tanks in Loddington Village which serve a residential population of ca. 30.
Avon	Cools Cottage (L)	1.6	Seasonally waterlogged fine loamy over clay soil; under-drained to varying levels of efficiency	Largely woodland and permanent pasture; grazed by beef cattle and calves in summer	No major wastewater discharges; 10 residents, all on septic tanks
	Priors Farm (H)	4.7		Grassland for intensive dairy production; more recent reversion to beef farming and forage maize. Stream receives direct runoff from farmyards, cattle crossings and buildings housing beef cattle during winter are located close to the stream	Resident catchment population of 515, of which 115 (22%) are served by septic tanks; the remainder of the population are on mains sewerage to a sewage treatment works in the northern part of the catchment. However, the treatment works discharges to a constructed wetland and not directly into the stream