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Sewage-effluent phosphorus: A greater risk to river eutrophication than agricultural phosphorus?

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Abstract

Phosphorus (P) concentrations from water quality monitoring at 54 UK river sites across seven major lowland catchment systems are examined in relation to eutrophication risk and to the relative importance of point and diffuse sources. The over-riding evidence indicates that point (effluent) rather than diffuse (agricultural) sources of phosphorus provide the most significant risk for river eutrophication, even in rural areas with high agricultural phosphorus losses. Traditionally, the relative importance of point and diffuse sources has been assessed from annual P flux budgets, which are often dominated by diffuse inputs in storm runoff from intensively managed agricultural land. However, the ecological risk associated with nuisance algal growth in rivers is largely linked to soluble reactive phosphorus (SRP) concentrations during times of ecological sensitivity (spring/summer low-flow periods), when biological activity is at its highest. The relationships between SRP and total phosphorus (TP; total dissolved P + suspended particulate P) concentrations within UK rivers are evaluated in relation to flow and boron (B; a tracer of sewage effluent). SRP is the dominant P fraction (average 67% of TP) in all of the rivers monitored, with higher percentages at low flows. In most of the rivers the highest SRP concentrations occur under low-flow conditions and SRP concentrations are diluted as flows increase, which is indicative of point, rather than diffuse, sources. Strong positive correlations between SRP and B (also TP and B) across all the 54 river monitoring sites also confirm the primary importance of point source controls of phosphorus concentrations in these rivers, particularly during spring and summer low flows, which are times of greatest eutrophication risk. Particulate phosphorus (PP) may form a significant proportion of the phosphorus load to rivers, particularly during winter storm events, but this is of questionable relevance for river eutrophication. Although some of the agriculturally derived PP is retained as sediment on the river bed, in most cases this bed sediment showed potential for removal of SRP from the overlying river water during spring and summer low flows. Thus, bed sediments may well be helping to reduce SRP concentrations within the river at times of eutrophication risk. These findings have important implications for targeting environmental management controls for phosphorus more efficiently, in relation to the European Union Water Framework Directive requirements to maintain/improve the ecological quality of impacted lowland rivers. For the UK rivers examined here, our results demonstrate that an important starting point for reducing phosphorus concentrations to the levels approaching those required for ecological improvement, is to obtain better control over point source inputs, particularly small point sources discharging to ecologically sensitive rural/agricultural tributaries.

Keywords: Eutrophication; Water Framework Directive; Phosphorus; Sewage; Agriculture; Rivers; LOIS; Humber; Wye; Avon; Thames

1. Introduction

Eutrophication of lowland rivers is of international concern and phosphorus (P) is a key limiting nutrient

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(Hecky and Kilham, 1988; Grobbelaar and House, 1995; Mainstone and Parr, 2002; Reynolds and Davies, 2001). The new European Union (EU) Water Framework Directive (WFD) requires widespread control of phosphorus inputs to rivers to sustain/improve riverine ecology: Directive 2000/60/EC, 2000 (EC, 2000). The major sources of phosphorus to rivers are sewage/industrial effluents (point sources) and agricultural runoff (diffuse sources). The relative importance of these sources has traditionally been assessed from annual flux budgets of dissolved and particulate phosphorus. These fluxes are often dominated by diffuse phosphorus inputs in storm runoff from intensively managed agricultural land (Heathwaite and Dils, 2000; Haygarth et al., 1998; Wade et al., 2002; Withers and Lord, 2002). It is estimated that about 50% of the annual phosphorus *load* to UK waters is now derived from agriculture (Defra, 2004) but ecological quality of rivers is primarily linked to phosphorus *concentrations* during periods of ecological sensitivity (spring and summer low river flows; Mainstone and Parr, 2002).

The WFD demands new approaches for managing and improving surface water quality across the EU for a wide range of chemical substances, with emphasis shifting from chemical towards ecological water quality standards. Phosphorus is targeted under the WFD because of its contribution to eutrophication of surface waters, particularly the proliferation of nuisance phytoplankton as well as epiphytic and benthic algae (Mainstone and Parr, 2002; Jarvie et al., 2004). Although there is no widely accepted UK/international water quality standard for phosphorus in river waters, a mean of 100 μG-P l^{-1}, or less, of soluble reactive phosphorus (SRP: the dissolved, largely inorganic and most bioavailable phosphorus fraction; Reynolds and Davies, 2001) has been proposed (EA, 2000; DoE, 1993). An analysis of SRP concentrations in 98 rivers in England and Wales showed that 80% of the rivers failed this target (Muscutt and Withers, 1996). The undesirable symptoms of eutrophication in rivers occur primarily at low flows during the growing season (from spring through to early autumn) when higher water residence times, abundant light levels and high water temperatures promote rapid algal growth (Mainstone and Parr, 2002). Further, within-river phosphorus cycling and flux attenuation involves a complex interaction between sediments, aquatic plants and biofilms and the water column (House and Denison, 1997, 2002; House and Warwick, 1999; House, 2003; Jarvie et al., 2002b, 2005).

In this paper, we draw on results of water quality studies from a wide range of UK river types to assess the importance of point and diffuse phosphorus inputs. Critically, sewage sources of phosphorus are characterised here using a relatively unreactive chemical tracer, boron (B), which is derived predominantly from detergents discharged in sewage effluent (Bassett, 1980; Dyer and Caprara, 1997; Neal et al., 1998; Jarvie et al., 2002a,c; Neal et al., 2005a). Here, our findings are integrated to provide new insights into the sources, timing and potential impacts of phosphorus in rivers.

2. Field studies and methodologies

Over the last decade or more, the Centre for Ecology and Hydrology at Wallingford has studied the sourcing and dynamics of river phosphorus concentrations across seven wide-ranging lowland UK catchments (Fig. 1). These catchments varied from large urban/industrial catchments (the Humber and Wear), to rural and agriculturally dominated catchments (the Tweed, Thames and Great Ouse) and to smaller rural rivers systems with a range of agricultural land-use intensities (the Herefordshire Wye and Hampshire Avon). They also included agricultural catchments with expanding urban centres alongside major watercourses (c.f. companion studies within this volume for the Thame (Neal et al., 2005b) and the Cherwell (Neal et al., 2005c) which are both in the Thames Valley).

At each of the river monitoring sites, weekly water-quality samples were collected over a number of years.

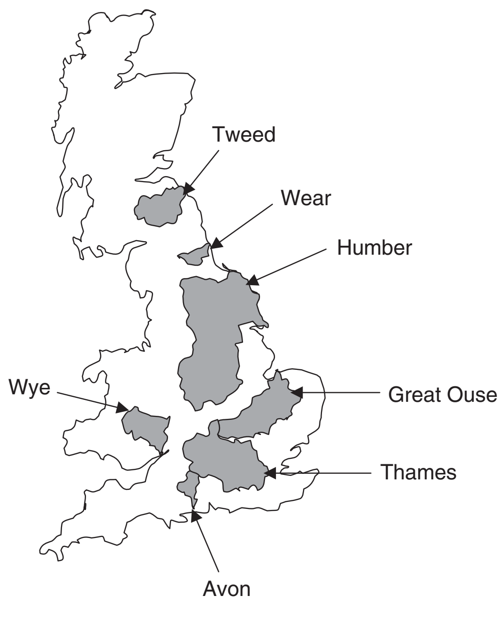

Fig. 1. Map of Great Britain showing the river catchment areas covered in the study. Water quality sampling was undertaken at 54 sites within these catchments.