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Kinetics of phosphorus release from a natural mixed grain-size sediment with associated algal biofilms

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Abstract

Experiments using flumes containing mixed grain-size sediment with an associated algal biofilm, from two sites on the R. Tame, investigated the sediment–water exchanges in heterogeneous sediment deposits. These results were considered in the light of findings of a companion study [Gainswin BE, et al. The effects of sediment size fraction and associated algal biofilms on the kinetics of phosphorus release. Sci Total Environ, this issue.] by considering this natural system in relation to the effects of the different sizes of material comprising the sediment.

Sediment samples were collected in trays installed in the river over a period of one growth cycle (March 2001–April 2002) and placed in flume channels with controlled water flow. The temperature, pH, and dissolved oxygen of the solution overlying the sediment were monitored automatically whilst filtered samples were obtained at 2-0h intervals over 48 h. The biomass, expressed as chlorophyll *a*, of the algal component of the biofilm from the surface of the sediment was estimated using methanol extraction. The composition of the sediment, viz. size fractions, organic matter and porosity, were determined at the end of the experiments.

The equilibrium phosphate concentration and a phosphorus transfer index were used to establish that a net uptake of phosphorus by some of the samples that occurred at the time of sampling. The results were modelled using a Diffusion Boundary Layer model and the maximum flux from the sediment (or limiting diffusion flux) compared for each of the samples. The limiting diffusion flux was highest at the most contaminated site—reaching ~180 nmol m^{-2} s^{-1} (normalised with respect to the river bed area). The limiting diffusion flux calculated for the composite samples was in agreement with the flux estimated from the contributions expected from the individual size fractions [Gainswin BE, et al. The effects of sediment size fraction and associated algal biofilms on the kinetics of phosphorus release. Sci Total Environ, this issue.]. The dominance of the flux contribution from the stones size fraction (>20 mm) confirms that sediment having a filamentous biofilm and associated particulate material results in a greater flux than a silt sediment without such a biomass.

Keywords: Phosphorus; Phosphate; Soluble reactive phosphorus; Equilibrium phosphate concentration; Algae; Algal biofilm; River sediment; Tame; Trent; URGENT

1. Introduction

There is now a strong focus on the regeneration of urban areas, and it is important to find the most effective and efficient techniques. Industrialisation has often left these urban heartlands severely contaminated, and it is essential to recognize any potential ecological risks from contaminated river sediments by understanding their complex internal processes.

One of the most common contaminants in rivers is dissolved phosphorus (Mainstone and Parr, 2002), an

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important nutrient (Bowes and House, 2001), which, when associated with particulate materials, may remain sequestered in sediments for long periods. However, physico-chemical changes in the system can cause it to be released (Golterman, 2001; House, 2003), and the development of an algal biofilm on the river bed (Woodruff et al., 1999a,b) is one of the factors that can influence such changes.

Large quantities of soluble inorganic phosphorus in waterways are the most common cause of eutrophication (Likens, 1972; Moss et al., 1986). In lentic systems, the sediment–phosphorus interaction has been studied in detail (Mortimer, 1941; Moss et al., 1986), but the bulk of research has been on silt sediments as this size fraction was thought to be primary responsible for fluxes of phosphorus. Although some earlier work concentrated on the effects of biofilm development on processes in the fine (<2 mm) fraction of a river sediment (Woodruff et al., 1999a,b), little information is yet available for riverine systems with a mixed grain-size sediment. A companion paper reported research into the effects different grain-size material (Gainswin et al., 2006-this issue) and an associated filamentous algal biofilm had on chemical fluxes at the sediment surface. The aims of the work reported here were to measure the flux of phosphorus, as the bioavailable soluble reactive phosphorus (SRP), out of a natural, heterogeneous sediment comprising various grain sizes, and to study the kinetics of these movements; also, to build on the findings of the previous study (Gainswin et al., 2006-this issue) by considering this natural system in relation to the effects of the different sizes of bed sediment material on the exchanges. This was carried out over an entire biofilm growth cycle with the objective of assessing what effects the seasonal changes in a natural system would have on the sediment–water exchange.

2. Methods

2.1. Field sites

Flowing through a large conurbation to the north of Birmingham, UK, the River Tame eventually joins the River Trent between Lichfield and Burton-on-Trent, where it supplies water to abstraction storage ponds. It has a history of contamination from heavy industry and is still subjected to effluents from numerous sewage treatment works; the largest of which impacting the field sites is Ray Hall (NGR SP0232094440) with a people equivalent (p.e., an estimate of the number of people served by a treatment plant) of 162,000 (Severn Trent Water unpublished data). Further information on the study area can be found in the companion paper (Gainswin et al., 2006-this issue). The two study sites considered to be the most suitable for sampling on the upper reaches of the Tame were Bentley Mill Way (BM) (NGR: SO 995994) and, approximately 7 km downstream, Sandwell Valley (SV) (NGR: SP 929028). They were selected to provide the broadest possible representation of bed-sediment types, although they are dominated by coarser material. Higher and lower flow regimes in this upper catchment were also represented, and the sites were sufficiently far apart to detect differences in water and sediment chemistry. All site visits were made over the period November 2000 to April 2003.

2.2. Field surveying and sampling

At each site, a 100-m reach was marked and divided into a grid of 10-m sections. Rectangular cross-sectioned, polypropylene sampling trays, 10 cm × 40 cm and 5 cm deep, were installed in the bed sediment longitudinally in-line with the direction of flow and at a depth such that their top edges were flush with the bed surface. Ten trays were installed randomly in the measured reach at each site to ensure potential variability in the bed characteristics was accounted for. Their positions within the grid system were determined by Excel random number generation (Gainswin et al., 2006-this issue). Trays were seeded with the material taken from the hole in the riverbed in which they were placed.

During site visits when flow conditions allowed, a set of field observations was made recording the changes in the general appearance of the bed of each 100-m measured reach and its margins. Field measurements of water temperature, pH, dissolved oxygen (DO) and conductivity were made and other physical and meteorological information was noted (Gainswin et al., 2006-this issue).

On removal of a sample tray for an experiment, additional entire sediment was obtained from each location to characterise the sediment for organic matter, porosity, density, and size fraction. The water flow velocity at each sampling position was measured prior to the removal of the tray . Large skeins of filamentous algae attached to the surfaces of the material in the trays were removed and used later in the chlorophyll *a* analysis. All materials were stored in the dark until return to the laboratory.

2.3. Experimental flumes

The flumes, developed from an earlier design (House et al., 1995b), comprised a pair of re-circulating