Science of the Total Environment 481 (2014) 157–166

Contents lists available at ScienceDirect

Science of the Total Environment

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

Distributed and dynamic modelling of hydrology, phosphorus and ecology in the Hampshire Avon and Blashford Lakes: Evaluating alternative strategies to meet WFD standards

P.G. Whitehead [a,*], L. Jin [b], J. Crossman [a], S. Comber [c], P.J. Johnes [g], P. Daldorph [d], N. Flynn [i], A.L. Collins [h], D. Butterfield [a], R. Mistry [d], R. Bardon [e], L. Pope [f], R. Willows [f]

[a] School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK
[b] Department of Geology, State University of New York College at Cortland, Cortland, NY 13045, USA
[c] Department of Environmental Science, Plymouth University, Drakes Circus, Plymouth PL4 8AA, UK
[d] Atkins Limited, Chadwick House, Birchwood, Warrington WA3 6AE, UK
[e] Wessex Water, Clevedon Walk, Nailsea, Bristol BS48 1WA, UK
[f] Environment Agency, Thames Regional Office, Kings Meadow House, Kings Meadow Road, Reading, Berkshire RG1 8DQ, UK
[g] School of Geographical Sciences, University of Bristol, University Road, Bristol, BS8 1SS, UK and Cabot Institute, University of Bristol, Bristol BS8 1UJ, UK
[h] Sustainable Soils and Grassland Systems Department, Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[i] School of Geography and Environmental Science, University of Reading, RG6 6AB. UK

HIGHLIGHTS

- Model phosphorus impacts on river phosphorus concentrations in the Hampshire Avon.
- Examine the effectiveness of mitigation policies for P control.
- P sources in the river are sourced equally from agriculture and from STWs.
- P removal from both agricultural sources and STWs are required to meet the WFD.

ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form 30 January 2014
Accepted 2 February 2014
Available online 2 March 2014

Keywords:
Water quality
Phosphorus
Modelling
Hampshire Avon

ABSTRACT

The issues of diffuse and point source phosphorus (P) pollution in the Hampshire Avon and Blashford Lakes are explored using a catchment model of the river system. A multibranch, process based, dynamic water quality model (INCA-P) has been applied to the whole river system to simulate water fluxes, total phosphorus (TP) and soluble reactive phosphorus (SRP) concentrations and ecology. The model has been used to assess impacts of both agricultural runoff and point sources from waste water treatment plants (WWTPs) on water quality. The results show that agriculture contributes approximately 40% of the phosphorus load and point sources the other 60% of the load in this catchment. A set of scenarios have been investigated to assess the impacts of alternative phosphorus reduction strategies and it is shown that a combined strategy of agricultural phosphorus reduction through either fertiliser reductions or better phosphorus management together with improved treatment at WWTPs would reduce the SRP concentrations in the river to acceptable levels to meet the EU Water Framework Directive (WFD) requirements. A seasonal strategy for WWTP phosphorus reductions would achieve significant benefits at reduced cost.

1. Introduction

In Europe, legislation including the Water Framework (WFD), Urban Wastewater Treatment (UWWTD) and Habitats Directives set objectives for wastewater treatment and water quality standards with respect to phosphorus (P). The current regulatory environment poses as a major challenge to the water sector in the UK. Approximately 1000 waste water treatment plants (WWTPs) are predicted to be causing downstream exceedences of Environmental Quality Standards (EQSs) as specified under the WFD (Comber et al., 2009). This prediction does not take into account the impacts of upstream inputs, such as from agriculture, or other WWTPs. With approximately 700 WWTPs in the UK planning or already implementing measures to reduce P loads to vulnerable water bodies it is imperative that an accurate assessment of best management practises is made.

It has become apparent that a catchment-based approach is required to improve water quality and ecological status using a combination of measures to reduce agricultural and wastewater derived inputs, including consideration of options such as seasonal-based permitting of P

* Corresponding author. Tel.: +44 7972805094.
E-mail address: paul.whitehead@ouce.ox.ac.uk (P.G. Whitehead).

0048-9697/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2014.02.007

discharges from WWTPs. Currently water companies are obliged to meet annual average targets of typically 1 or 2 mg/l of total phosphorus (TP) all year round, depending on the size of a WWTP and sensitivity of the receiving water. However, a more beneficial ecological outcome may be derived from applying tighter permits during summer months when biological activity is at its highest, then allow a more relaxed permit during the winter when higher flows and lower productivity ensure that the impacts of P derived from WWTPs would be significantly reduced.

In this paper we assess the hydrology and water quality of the Hampshire Avon, using the model INCA-P (Wade et al., 2002a; Whitehead et al., 2011). By simulating the phosphorus balances throughout the catchment and applying a series of management strategies, we aim to quantify the effects of alternative control measures such as P removal at WWTPs or P reductions from agricultural sources. Phosphorus budgets and mitigation measures have been investigated from a field data perspective or an export coefficient approach by many lead researchers such as Sharpley et al. (1994), Jarvie et al. (2002, 2006), Johnes and Butterfield (2003), Neal and Jarvie (2005), Neal et al. (2010, 2006) and Zhang et al. (2012), but in this study we utilise a process based dynamic model, which allows a more complete mass balance and an assessment of the dynamic interactions within the catchment.

2. The Hampshire Avon

The Hampshire Avon lies within the counties of Dorset, Hampshire and Wiltshire and has a catchment area of approximately 1750 km^2 (Fig. 1). It is largely a spring fed, groundwater dominated river giving relatively stable base flow throughout the year. The majority of the river is designated as a Site of Special Scientific Interest (SSSI); it has also been declared as a Special Area of Conservation (SAC) under the European Union (EU) Habitats Directive. Parts of the catchment lie within Areas of Outstanding Natural Beauty (AONB), areas of high scenic quality that have statutory protection in order to conserve and enhance the ecology of the river system. Many of the SSSI units are currently judged to be in an unfavourable condition mainly due to adverse nutrient levels, particularly phosphates, and reduced flows either from abstraction or historic land drainage and channel modifications. Currently only 30% of water bodies in the catchment are considered to be in a good ecological condition (Environment Agency, 2011). Soluble reactive phosphorus concentrations exceeding the Environmental Quality Standard (0.12 mg-P/l) are a major source of water body classification not reaching good status in the Avon. Concentrations exceeding the EQS for 'good' status are observed sporadically along the length of the catchment and values generally exceed the value for 'high' status (0.05 mg-SRP/l) which a river that is classified as a SAC should be seeking to achieve.

2.1. Geology

The Hampshire Avon, although predominantly a Chalk catchment, has a varied geology. Much of the upper catchment is underlain by the Chalk of Salisbury Plain. But elsewhere older formations such as the Upper Greensand, Gault, Lower Greensand, Wealden clay and the Purbeck and Portland limestones are exposed. In other places tertiary deposits such as the London clay, Poole formation, Branksome sand and Barton group all overlie the Chalk. Also, river terrace deposits and alluvium are present in the Avon valley south of Salisbury. Except for some areas in the New Forest, the river is largely spring-fed with the Chalk strata providing a large storage capacity and relatively stable base flow throughout the year. The Chalk and Upper Greensand are classified under the Environment Agency (EA) Policy and Practice for the Protection of Groundwater as highly vulnerable major aquifers,

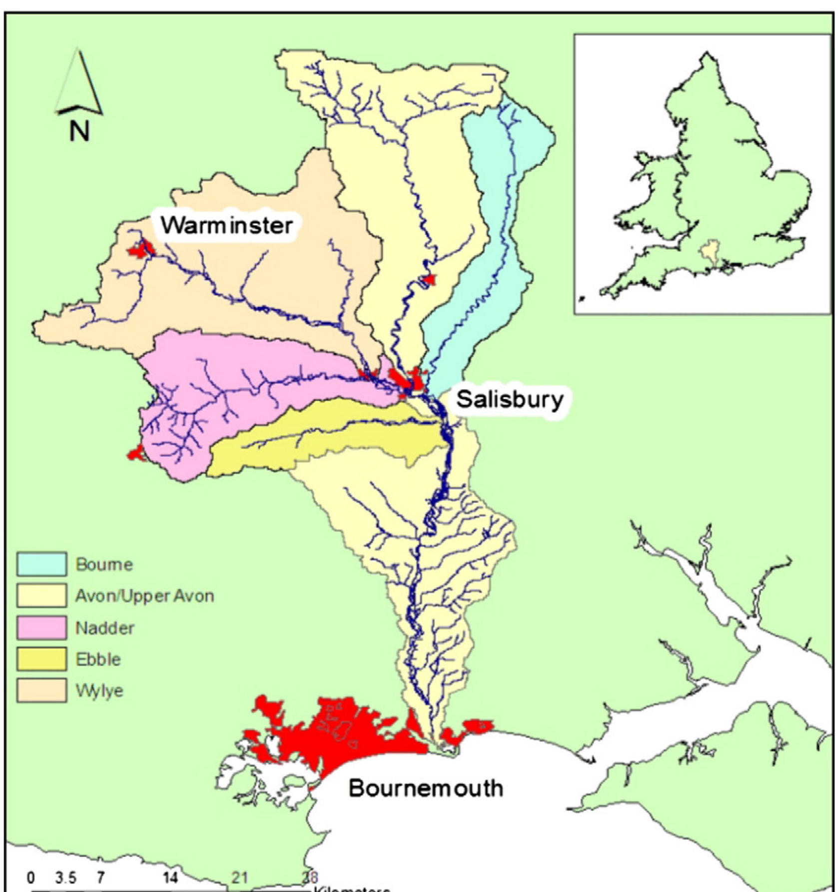

Fig. 1. River Avon, Hampshire showing the main tributaries and towns.