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Changes in water quality of the River Frome (UK) from 1965 to 2009: Is phosphorus mitigation finally working?

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ABSTRACT

The water quality of the River Frome, Dorset, southern England, was monitored at weekly intervals from 1965 until 2009. Determinands included phosphorus, nitrogen, silicon, potassium, calcium, sodium, magnesium, pH, alkalinity and temperature. Nitrate-N concentrations increased from an annual average of 2.4 mg l^{-1} in the mid to late 1960s to 6.0 mg l^{-1} in 2008–2009, but the rate of increase was beginning to slow. Annual soluble reactive phosphorus (SRP) concentrations increased from 101 μg l^{-1} in the mid 1960s to a maximum of 190 μg l^{-1} in 1989. In 2002, there was a step reduction in SRP concentration (average = 88 μg l^{-1} in 2002–2005), with further improvement in 2007–2009 (average = 49 μg l^{-1}), due to the introduction of phosphorus stripping at sewage treatment works. Phosphorus and nitrate concentrations showed clear annual cycles, related to the timing of inputs from the catchment, and within-stream bioaccumulation and release. Annual depressions in silicon concentration each spring (due to diatom proliferation) reached a maximum between 1980 and 1991, (the period of maximum SRP concentration) indicating that algal biomass had increased within the river. The timing of these silicon depressions was closely related to temperature. Excess carbon dioxide partial pressures ($EpCO_2$) of 60 times atmospheric CO_2 were also observed through the winter periods from 1980 to 1992, when phosphorus concentration was greatest, indicating very high respiration rates due to microbial decomposition of this enhanced biomass. Declining phosphorus concentrations since 2002 reduced productivity and algal biomass in the summer, and $EpCO_2$ through the winter, indicating that sewage treatment improvements had improved riverine ecology. Algal blooms were limited by phosphorus, rather than silicon concentration. The value of long-term water quality data sets is discussed. The data from this monitoring programme are made freely available to the wider science community through the CEH data portal (http://gateway.ceh.ac.uk/).

1. Introduction

The River Frome in Dorset, southern England, is one of the most intensively studied rivers in the UK. The Freshwater Biological Association's River Laboratory facility at East Stoke on the banks of the lower reaches of the River Frome, and the catchment's inclusion in the Natural Environment Research Council's Lowland Catchment Research programme (LOCAR) (Wheater and Peach, 2004) have provided a strong focus for integrated research on this environmentally important Chalk river since the 1960s.

The large number of resulting studies, covering a wide range of physical, chemical and biological parameters, provides a major resource for future interdisciplinary catchment research. Long-term changes in the River Frome's water chemistry (Casey, 1975; Casey and Newton, 1973; Howden et al., 2010) and nutrient concentrations (Casey, 1986; Casey and Clarke, 1979; Howden and Burt, 2008) have been assessed, both temporally and spatially, along the river continuum. The sources of nutrients entering the river (Bowes et al., 2008; Bowes et al., 2009b; Casey et al., 1993; Hanrahan et al., 2001), the fates and behaviour of these nutrients within the river channel (Bowes et al., 2005; Bowes et al., 2009a; Casey and Farr, 1982; House et al., 2001; Sanders and Trimmer, 2006) and how these nutrients affect algal growth rates (Bowes et al., 2007) have been intensively studied. Inputs of groundwater along the entire river continuum have been directly quantified at high spatial resolution (Arnott et al., 2009) and temporal changes in groundwater nitrate concentrations across the catchment have been modelled (Smith et al., 2010). Sediment sources (Ballantine et al., 2009; Collins and Walling, 2007b) and fate

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within the river channel (Collins and Walling, 2007a; Cotton et al., 2006; Heppell et al., 2009) have also been investigated. The biota of the River Frome has been extensively studied over the last four decades, detailing macrophyte (Gurnell et al., 2006; O'Hare et al., 2007), fish (Clough et al., 1998; Mann, 1989; Welton et al., 1999), invertebrate (Armitage et al., 2003; Cannan and Armitage, 1999; Pinder and Farr, 1987) and microbial (Bradley et al., 2010) distributions and assemblages.

Many of these studies have been either directly based upon or supported by the existence of a unique data set of weekly water-quality monitoring for the River Frome at East Stoke, which has been maintained from 1965 until 2009. Such long-term data sets are rare in the UK, and of great national and international importance, as they supply vital evidence in assessing the effectiveness of previous catchment management policies (Burt et al., 2008; Holmes, 2006), and provide an 'early warning system' that is able to detect both sudden and long-term changes in chemical and biological functioning (Burt et al., 2010). Such data also provide a vital resource for environmental modellers, allowing them to assess the likely outcomes of future policy decisions, changes in catchment land use and to predict the effects of processes such as climate change.

This paper presents, for the first time, the complete time series for all determinands from this 44-year data set. The changes in water chemistry and nutrient concentrations are examined in the context of known land use changes within the catchment and used to infer possible changes in riverine ecology from the seasonal to the decadal scale. The core to the paper is the examination of a key environmental management question: is phosphorus mitigation finally working, both in terms of reducing nutrient concentrations in the river, and reducing excessive algal biomass that is associated with the process of eutrophication? The impact that changing nutrient concentrations have on the biological functioning of our rivers has become critically recognised within the context of the Water Framework Directive (WFD). However, it is not clear how changes in water quality are translated into changes in ecological status, and there is growing evidence that step changes in nutrient status often have little or no impact on riverine biology in UK rivers (Kelly and Wilson, 2004; Neal et al., 2010). The impact of the many catchment management and land-use changes that have occurred over the decades can only be fully assessed and understood by the presence of long-term monitoring data sets such as this one for the River Frome.

The authors understand the great value that a resource such as this data set offers, not only to researchers working on the River Frome catchment, but also to environmental scientists in general, studying long-term changes in river chemistry and biology. Therefore, alongside the publication of this paper, the joint owners of these data, the Centre for Ecology and Hydrology (CEH) and their parent organisation, the Natural Environment Research Council, and the Freshwater Biological Association, will release the entire data set for use by the wider scientific community. It is hoped that this data set will be of use for environmental research, modelling, catchment management and as a resource for education. These data can be downloaded through the openly accessible data portals at http://gateway.ceh.ac.uk/ (the CEH Information Gateway) and the Freshwater Biological Association's data portal at www.freshwaterlife.org/data. River Frome discharge data, gathered from the Environment Agency gauging station at East Stoke and provided by the CEH National River Flow Archive, have also been integrated into the water quality data set, to increase the utility of this long-term record.

1.1. Details of the data set

The Freshwater Biological Association began weekly monitoring of the water chemistry of the River Frome at East Stoke, Dorset, (National Grid Reference SY 867868) in January 1965. The maintenance of the data set was subsequently taken over by the Institute of Freshwater Ecology (1989 to 2001) and the Centre for Ecology and Hydrology from 2002 until monitoring ceased at the end of May 2009, with the closure of CEH's Dorset site. From 2004 to 2006, samples were analysed by an external laboratory (Thames Water) as part of the LOCAR research programme. The sampling record is relatively continuous, consisting of over 2100 weekly samples, equivalent to an average of 49 samples per year over the entire monitoring period. The range of water quality determinands analysed has increased over the decades, to include phosphorus and nitrogen speciation, major anions, suspended sediment concentration, and physical determinands, such as temperature and conductivity (Table 1).

1.2. Study area

The River Frome extends from the village of Evershot on the Dorset–Somerset border, to Poole Harbour (Fig. 1). It has a catchment area of 414 km^2 (Marsh and Hannaford, 2008), which is mainly underlain by Cretaceous Chalk bedrock, with areas of Cretaceous greensand in the River Hooke sub-catchment. A fuller description of the geology is given elsewhere (Arnott et al., 2009). The land use is primarily agricultural (mainly grassland and cereals), with some aquaculture (watercress production) on the River Frome (around the town of Dorchester) and the River Tadnoll. Dorchester is the only significant urban area in the catchment, with a population of 16,180 in 2001 (Bowes et al., 2009b). For the period 1965 to 2005, the mean annual rainfall at East Stoke was 1020 mm, the mean annual discharge was 6.38 $m^3 s^{-1}$, and the baseflow index was 0.84 (Marsh and Hannaford, 2008).

2. Methodology

Water samples were manually sampled from the main flow of the river at the flow gauging station at East Stoke, filtered on return to the laboratory (within one hour) and analysed as rapidly as possible (usually within a few days and always within one week) to minimise errors associated with sample stability. Samples that could not be analysed within this allotted time, due to instrument break down, failure to meet quality control standards, or due to lack of analytical staff time, were omitted from the data set.

Due to the long-term nature of this data set, the methodologies used to quantify determinands have usually changed over time. With each changeover of analytical method, the old and new methods were

Table 1
List of determinands that form part of the River Frome water quality data set, and periods when each determinand was monitored.

Determinand	Dates measured	Number of observations
pH	Jan 1965–May 2009	2016
Alkalinity (Meq l^{-1})	Jan 1965–May 2009	2066
Conductivity (μS cm^{-1})	May 1991–Apr 2007	644
Water temperature (°C)	Jan 1992–Dec 2008	707
River discharge ($m^3 s^{-1}$)	Oct 1965–May 2009	2076
Suspended solids (mg l^{-1})	July 1999–Dec 2003 March 2006–May 2009	275
Nitrate-N (mg l^{-1})	Jan 1965–May 2009	2089
Ammonium (mg l^{-1})	Jan 1965–Nov 1966 March 2006–May 2009	124
Soluble reactive P (μg l^{-1})	Jan 1965–May 2009	2079
Total P (μg l^{-1})	May 1991–Nov 2004 March 2006–May 2009	647
Total dissolved P (μg l^{-1})	May 1991–Nov 2004 March 2006–May 2009	607
Dissolved reactive Si (mg l^{-1})	Jan 1965–May 2009	2090
Sodium (mg l^{-1})	Jan 1965–May 2009	2065
Potassium (mg l^{-1})	Jan 1965–May 2009	2059
Magnesium (mg l^{-1})	Jan 1965–May 2009	2048
Calcium (mg l^{-1})	Jan 1965–May 2009	2072
Chloride (mg l^{-1})	Jan 1997–May 2009	468
Sulphate (mg l^{-1})	Jan 1997–May 2009	454