Agricultural Water Management 131 (2014) 156–162

Contents lists available at ScienceDirect

Agricultural Water Management

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

Estimating the contribution of in-stream cattle faeces deposits to nutrient loading in an English Chalk stream

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ARTICLE INFO

Article history:
Received 1 April 2013
Accepted 18 August 2013
Available online 25 October 2013

Keywords:
Water quality
Chalk stream
Nutrient loading
Faeces
Cattle

ABSTRACT

Numerous studies have shown that the addition of faecal matter from livestock to aquatic ecosystems can have a detrimental effect upon water quality. English Chalk streams, as groundwater-dominated rivers of high ecological importance, are particularly susceptible to nutrient loading from cattle faeces. Naturally low concentrations of nitrogen, phosphorus and potassium in such rivers increase their vulnerability to external perturbation from organic matter inputs. Despite this, the amount of faeces directly contributed by livestock such as cattle to a river system is rarely quantified.

To provide an assessment of nutrient loading due to cattle, a study combining observational data of animal behaviour with faecal analysis was undertaken in an English Chalk stream. Results show that cattle faeces was 89.4% water, containing 0.79% nitrogen, 0.43% phosphorous and 0.43% potassium by wet mass. It was estimated that a herd of 33 cattle deposited over 8 tonnes of faeces into a 770 m river reach over a seven-month period in 2010. This loading is estimated to have increased in-stream nitrogen, phosphorus and potassium concentrations in the reach by 0.0036 mg l^{-1}, 0.002 mg l^{-1} and 0.002 mg l^{-1} respectively; a small proportion of the overall nutrient content of the river. Moreover, it has been demonstrated that by combining behavioural data with faecal data it is possible to estimate the likely nutrient loading due solely to direct inputs from cattle faeces. With sufficient data, calculations such as those employed in this study can be used to provide accurate estimates of the nutrient loading due to livestock in watercourses.

1. Introduction

Direct and indirect inputs of organic material from cattle faeces and urine to watercourses have been of interest to land managers for several decades (Doran and Linn, 1979; Gary et al., 1983). However, the most well researched aspect of water quality changes induced by cattle excrement pertains to human health, and specifically the prevalence of *Escherichia coli* bacteria in water (Collins and Rutherford, 2004; Davies-Colley et al., 2004). Where nutrient loading indicators such as nitrogen and phosphorus have been measured, investigations are often concerned with pathogens and disease; methemoglobinemia (blue baby disease) and carcinogenic materials from nitrogen, and the threat of cyanobacteria poisoning from phosphorus induced eutrophication (Hubbard et al., 2004). Moreover, the majority of existing studies have been conducted in the rangelands of Australasia and North America, where river characteristics and cattle herd size are generally different to those of southern England's lowland Chalk streams (Fleischner, 1994; Davies-Colley et al., 2004; Monaghan et al., 2005).

English Chalk streams are recognised internationally for their ecological status; England has the greatest length of Chalk streams in Europe, with 161 Chalk streams in England spanning from the River Hull in Humberside to the River Frome in Dorset, and 10 Chalk stream Sites of Specific Scientific Interest (Environment Agency, 2004). Chalk streams are groundwater-dominated and therefore exhibit high water quality, with low suspended sediment concentrations, high water clarity and comparatively stable thermal regimes (Mackey and Berrie, 1991; Sear et al., 1999; Webb and Zhang, 1999; Heywood and Walling, 2003). Natural background values of nutrients such as phosphorus, nitrogen and potassium are relatively low in Chalk streams, but can be raised due to sewage and other allochthonous inputs from agricultural land-use, with undesirable consequences (Casey et al., 1993; Bowes et al., 2005; Jarvie et al., 2008).

Phosphorus concentrations in Chalk streams have fallen over the past 20 years as a result of phosphorus stripping at sewage works and changes in land-use practices (Young et al., 1999; Hanrahan et al., 2003; Neal et al., 2010; Bowes et al., 2011). Typical

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http://dx.doi.org/10.1016/j.agwat.2013.08.015

background levels of phosphorus are between 0.01 and 0.03 mg l^{-1} in healthy Chalk streams (Robach et al., 1996). Elevated phosphorus levels can have numerous detrimental effects, as explained by Mainstone (1999), including: encouraging changes in plant community composition towards a greater abundance of rooted plants; increasing the abundance of filamentous and epiphytic algae and thereby reducing in-stream light levels; and increasing growth rates of river weeds, such as *Ranunculus aqualatis*, which require management. Phosphorus can moderate primary productivity in many surface waters (Correll, 1999) and studies have shown the link between phosphorus and plants, with work by Bowes et al. (2011) demonstrating that algal biomass and productivity declined commensurately with declines in phosphorus levels on the River Frome in Dorset (Withers and Jarvie, 2008).

Nitrogen is relatively abundant within Chalk streams compared to phosphorus due to the nitrogen-rich status of English Chalk aquifers (Mainstone, 1999; Whitehead and Lawrence, 2006). Consequently, in most situations Chalk streams are less sensitive to changes in nitrogen levels than they are to changes in phosphorus levels (Mainstone and Parr, 2002). Nonetheless, large deviations from background nitrogen concentrations (background concentrations are typically between 2 and 4 mg l^{-1} in healthy Chalk streams) can be detrimental to water quality and in-stream organisms (Heathwaite et al., 1996; Houlbrooke et al., 2004; Jarvie et al., 2006; Jackson et al., 2008). As with other elements, nitrogen availability varies temporally over the course of a day and through the seasons (Whitehead et al., 2002). Moreover, nitrogen concentrations have increased markedly over the last 50–100 years in many Chalk rivers as a consequence of the intensification of land-use, effluent inputs from sewerage works and runoff from urbanised areas (Casey et al., 1993; Neal et al., 2002; Whitehead et al., 2002; Casey and Clarke, 2006).

Potassium is not as significant as either phosphorus or nitrogen in instigating ecological changes within Chalk streams. Whereas both nitrogen and phosphorus are essential to the construction of plant materials and the transfer of energy within plants, the principle use of potassium by most plants species is in water regulation and drought resistance (Hopkins and Hüner, 2008). Consequently, whilst potassium may improve the resistance of Chalk river species to drought (Ladle and Bass, 1981), it is unlikely to trigger algal blooms or eutrophication (Ladle and Casey, 1971). However, potassium is one of the three primary nutrients, and elevated concentrations have been recorded previously in Chalk streams, particularly downstream of watercress farms (Casey and Smith, 1994).

In recent years a perception has developed amongst cattle farmers that activity by their livestock may have detrimental effects upon river systems. Clothier (2009) reports that the number of dairy farms in England with fenced-off watercourses (to prevent bank erosion by cattle) has increased from 46% in 2006 to 66% in 2009, whilst the number of dairy farmers removing cattle early or introducing cattle late in the grazing season in an attempt to reduce their environmental impact has risen from 70% in 2006 to 90% in 2009. Although a few studies have shown that in-stream cattle activity within Chalk streams negatively affects certain species of fish (Summers et al., 2008) and aquatic invertebrate (Harrison and Harris, 2002), no published studies have yet attempted to quantify the effects of in-stream cattle activity upon water quality.

Here we quantify the amount of faeces produced by cattle and investigate the composition of cattle faeces in terms of the aforementioned nutrients. By combining observational data from Bond et al. (2012) with faecal analysis data, we calculate the likely nutrient loading due to direct cattle faecal inputs to an English Chalk stream.

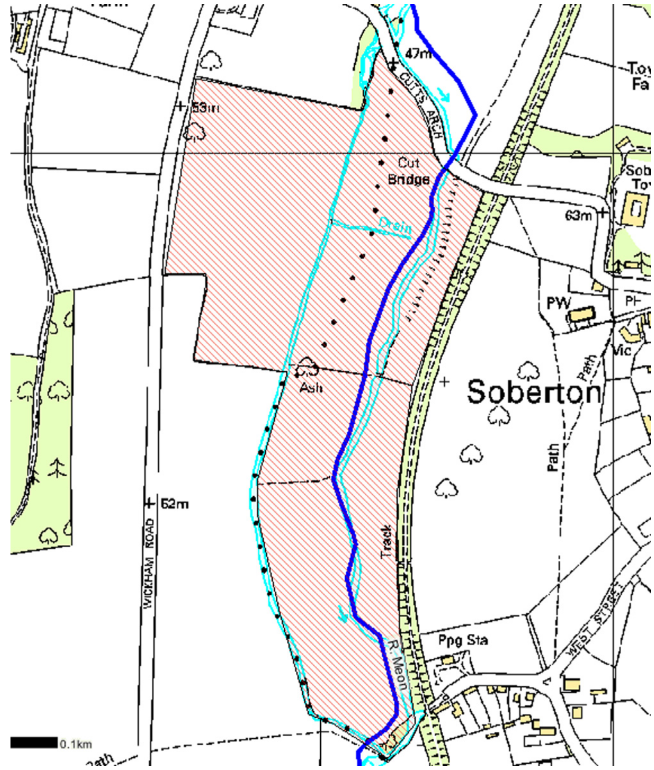

Fig. 1. A map of the study site situated south of Droxford in Hampshire, UK.

2. Methods

2.1. Study site and sample collection

The study was conducted on the grazed floodplain of the River Meon at Droxford in Hampshire, England (detailed in Bond et al., 2012 as the southern Midlington site: Fig. 1).

The River Meon is characteristic of a classic Chalk stream: groundwater-dominated as it is underlain by Cretaceous Chalk bedrock. The study site experiences a temperate climate, with approximately 650 mm of rainfall and mean monthly temperatures between 1 and 18 °C in 2010. Agriculture is the principal land-use within the Meon catchment; livestock are grazed in and adjacent to the river floodplain and arable crops are grown on the valley slopes. Along this reach the River Meon has a mean bank-full width of approximately 10 m, a mean average depth of 0.5 m. The average stream discharge (Q50) is 0.99 $m^3 s^{-1}$, with flow velocities in excess of 1 ms^{-1} in some locations. Cattle have unrestricted access to the river, which flows for 770 m through the 19 ha site. Between April and October 2010, 33 Holstein bullocks aged between 8 and 10 months at the time of introduction (approximately 2 livestock units per hectare) were kept at the study site. Twenty fresh (moist) cow pats produced by these cattle were collected on each day between 16th and 20th August 2010. Faecal samples were weighed and then replaced in the location they were found; half of the samples (ten from each day) were retained for laboratory analysis.

2.2. Laboratory methods

2.2.1. Oven drying

Fifty samples of cattle faeces weighing approximately 100 g each were taken from cow pats collected across the study site. From these, 60 smaller samples (between 1 and 20 g in weight) were then weighed before being dried in an oven at 70 °C for 24 h to remove moisture. Once dried, samples were weighed again and