Journal of Hydrology 515 (2014) 166–179

Contents lists available at ScienceDirect

Journal of Hydrology

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

A catchment study of sources and sinks of nutrients and sediments in south-east Australia

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ARTICLE INFO

Article history:
Received 6 December 2012
Received in revised form 3 February 2014
Accepted 14 April 2014
Available online 30 April 2014
This manuscript was handled by Laurent Charlet, Editor-in-Chief, with the assistance of Ewen James Silvester, Associate Editor

Keywords:
Land use
Water quality
Sediments
Nitrogen
Phosphorus
Diffuse source pollution

SUMMARY

A study of nutrient and sediment generation was carried out on a dairy farm in south eastern Australia over a period of two years. The study collected nitrogen (N), phosphorus (P) and total suspended sediment (TSS) samples from three headwater subcatchments totalling 4.4 km^2 in area, which had streamflow measurement sites located at their outlets. In addition to these three sites, samples were collected from farm tracks, the discharge from a farm dam (water storage pond) and a rainfall sampler. Over 20 runoff events were monitored in addition to background flows in the catchment. The data enabled nutrient exports to be estimated from the total catchment and two of the three subcatchments. The atmospheric nutrient loads were also estimated and found to be similar to other studies in the region, and were low compared with the nutrient export. The nutrient load estimates indicated that a large proportion of the catchment Total Nitrogen (TN) and Total Phosphorus (TP) loads originated from critical source areas on the farm associated with dairy operations, and that the catchment TN and TP export rates were high compared to other studies. The sediment data also indicated that TP concentrations were closely related to TSS in samples collected from surface runoff. Catchment TN loads in baseflow were high relative to the total load, probably due to indirect effluent and direct groundwater discharges into watercourses, with high concentrations of soluble N (nitrate plus nitrite and ammonium). The farm dam was found to trap a high percentage (>60%) of the influent TP load; however, the retention of TN by the dam was seasonally varying and close to net neutral.

1. Introduction

An understanding of sediment and nutrient dynamics from headwater catchments to receiving water bodies such as lakes, estuaries and coastal waters is important as high export rates can have detrimental effects on water quality and the aquatic environment (Young et al., 1996; Harris, 2001; Sutton et al., 2011). Pastoral agriculture, particularly intensive dairy farming, has been identified as a high export source in many places (Drewry et al., 2006; Haygarth et al., 2004; Holz, 2010; Sharpley et al., 2008; Wilcock et al., 2007). Smith et al., (2013) showed that intensification of the dairy industry in south-western Victoria was associated with increasing nutrient (N and P) concentrations in water bodies at the catchment scale. Dairy farms are an inter-related, complex mix of potential sources and sinks of N and P. Studies typically assess the role of agricultural fields (paddocks) as the source of these nutrients to water bodies; however, farm buildings, farmyards, barns and dairy sheds have the potential to export nutrients, particularly organic forms of N and P, from animal wastes (Dougherty et al., 2004; Edwards et al., 2008). Export from farmyards remains a largely overlooked research topic (Edwards et al., 2008). Pionke et al., (2000) introduced the concept of Critical Source Areas (CSA) as high runoff generating areas of the landscape that also have the potential to generate high nutrient loads. The farm features described above fit into this definition. The CSA concept has been used more extensively for P generation (Heathwaite et al., 2005a; Müller et al., 2010) than for N generation (Pionke et al., 2000).

Farm tracks are one important potential CSA, however their contribution to nutrient and sediment export from a catchment is often overlooked (Monaghan and Smith, 2012). A study in the Bog Burn catchment (NZ) by Monaghan and Smith (2012) found that overland flow from tracks and laneways was highly enriched in both soluble forms of N and P, and particulate forms of P. Using estimates of urine and dung loadings per animal from the literature, Eckard et al. (2007) visually observed N deposition on laneways and in sheds due to dairy cows moving around a farm

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http://dx.doi.org/10.1016/j.jhydrol.2014.04.034
0022-1694/

and estimated that deposition accounted for 33–52% of the overall N losses from the farm (using published data on loading rates). The role of impervious surfaces such as farm tracks and unsealed roads has been investigated in European catchments for sediment transport. Gruszowski et al. (2003), found that 30% of the suspended sediment transported to the River Leadon (UK) was contributed from roads. However, P export from the Sem (Southern England) catchment studied in Deasy et al. (2008) was dominated by drainflow, from one field (tile) drain constructed by the farmers to relieve waterlogging, and P fluxes were two orders of magnitude higher in the drain than in the overland flow from the tracks.

It is clear that farm tracks and other farm infrastructure containing CSAs can be important pollutant sources. Management of these sources requires the identification of the CSAs (Heathwaite et al., 2005a) and selecting appropriate mitigation measures, for example fencing off waterways to prevent stock access and constructing riparian buffer strips to trap particulate nutrients (as used in the Toenepi catchment in New Zealand (Wilcock et al., 2007)). In the late 1990s, best management practices (BMPs), including the diversion of dairy shed effluent from the stream to land discharge were also introduced in the Toenepi and other New Zealand dairy farming catchments. These changes led to a considerable improvement in stream water quality over 5–10 years of nutrient monitoring (Wilcock et al., 2007). Monaghan and Smith (2012) recommended sediment traps and bunding track drainage to ensure that this runoff does not enter watercourses.

Fields are a potentially significant nutrient source and intensively grazed dairy fields have been extensively studied in Australia and elsewhere for P (Nash and Murdoch, 1997; Nash and Halliwell, 1999; Fleming and Cox, 2001; Barlow et al., 2005; Weatherley et al., 2011) and for N (Ridley et al., 2001; Eckard et al., 2004, 2007; Barlow et al., 2007). For an intensively-grazed runoff plot in Darnum, Victoria, Haygarth et al. (2004) found that overland flow and interflow generated concentrations of filterable reactive P (FRP) were relatively constant during events compared with the variable runoff from the plot (although at peak runoff some dilution was observed). They suggested that the Darnum results were typical of small-scale runoff plots, which were much smaller than the catchments in other studies. In the Jubilee catchment (UK), Deasy et al. (2009) found that surface runoff sources (from a field) contributed 0.1% and 1.0% of the catchment runoff and sediment load respectively. Surface runoff was limited and restricted by low connectivity between the hillslope and stream.

In regions of the world with highly-variable climates (prone to drought or extended dry seasons), including south-eastern Australia, farmers tend to store water on-farm using farm dams (small storage reservoirs). Farm dams have also been largely overlooked in the literature as a source or sink of sediments and nutrients, and their effect on water quality is not well known in Australia (Brainwood et al., 2004), or internationally (Maxted et al., 2005; Fairchild and Velinsky, 2006). In the USA, Lessard and Hayes (2003) studied small ponds in a humid temperate climate zone for SS and TP removal, but did not find any evidence of TP removal at downstream monitoring sites. In New South Wales, Australia, (Brainwood et al., 2004) found that water quality in three farm dam monitoring sites was related to the land use of the impounded catchment but did not evaluate nutrient removal. Additionally, on dairies farmers often use ponds or tanks to store effluent to recycle nutrients on farm, and these may overflow during wet spells and pollute watercourses (Müller et al., 2010), in which case they become a source rather than a sink of nutrients.

Instream concentrations of dissolved and particulate nutrients typically respond to flow variations due to the changing importance of different water sources, the biogeochemical dynamics of those sources, and differences in steam processes such as erosion. The role of storm events in generating high sediment and nutrient loads has been studied in some detail, particularly as a source of particulate P (PP) (Pionke et al., 1999, 2000; Correll et al., 1999; Haygarth et al., 2004, 2005b; Deasy et al., 2008; Sharpley et al., 2008), and less frequently as a source of N, especially nitrate (Correll et al., 1999; Pionke et al., 1999; Poor and McDonnell, 2007), and particulate N (PN), which is often included in TN instead of being separately analysed.

Often the great majority of annual export is in the largest couple of runoff events due both to increased concentrations and the volume of runoff involved (e.g. Pionke et al., 1999; Nash and Murdoch (1997). Studies involving intensive (temporal and spatial) monitoring of storm events can quantify runoff and sediment exports at different spatial scales (e.g. Deasy et al., 2011). Johnes (2007) analysed a set of catchments in the UK with daily P time series data. She found that the catchments having a low baseflow index (BFI) tended to export mostly PP during events, and that a large percentage of the annual TP export was from events rather than low-flow (baseflow) periods. A low BFI indicates that event runoff tended to dominate their hydrographs. Haygarth et al. (2004) reported that 69% of the annual TP load was exported from a 1.8 ha paddock in a single runoff event.

Typically the concentrations of sediment associated materials such as PP and PN increase during runoff events (a "concentration" effect) and there is some evidence that common hydrological pathways are involved (Kato et al., 2009; Correll et al., 1999). Kato et al. (2009) observed that a "first flush" mechanism was apparent in the export of TP, PP, PN and ammonium during events. They stated that particulates were more likely to be exported in the first flush than dissolved nutrients since a readily mobilised source was available on the farmland soil surface, and in the substrate of dry drainage canals. Concentrations of dissolved material such as nitrate often decrease (a "dilution" effect) as flow increases during an event (Holz, 2010; Poor and McDonnell, 2007). Sometimes other factors can control temporal variation. For example, Holz (2010) found that ammonium varied as a function of grazing events rather than flow.

We have identified several clear knowledge gaps based on a review of the research in worldwide regions that may have similar conditions (climate and agricultural activities) to the south east region of Australia. The first is the importance of tracks in conveying sediments and nutrients to watercourses during storm events. The second is the role of farm dams in potentially mitigating nutrient export. Thirdly, many previous studies have concentrated on carefully designed field experiments at small spatial scales. This study investigates nutrient (N and P) export from headwater subcatchments containing a working dairy farm in south-eastern Australia. It also examines the effect of farms tracks and a farm dam on those loads. This paper aims to quantify the role of various catchment elements as sources and/or sinks of nutrients in a dairy farming catchment, to examine the differences in sources between storm event periods and baseflow periods and to quantify atmospheric deposition of nutrients.

2. Methods

2.1. Description of study area

The monitoring sites were situated on a 188 ha dairy farm located in the 4.4 km^2 Poowong East headwater catchment (PEC) of the Lang Lang River located at (38.33°S, 145.83°E) in Victoria Australia, approximately 130 km south east of Melbourne (Fig. 1). The land use in the PEC is almost entirely intensively-grazed pasture, mostly associated with dairy cattle and some beef cattle, particularly in the upper SW part of the catchment (Table 1). Monitoring was carried out at the farm between August 2009 and November 2011.