



Source strengths, transport pathways and delivery mechanisms of nutrients, suspended solids and coliforms within a small agricultural headwater catchment

Anthony C. Edwards ^{a,*}, Helen A. Watson ^b, Yvonne E.M. Cook ^b

^a Scottish Agricultural College, Craibstone, Aberdeen, AB21 9YA, UK

^b The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK

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ABSTRACT

Analysis of water samples and accompanying flow data collected (on ~100 occasions) from well defined land drain outlets located in a small catchment in NE Scotland were made over a five year period. The complex relationship between individual sources that can exist even within a small (200 ha) agriculturally managed headwater catchment was clearly evident. On average ~60% of the measured flow from the catchment outlet was accounted for, with ~50% originating from field drains and 10% from the farmyard. Certain field drains stopped flowing during the summer. Flow from the farmyard was continuous, and because livestock were present all year round also represented a renewable source of potential contaminants. The majority of nitrate and suspended sediment originated directly from field drainage. The variability in nitrate concentration between individual field drains was large and probably reflected differences in soil drainage properties. Farmyard drainage contributed a large proportion of the ammonium, phosphate and Faecal Indicator Organisms (FIO) measured as a flux from the catchment. On numerous sampling occasions the combined flux from individual sources was greater than the corresponding loss measured at the catchment outlet. This was attributed to result from the temporary storage/retention mechanisms (sedimentation, transformation or biological uptake/exchange) that can operate within the stream channel. Despite many fields being grazed and/or receiving regular applications of slurry/manure, the majority ~60% of the total flux of FIO still originated from the 'farmyard', with significant contributions from the field drains only occurring during the autumn. The presence of field drinkers and secure well maintained fencing denying cattle access to the open drainage channel (often a recommended best management practice) may well have contributed to this observation. Benefits to water quality that might arise from riparian management, such as buffer strips in this particular situation may be limited due to the dominant contribution originating from land drains and farmyard.

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1. Introduction

Understanding relationships between source, transport and delivery of agricultural pollutants at larger geographical scales (sub-catchment) have been linked with broad patterns and trends in adjacent land use. The complexity of these relationships is becoming increasingly evident through analysis of studies made at smaller geographical scales (e.g., Soulsby et al., 2003; Arnscheidt et al., 2007) or sampling at higher temporal resolution (e.g., Jordan et al., 2007). The commonly made distinction between 'diffuse' and 'point' sources of pollutants is becoming more difficult to define as the contribution from various small piped flows becomes more apparent (e.g., Withers et al., 2009). The increased potential risk that field drains may pose with respect to transport of various contaminants e.g., phosphorus have been well highlighted (e.g. Dils and Heathwaite, 1999; Hooda et al., 1999; Deasy et al., 2008). On a catchment basis land drainage schemes, increase the degree of hydrological

linkage between potential source and points of delivery. The area of land drained in Scotland has been estimated as ~600,000 ha during the 60 year period from 1930 (Robinson, 1990). Farmyards, especially those where livestock are present, also represent a potentially significant and renewable source of contaminants (ammonium (NH₄-N), phosphate (PO₄) and Faecal Indicator Organisms (FIO)) (Edwards et al., 2008). Point sources of FIO derived from farmyard runoff have been shown to be important in contributing to the spatial pattern of contamination in a small agriculturally dominated tributary of the River Don in Aberdeenshire (Rodgers et al., 2003). Significant temporal variation was also observed in response to the hydrological conditions within the catchment. Higher flows and more frequent washout of stored bacteria in winter and spring months led to lower FIO concentrations than detected during the summer. The contribution individual sources make can be difficult to quantify, however any improvements in understanding of transport pathways and total losses would help with the targeting and prioritisation of best management practices (BMP). Commonly advocated BMP emphasise riparian zones through restricting livestock access to streams and the development of buffer strips. Land drains are likely to 'by-pass' and therefore been less influenced by these types of practices.

* Corresponding author. Tel.: +44 1224711000.

E-mail address: tledwards25@btinternet.com (A.C. Edwards).

Here we compare the range in composition and flux of nitrogen and phosphorus together with other elements, suspended sediment (SS) and FIO for field and farmyard drainage samples collected in a small stream draining a predominantly agricultural catchment (~200 ha) in NE Scotland. Instantaneous loads were calculated and used to estimate the relative contribution individual sources made to total losses for the catchment.

2. Material and methods

2.1. Farm/catchment details

The experimental site is located within an area typical of agricultural land in Aberdeenshire (summarised by Domburg et al., 2000). The farm is situated within a headwater sub-catchment of the River Ythan and is ~200 ha in area most of which drains, in to a 1st/2nd order stream network (Fig. 1). The farm enterprise changed from dairy to predominantly arable cropping during 2000. Cattle were milked twice daily and the resulting periods of livestock movement represented an opportunity for possible faecal/urine contamination of paths and gateways. The main access route from grazing areas to the milking parlour was via a bridge across the stream (Fig. 1) and track which was never seen to contribute significant amounts of runoff directly to the stream. All fields had well maintained fencing, with in field water supply and no stream access for livestock. Permanent grazing (9.5 ha) is located adjacent to the main farm buildings and young cattle continued to be housed within the farmyard located towards the lower part of the experimental catchment. Most of the land has been artificially drained with an estimated drain length density of 6 km/km² which is five times the estimated stream/open channel density (1.2 km/km²). The main soil properties varied between reasonably well drained mineral soils to the west and north (field drains 6–8 Fig. 1) compared to poorly drained soils to the south of the main drainage channel (field drains 1–5 Fig. 1).

2.2. Sample collection and analysis

The stream its self was walked and numerous drains identified and eight sampled regularly. It was difficult to quantify the exact land area contributing drainage water it was possible to attribute certain fields and therefore management actions to particular drains. Water samples were collected from various locations (Fig. 1) at approximately

fortnightly intervals from June 1998 to February 2001, sampling stopped during the foot and mouth outbreak and commenced again in October 2001 but at a reduced, monthly frequency, until January 2004. Sampling sites included field drains (numbered 1–8 Fig. 1), a discrete piped flow from the farmyard (Site A Fig. 1) and finally the main outflow from the catchment (Site B Fig. 1). This lowest sampling point provided an estimate of the total instantaneous flux from the catchment and was used to apportion the relative contributions from upstream sampling points. The stream cattle crossing point was located below Site B. Instantaneous fluxes were calculated where ever individual flow data were available.

The river channel has been engineered (both straightening and dredging) in places and runoff from an adjacent road could enter upstream. Instantaneous flows were measured wherever possible at each sampling point by timing the collection of a known volume of water. Spot sampling is recognised as favouring low flows and for this reason the instantaneous flux measurements have not been extrapolated further to estimate total annual losses.

Water samples were all filtered (<0.45 µm membrane) immediately on return to the laboratory and stored in the dark at 4 °C prior to analysis. Nitrate (NO₃-N) and NH₄-N were determined colorimetrically using a Traacs autoanalyser (industrial methods 330-86E and 333-86E) and PO₄-P using the molybdenum blue procedure of Murphy and Riley (1962). Chloride was determined using ion chromatography (Dionex), dissolved organic carbon (DOC) as CO₂ after combustion and all other elements (Ca, Mg, Na, K, S, Si, Al, Fe, Cu, Zn and Mn) by inductively coupled plasma atomic emission spectrometry. Total and faecal coliforms (TC and FC) were determined by Colilert (Idexx Laboratories) within 6 hr of sample collection.

3. Results

3.1. Flow

Flow from the catchment outlet varied over three orders of magnitude from 0.6 to 72 l/s (mean 14 and median 10 l/s) over the 93 sampling occasions. Assuming an average rainfall of 790 mm (Aberdeen airport (Dyce) 1971–2000) and an estimated runoff of 60% then an average flow approximately double the observed mean value would have been expected. The flows for individual sampling occasions are averaged by month for the total time period and the relative contributions from field and farmyard drains indicated (Fig. 2). Flows become

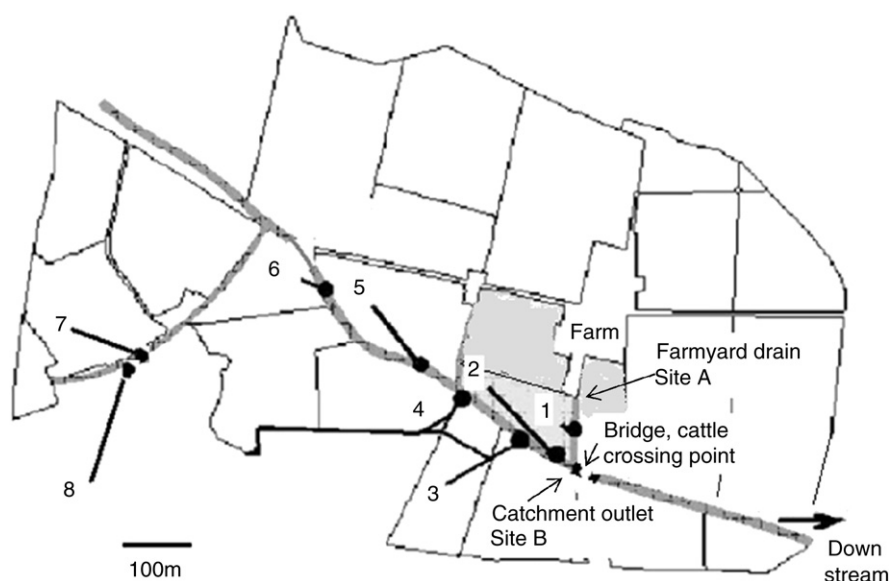


Fig. 1. Schematic of farm sampling sites in the Ythan catchment. Bold black lines indicate approximate orientation of field drains, with closed black circles denoting field drain outfalls. Grey lines denote open ditches. Site B is the main downstream sampling point used to calculate losses from the catchment. The farm building and yard are indicated and connected via an open ditch. Areas of permanent pasture are indicated by grey shading.

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