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Original Research Article

Transport of contaminants in agricultural catchments during snowmelt: buffer strips vs. preferential flow paths

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ABSTRACT

Knowledge of hydrological pathways is essential for an understanding of ability of riparian buffers to mitigate the impact of diffuse pollutants on freshwater ecosystems. We examined flow paths and source areas of contaminants in an agricultural catchment in NE Poland during snowmelts in 2009 and 2010. End-member mixing analysis showed that stream chemistry was controlled by the shallow runoff components. Their contribution to stream runoff varied significantly depending on soil frost, catchment wetness and the water input from snowmelt. In 2009 overland/rill flow was the main mechanism of runoff generation because of the low permeability of the frozen ground. Overland flow had the pronounced impact on stream chemistry during peak discharges, when it amounted up to 70% of discharge (*Q*). Riparian ground/soilwater runoff was important component of runoff throughout stream recession, when it contributed up to 50% of *Q*. High catchment wetness, lack of soil frost and large snowmelt input in 2010 resulted in enhanced infiltration and rapid and large groundwater response. Melt water and tile drain outflow were found to be the major peak runoff components. In 2009 overland flow together with discharge of shallow groundwater were responsible for the export of 88% of nitrate and 98% of orthophosphate. During snowmelt of 2010 70% of NO_3^- and 80% of PO_4^{3-} moved via tile drain network. As migration of chemicals was controlled by preferential flow structures, it is very likely that vast majority of contaminants fluxes bypassed buffers and structures, which could constrain their impact on stream quality.

1. Introduction

The EU Water Framework Directive (WFD 2000/60/EEC) was established to reduce the effect of agriculture and development on the quality of surface water and groundwater to prevent further deterioration of and to protect and enhance the status of aquatic ecosystems. The main policy tools of this directive involve the integration of land and water management within river basins (Zalewski, 2011), with particular attention to regulating potentially damaging activities through Codes of Good Agricultural Practices or the establishment of controlled areas such as Nitrate Vulnerable Zones (Petry et al., 2002). Of special concern is the promotion of buffer strips to control the entry of diffuse source pollutants into surface waters (Vought et al., 1995). Recent studies on buffer strips have indicated additional ecosystem benefits of riparian vegetation and wetlands along stream corridors for humans and the natural environment (Mitsch and Jorgensen, 2003), including carbon sequestration, hydrological regime modification and the protection of biodiversity at the landscape as well as regional scale (Brian et al., 2004; Blank et al., 2011; Hefting et al., 2012).

The effectiveness of buffer strips for nutrient removal depends upon numerous factors, among which maintaining the soil water regime and soil biotic communities seem

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to be of great importance. An efficient buffer must have the ability to change the surface and subsurface flow hydraulics for adequate contact between the water and soil to permit pollutant removal by a combination of physical, chemical and biological processes: denitrification, sorption, vegetative biomass uptake and microbial immobilization (Correll, 2005; Hefting et al., 2005). The leading role of hydrology has been confirmed in many detailed micro/mesocosm experiments and point-scale field studies demonstrating the great ability of riparian soils and vegetation to reduce the load of nutrients such as nitrates and phosphorus (Lowrance et al., 1984; Norris, 1993; Lam et al., 2011).

Some studies of vegetative buffers have demonstrated that certain generalizations and schemes established in recent decades are occasionally inadequate to describe the relationship among hydrological processes, landscape management and water quality. Although the results of small-scale field measurements are often consistent with laboratory findings, attempts to scale up these findings and models to entire hillslopes or catchments often fail. Despite promising laboratory results, the examination of buffer zones on a broader scale in rural catchments has yielded limited success in controlling water pollution due to the concentration and channeling of runoff in natural drainage ways before reaching the vegetated buffer zone. Indeed, hydrologists continue to demonstrate that the enormous heterogeneity and complexity of runoff processes are most likely controlled by network-like preferential flow structures that regulate the timing and spatial location of water flow and contaminant fluxes (Weiler and McDonnell, 2007). The timing and duration of pollutant fluxes is of particular importance in temperate and boreal climate zones, where the most pronounced runoff events occur at the transition between winter and spring, when vegetation is still in the dormant phase. Thus, the effect of buffer zones on nutrient removal may be season dependent.

Knowledge of hydrological pathways is essential for an understanding of riparian zone chemistry (Hill, 1996; McGlynn et al., 1999) and its ability to mitigate the impact of agriculture-derived pollutants on freshwater ecosystems (Soulsby et al., 2002). Therefore, in the present paper, we attempt to provide answers to some of the problems formulated above.

The objective of this paper is to better understand the flow paths and source areas that control the fluxes of dissolved compounds from a small agricultural catchment in a temperate climate zone. We focused on spring snowmelt because the snowmelt event is regarded as a prominent factor affecting the quality of water ecosystems in moderate- and high-latitude catchments (Laudon et al., 2004). We hope that our study will contribute to the discussion of the importance of vegetative filter strips in protecting watercourses from the negative impacts of diffuse pollution.

2. Site description and methods

The field study was located within the catchment (187 ha) of an unnamed stream that is a left-bank tributary

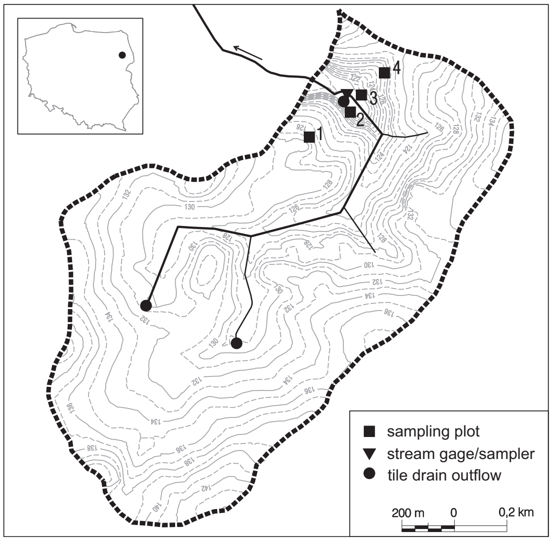

Fig. 1. Location instrumentation and sampling plots in the catchment. Contour lines are in meters.

of Horodnianka River, NE Poland (Fig. 1). The elevation range of the catchment is between 118 m and 142 m above sea level. The catchment is rural and has mixed land use: 75% arable lands, 16% grasslands, 3.5% woodlands and 5.5% built-up areas and wastelands. Approximately 60% of the agricultural land is artificially drained, mainly by underground pipes.

The catchment is composed of ground moraine forming gently rolling hills. Surficial sediments consist of medium deep sands and loamy sands underlain by glacial till and, in some places, of light and medium loams. The depth to the till varies from 2 to 0.5 m along the side slopes and 0.4–0.7 m in the valley-bottom locations. More than 20% of the area is covered with patches of deep sands and gravels that form isolated kame hills, which are the highest elevated forms in the catchment. The valley is filled with organic sediments, mainly shallow (up to 50 cm), highly decomposed peats and alluvial muds. The valley bottom is narrow, and the watercourse bed has cut it to a depth of 80–100 cm. For a substantial proportion of the valley's length, arable lands approach the stream bed at a distance of 5–10 m. The width of the riparian zone in the studied reach of the stream is narrow and varies from 10 to 20 m. The riparian soils consist of organic rich clayey sands with a depth of 60–80 cm overlying morainic till. Vegetation consists of a mosaic of permanent grassland and alder carr (*Alnus glutinosa*) with an admixture of hackberry (*Prunus padus*).

The climate is temperate, with a distinctly marked continental and a lesser boreal influence. The average rainfall is 584 mm year^{-1} (1960–2006), and the mean air temperature is 6.9 °C. The monthly average temperature ranges from −4.5 °C in January to 17.3 °C in July. Permanent snow cover exists an average of 70–80 days every year between late December and early March. The depth of soil frost penetration reaches 50 cm (Atlas klimatu Polski, 2005; Górniak, 2000). Peak runoff typically occurs