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Reprint of "Hydrological pathways and nitrogen runoff in agricultural dominated catchments in Nordic and Baltic countries"☆

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ABSTRACT

Nitrogen (N) transport and retention in streams are largely determined by hydrological characteristics (e.g. water runoff, baseflow index (BFI) and flashiness index (FI)) in the catchment. It is important to know the impact of catchment characteristics such as land use, subsurface drainage intensity, elevation difference and catchment size on the hydrological properties and N loss. This paper presents a comparison of the magnitude and variation of the baseflow and flashiness in streams in relation to the selected geographical and drainage characteristics for thirty studied agriculture dominated catchments in the Nordic and Baltic countries and the effects it can have on N loss. The analysis included measured data from the total discharge and nitrogen loss at the catchment outlets for the period from the beginning of 1993 to 2011, although there is variation in the length of periods among catchments and countries. The study revealed that the rate of subsurface drainage systems and drainage intensity (given as lateral tile drainage spacing) were statistically significant explanatory variables in explaining differences in hydrological characteristics between catchments. There is a considerable increase in the FI, almost by a factor of three, when using hourly discharge values instead of average daily values, indicating that large diurnal variation in discharge can occur, especially at higher FI values. The analysis also showed that there is a negative relation between FI and the BFI, i.e. a high BFI corresponding to a low FI and vice versa. In general, there seems to be a positive relationship between long-term average runoff and N loss, with the highest runoff and N loss occurring in the Norwegian catchments. However, flow path can have a significant influence on the N loss.

1. Introduction

Agriculture contributes nutrients to the environment, and is to a large degree responsible for the eutrophication of inland waters and coastal zones. In the Baltic Sea catchment area, the major anthropogenic source of waterborne nitrogen is diffuse inputs which constitute around 70% of the total load into surface waters within the catchment area. Agriculture alone contributes approximately 80% of the total reported diffuse load (Stålnacke, 1996; HELCOM, 2009). Several authors (e.g. Kauppi, 1979; Rekolainen, 1989; Zabłocki and Pieńkowski, 1999; De Wit, 2000; Mander et al., 2000; Vagstad et al., 2004; Iital et al., 2005) have described the relative importance of different factors, e.g. land use, fertilization rate, livestock density, topography and soil type, influencing the loss of nitrogen. Nutrient losses, especially nitrogen, are well correlated with variations in discharge (Stålnacke and Grimvall, 2000). However, when comparing the results of different water quality monitoring programmes in catchments with a relative high agricultural share, large differences in nutrient losses can be observed under otherwise almost similar climatological conditions and

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agricultural practices (Vagstad et al., 2004). Also, catchment scale can play a role in the nutrient loss processes. Deelstra et al. (2005) and Lagzdins et al. (2012) found a decrease in nitrogen concentration in Latvian catchments with an increase in catchment scale. In addition to a decrease in area-specific fertiliser application rates, it was concluded that flow processes also had an important impact on water chemistry. Similar findings were made by Tiemeyer et al. (2006) when studying nutrient losses in artificially drained catchments in north-east Germany. When comparing nutrient losses from small agricultural catchments in the Baltic and Nordic countries, Vagstad et al. (2004) found that high groundwater contributions, e.g. a higher share of the baseflow in the catchment discharge, might lead to lower nitrogen loss. Hydrological pathways are of great importance not only for the transport of nitrogen but also for nitrogen transformation processes in soils and the buffering capacities of the catchment area. Thus, a good understanding of the hydrology is necessary to understand the processes leading to nitrogen loss and retention. Besides surface and groundwater flow, subsurface drainage systems are also an important pathway for both water and transport of nitrogen in agricultural dominated catchments (Deelstra 2013; Kværnø 2013). However, its magnitude is very much influenced by soil type and drainage systems, (for example Skaggs et al., 1994; Gilliam and Skaggs, 1986). Kladivko et al. (2004) and Nangia et al. (2009) showed the importance of drain spacing on the magnitude of these losses, indicating greater N loss with narrower drain spacing. A study carried out by Paasonen-Kivekàs et al. (1999) also showed the importance of subsurface drainage systems on transport of nitrogen in Finland, especially highlighting the effects of the macropore system on this transport. In the analysis of runoff at the catchment outlets, no differentiation can be made between the different flow paths contributing to the total runoff. However, to quantify the contribution from groundwater in the total runoff, techniques can be used to differentiate between fast and slow flow processes, the slow flow representing the groundwater contribution or baseflow. One methodology is the determination of the base flow index (BFI), i.e. the contribution of the slow flow or groundwater flow in the total runoff measured at the catchment outlet. An overview of different methods to differentiate between fast and slow flow processes in the catchment is given by Brodie and Hostetler (2005). Baker et al. (2004) developed a flashiness index (FI), reflecting the frequency and rapidity of short term changes in daily runoff values, representing the fast flow. The objective of this study has been to find a relation between catchment characteristics and the hydrological characteristics of BFI and FI. The catchment characteristics considered were subsurface drainage density, catchment size, land use and elevation difference. The hydrological characteristics have furthermore been used to assess the differences in nitrogen loss between catchments.

2. Materials and methods

2.1. Description of catchments

Long-term monitoring data on discharge and N loss from thirty agricultural dominated catchments in the Nordic-Baltic region, covering the period 1992–2011, have been used in this analysis. The main characteristics of the studied agricultural catchments are presented in Table 1. For an overview of the location of the catchments, the reader is referred to Stålnacke et al. (2014). All the catchments in the seven countries are a part of environmental monitoring programmes, providing information about the nutrient concentrations and losses to inland surface waters. There is a large variation in catchment size, the smallest one being the Time catchment in Norway (1.0 km^2), the largest one being C6 in Sweden (33.1 km^2). The proportion of agricultural land varies from 35% in the Naurstad catchment, Norway to 99% in Bolbro bæk, Denmark. Only three out of thirty catchments have a proportion of agricultural land of less than 50% while in twenty-three catchments, agriculture represents more than 60% of the total area. In all but one catchment forest is present; in six catchments this represents more than 30% of the total land area. A third land use type was identified, encompassing the other land use forms represented by urban areas and scattered dwellings, and in some cases peat land. In all catchments different soil types are present, varying from sand to clay soils. The soil types representing the main share of agricultural land are indicated in Table 1. Soil types play an important role in determining subsurface drainage design and in some cases are not in need of artificial drainage, exemplified by the Horndrup and Bolbro bæk catchments in Denmark. However in many cases artificial drainage is needed to drain excess water during the autumn and spring period, facilitating tillage operation and early land preparation. In the studied catchments, drain spacings vary from 8 to 26 m with depths varying 0.8–1.2 m below soil surface (Table 1). The topography of the catchments varies from relatively flat to hilly. The catchments in Norway have the largest range in elevation difference, varying from 65 to 423 m. The catchment with the smallest elevation difference is the Berze catchment, located in Latvia.

2.2. Discharge measurement, water sampling and calculation of nitrogen loss

In all catchments the discharge is measured continuously using either a mechanical recorder or data logger in combination with a discharge measurement structure. The discharge measurement structures used vary among the catchments and V-notches, broad-crested weirs and crump weirs are used. In all the cases, the discharge is calculated based on the recorded water level and a known head - discharge relation for the measuring structure. Composite water quality samples are collected for the majority of catchments on a volume proportional basis and in cases where no data logger is available, on a time proportional basis. The nitrogen loss for a sampling period is calculated on the basis of the measured discharge and concentrations in composite samples.

2.3. Flashiness index and baseflow index

The studied hydrological characteristics involved both the flashiness index and the baseflow index. Flashiness, or rate of change, refers to how quickly flow changes from one condition to another and has been widely used to describe urban hydrology and the effects of urban development on stream hydrology (Schoonover et al., 2006). In this case, the coefficient of variation (CV) is an indicator of the flashiness. Schoonover et al. (2006) also showed that the watersheds with a high CV had a corresponding low BFI. Similar findings were made by Deelstra et al. (2008) in a comparative study on hydrology in small basins. Jordan et al. (2004) when investigating the patterns of phosphorus (P) transfer from fertilised soils to streams and processes responsible for these losses used flashiness in explaining phosphorus transport processes. In their study the flashiness was represented by the Q5:Q95 ratio, being the 5 and 95 percentile from the flow duration curve and where a high Q5 discharge or low Q95 discharge (or a combination of both) will yield a high ratio. Baker et al. (2004) developed a flashiness index (FI, Eq. (1)) which among others was used to detect changes in the hydrological behaviour due to changes in the landscape. In analysing the hydrology from catchments, varying in size from 10 to more than 10^4 km^2, they showed that the FI decreased with an increase in the catchment scale. An advantage of the index is that it is independent of the annual discharge in a catchment; the FI combines characteristics such as CV and the Q5:Q95 ratio. The flashiness index (FI) is