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Review Paper

The importance of the riparian zone and in-stream processes in nitrate attenuation in undisturbed and agricultural watersheds – A review of the scientific literature

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SUMMARY

We reviewed published studies from primarily glaciated regions in the United States, Canada, and Europe of the (1) transport of nitrate from terrestrial ecosystems to aquatic ecosystems, (2) attenuation of nitrate in the riparian zone of undisturbed and agricultural watersheds, (3) processes contributing to nitrate attenuation in riparian zones, (4) variation in the attenuation of nitrate in the riparian zone, and (5) importance of in-stream and hyporheic processes for nitrate attenuation in the stream channel. Our objectives were to synthesize the results of these studies and suggest methodologies to (1) monitor regional trends in nitrate concentration in undisturbed 1st order watersheds and (2) reduce nitrate loads in streams draining agricultural watersheds.

Our review reveals that undisturbed headwater watersheds have been shown to be very retentive of nitrogen, but the importance of biogeochemical and hydrological riparian zone processes in retaining nitrogen in these watersheds has not been demonstrated as it has for agricultural watersheds. An understanding of the role of the riparian zone in nitrate attenuation in undisturbed watersheds is crucial because these watersheds are increasingly subject to stressors, such as changes in land use and climate, wildfire, and increases in atmospheric nitrogen deposition.

In general, understanding processes controlling the concentration and flux of nitrate is critical to identifying and mapping the vulnerability of watersheds to water quality changes due to a variety of stressors. In undisturbed and agricultural watersheds we propose that understanding the importance of riparian zone processes in 2nd order and larger watersheds is critical. Research is needed that addresses the relative importance of how the following sources of nitrate along any given stream reach might change as watersheds increase in size and with flow: (1) inputs upstream from the reach, (2) tributary inflow, (3) water derived from the riparian zone, (4) groundwater from outside the riparian zone (intermediate or regional sources), and (5) in-stream (hyporheic) processes.

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1. Introduction

During the last 20 years recognition of the influence of riparian zone processes on water quality has led to a growing interest in the use of riparian buffer zones along river corridors to mitigate the effects of non-point source pollution (Hill, 1996). The use of riparian zones as water-quality management tools results primarily from studies of agricultural watersheds, where large reductions in the concentrations of nitrate, suspended sediment, and, to a lesser degree, phosphorus, have been observed as water flows through riparian zones. Undisturbed headwater streams have been shown to be very retentive of nitrogen, sometimes exporting less than one-half of the input of dissolved inorganic nitrogen (Likens et al., 1977; Peterson et al., 2001). The importance of the riparian zone in the attenuation of nitrate in undisturbed watersheds, however, is largely unknown.

Understanding how hydrological and biogeochemical processes in the riparian zone and in the stream channel (hyporheic zone) control the concentrations of nitrate in undisturbed watersheds is crucial because these watersheds are increasingly subjected to stressors such as changes in land use and climate, wildfire, and increases in atmospheric deposition of nitrate (Landers et al., 2008). Therefore, understanding the processes controlling the concentration and flux of nitrate is critical to identifying and mapping watersheds vulnerable to stresses and predicting the effects of these stresses on water quality. There is also a need to better understand how these processes control the concentrations of nitrate in agricultural watersheds to better manage riparian zones as buffer zones to reduce nitrate loads in streams.

In this paper, the use of the terms "watershed", "basin", "streamflow", and "discharge", follow the usage of the author(s) of the papers included in this literature review. The term hyporheic zone refers to the subsurface zone, where stream water flows through segments of its adjacent bed and banks and is characterized by the mixing of stream water and groundwater (Triska et al., 1993; Winter et al., 1998; Hill and Lymburner, 1998) (Fig. 1).

This review provides a summary of published research primarily from glaciated regions in the United States, Canada, and Europe that demonstrates the importance of biogeochemical and hydrological processes in the riparian zone and in the stream channel on stream nitrate concentration in undisturbed and agricultural watersheds. These watersheds vary in size from small headwater watersheds to large rivers such as the Mississippi. Our purpose is to suggest methodologies to (1) monitor regional trends in nitrate concentration in undisturbed 1st order watersheds and (2) reduce nitrate loads in streams draining agricultural watersheds.

2. Transport of nitrate from terrestrial ecosystems to aquatic ecosystems

Riparian zones in any watershed can be a net source or a net sink of nitrate depending on the flow path of water draining to the stream. Measurements of stream chemistry over short (individual storms and snowmelt) and longer (seasonal and year-to-year monitoring) time scales have shown that temporal and spatial variations in nitrate concentration result from temporal changes in flow paths.

In undisturbed forested watersheds, evidence that riparian zones serve as a source of nitrate is observed when increases instream nitrate above base flow concentrations occur during snowmelt and/or rainfall events. Peaks in nitrate concentration usually occur before peaks in stream discharge (Denning et al., 1991; Stottlemyer and Troendle, 1992; Hill, 1993; Creed and Band, 1998; Ohrui and Mitchell, 1998; Correll et al., 1999; Hill et al., 1999; Campbell et al., 2000; Coats and Goldman, 2001; Bechtold et al., 2003). Similar increases in nitrate have also been measured in streams draining mixed land use and agricultural watersheds (Schnabel, 1986; Schnabel et al., 1993; Correll et al., 1999; Kalkhoff et al., 2000; Royer et al., 2004). This temporal behavior is a "flushing effect" when a water table rises to the soil surface with subsequent mobilization of nutrients stored near or at the soil surface (Creed et al., 1996; Creed and Band, 1998). When saturated throughflow is deep below the soil surface, nitrogen accumulates in the soil, resulting in small export of nitrogen into adjacent waters. As saturated throughflow rises, nitrogen is flushed from the soil to the stream. As saturated throughflow intersects the soil surface, nitrogen formed in the highly bioactive surface of the soil is flushed resulting in large export of nitrogen into adjacent waters.

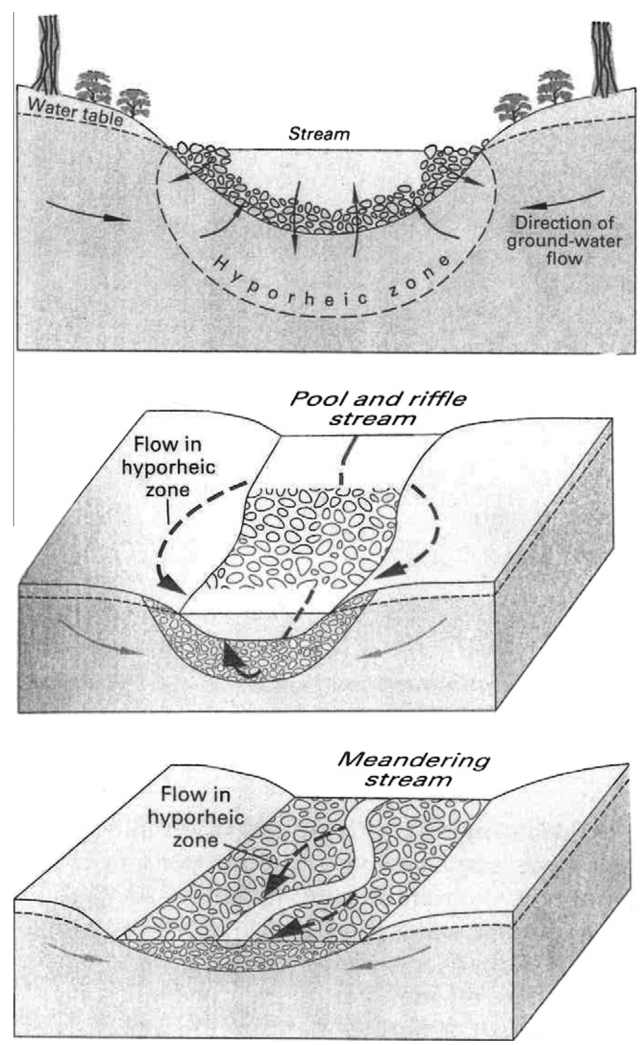

Fig. 1. Examples of stream hyporheic zones (from Winter et al., 1998).