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Contrasting behaviour of two riparian wetlands in relation to their location in the hydrographic network

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SUMMARY

Although many studies have focused on the hydrological behaviour and classification of wetlands, the wide diversity of wetlands makes a clear and operational view difficult. The objective of this work is to compare the organisation and behaviour of two riparian wetlands (RWs) located, respectively, along Strahler order-2 and order-5 streams of the Scorff River catchment (Brittany, France). Groundwater table dynamics were monitored at the RWs during one hydrological year. Hydrochemistry was characterised during hydrological periods of high and low hydraulic head. The results show clearly the contrast in geomorphological and pedological organisation between the two RWs. In addition, the RW along an order-2 stream exhibited a strong hydrological connectivity with the adjacent hillslope whereas the RW along an order-5 stream showed a strong hydrological connectivity with the adjacent stream. We also observed the contrast between conditions favourable for high and permanent denitrification but on low nitrogen fluxes for order 2, and conditions less favourable to denitrification but on strong nitrogen fluxes for order 5. The relation between the contrasting hydrological and hydrochemical behaviour of these two RWs and their stream orders is discussed from the literature and local observations of the catchment. The results support the hypothesis of a relation between stream order and the hydrological and hydrochemical behaviour of the RWs and thus a catchment-scale organisation which may be taken into consideration in management strategies.

1. Introduction

The spatial variability of the hydrological and hydrochemical behaviour of riparian wetlands (RWs), and therefore of their buffering capability (Cirmo and McDonnell, 1997; Viaud et al., 2004), is large. In a meta-analysis of 45 published studies about nitrogen removal within riparian areas, Mayer et al. (2007) calculated a mean effectiveness of 67.5% for nitrate fluxes (F_{NO_3}), but individual values ranged from −248% (the riparian area acting like a source) to 100% (the riparian area acting like a sink). Within a given mesoscale catchment, geomorphology and soil characteristics are the main factors explaining this spatial variability (Ranalli and Macalady, 2010).

Important geomorphological features include the size and slope of RWs and adjacent hillslopes. Groundwater in a large, flat RW has a sufficient residence time and contact with the upper horizons of soil for denitrification and nitrogen uptake to occur (Burt et al., 2002a; Vidon and Hill, 2004a,b). A large hillslope supports the permanence of the groundwater supply for the RW, i.e. a long hydrological connectivity of the RW with the adjacent hillslope and the stream (Jencso et al., 2009; McGlynn and Seibert, 2003). Important soil characteristics include texture, depth and organic matter content (Pinay et al., 2000). Fine-textured soil limits flow velocity and favours reducing conditions and denitrification but may cause a bypassing of superficial soil horizons through more permeable horizons (Puckett and Hughes, 2005) or by surface seep (Gold et al., 2001). Deep soil can support a long hydrological connectivity between RW, hillslope groundwater and stream but can also lead to drying of superficial horizons. Additionally, a higher content and depth of organic matter inclusion favours heterotrophic denitrification (Davidsson and Stahl, 2000). In an agricultural environment, hydraulic works like ditch, tile, pipe drain are also important factors that must be considered in this variability (Lowrance et al., 1984).

Seasonal patterns of The RW buffering capability appear to be strong and to vary in space. Some authors have observed that buffering capability can be reduced during a high-water period due to the combination of short residence time, low plant uptake and a greater possibility of surface runoff (Devito and Dillon, 1989; Maître et al., 2003). However, in other sites, the buffering capability is stronger during a high-water period due to stronger fluxes through superficial soil horizons (Burt et al., 1999; Clément et al.,

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2003). To assess the spatial and seasonal organisation of RW behaviour and buffering capability, additional site-specific studies are needed, as well as general conceptual models (Vidon and Hill, 2004a,b).

In line with scaling analyses of the organisation of the hydrographic network (Cudennec et al., 2004; Dodds and Rothman, 1999; Rodriguez-Iturbe and Rinaldo, 1997), conceptual patterns of the organisation of geomorphology (Schumm, 1977), pedology (Kang and Lin, 2009; Mourier et al., 2008) and interactions between RWs, streams, and hillslopes (Stanford and Ward, 1993; Tabacchi et al., 1998) as a function of upstream–downstream gradients have been proposed. The organisation of riparian hydro-geomorphology and pedology as a function of the Strahler stream order (Strahler, 1957), allows us to hypothesise that the hydrological and hydrochemical behaviour of RWs depends on their hydrographic position.

The objective of this work is twofold: (1) to compare the behaviour of two RWs of the Scorff catchment connected to streams of Strahler orders 2 and 5, respectively, and (2) to identify geomorphological and pedological controls on functional differences. Specifically, the comparison is based on dynamics of the hydraulic head and solute concentrations in RW groundwater, on an evaluation of the exchange of water and nitrogen between RW groundwater and the stream, and finally on the potential RW buffering capability. The representativeness of the two sites, the generality of the conclusions and conceptual scaling implications are discussed based on pedological observations performed within the catchment and similar contexts.

2. Materials and methods

2.1. Location of the two study sites

The two study sites, Le Reste (T2, 47°57′19″N, 03°16′60″W) and Locorion (T5, 47°59′30″N, 03°18′48″W), are included in the Scorff catchment (www.inra.fr/ore_pfc, last visited in February 2011) in Brittany, France (Fig. 1). The geological substrate is mid- to large-grained biotitic and muscovitic granite. The granite is covered by relatively young deposited material (alluvium) in the riparian zones, which are considered RWs due to water-saturated alluvium. The two RWs are not artificially drained permanent meadows, and streams are not ditched and cut-off. T2 and T5 are 4.7 km apart (9.4 km along the hydrographic network). Mean annual net precipitation (precipitation minus actual evapotranspiration) is 540 mm (Météo France, calculated from 1970 to 2006 monthly data). T2 is located along an order-2 stream (Scorff tributary) that drains a catchment area of 0.6 km^2. T5 is located along an order-5 stream (Scorff) that drains a catchment area of 129.8 km^2. The hydrographic network used to define the stream orders of the two sites was modelled from a 50-m-resolution DTM and from a regional map of the mean annual discharge using a model of a monodirectional drainage network and a threshold of drained volume of $65 \times 10^3\ m^3$ to the source points of the hydrographic network (Aurousseau and Squividant, 1996).

2.2. Geomorphological et pedological characterisation

The topography of T2 and T5 was measured with a theodolite (WildT1000, LEICA) with an accuracy (i.e., standard deviation) of 9×10^{-4} deg for the azimuth and 3×10^{-3} m for the distance. The soils were described from auger drillings during spring 2006 along a piezometer transect perpendicular to the stream (described in the next section). The classification used was the World Reference Base of Soil Resources (IUSS, Working Group WRB, 2006). Criteria used to describe the horizons were organic matter content, texture, intensity of hydromorphic features and saturated hydraulic conductivity (*Ks*). The organic matter content provides an indication of the potential sources of organic carbon to support denitrification. Texture is one of the main drivers of soil hydraulic properties. Intensity and depth of hydromorphic features are often used as indicators of redox conditions and saturation by groundwater which both influence denitrification. Hydromorphic features are observed visually by iron segregation and by the ferrous iron test that identifies stagnic or gleyic horizons. The reagent used is 1,10-phenanthroline (Richardson and Bigler, 1984), which, when

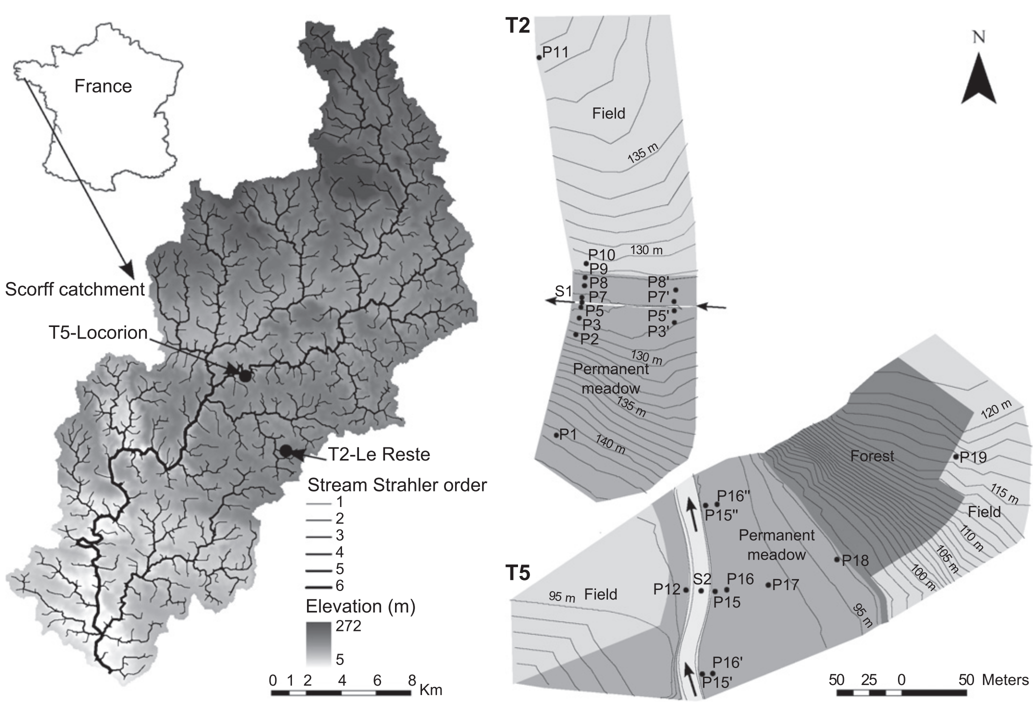

Fig. 1. Location of study sites and the piezometer system (location of piezometers P4, P6, and P13 on Fig. 2).