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Long-term nitrate removal in a buffering pond-reservoir system receiving water from an agricultural drained catchment

Julien Tournebize [a,*], Cédric Chaumont [a], Corinne Fesneau [a], Angéline Guenne [a], Bernard Vincent [a], Josette Garnier [b], Ülo Mander [a,c]

[a] *Hydrosystems and Bioprocesses Research Unit, National Research Institute of Science and Technology for Environment and Agriculture (Irstea), 1 rue Pierre-Gilles de Gennes CS 10030, F92761 Antony Cedex, France*
[b] *CNRS, UMR 7619 Sisyphe, Université Pierre et Marie Curie, Paris 6, 4 place Jussieu, 75252 Paris Cedex 05, France*
[c] *Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia*

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ABSTRACT

The European Directive 2000/60/CE delineates the objectives of a good ecological and chemical status for rivers to achieve before 2015. The present project focuses on a pond-reservoir system (later referred to as a constructed wetland, CW), which can be used as a buffering system to lower the impact of agricultural practices on hydrosystems and decrease or limit the transfer of contaminants flowing toward surface waters.

The CW studied is located at Aulnoy, 70 km northeast of Paris (France). The aim was to assess the efficiency of a CW in terms of nitrate removal and analyze the hydrological balance of the CW and the agricultural catchment. This study showed potential nitrate removal based on a decrease in average nitrate contents measured over a period of 8 years between the inlet and the outlet of the CW. Average values of 12.6 14 and 6.4 mg $N–NO_3/L$, respectively, were measured at the main drain, the spring and the reservoir; this led to a 50 ± 18% (mean ± standard deviation) reduction of nitrate fluxes. The semi-potential denitrification experiments confirmed the denitrification capacity of CW sediments. Conclusively, this CW can treat waters from agricultural drainage, producing outflow quality in line with the expectations of a good ecological status as defined by the European Directive 2000/60/CE.

1. Introduction

Since agricultural applications of fertilizers have increased since World War II, water quality has become a pressing environmental issue. The European Directive 2000/60/CE outlines the objectives to improve the ecological and chemical status of rivers by 2015. The Common Agricultural Policy (CAP) provides funding to stimulate local action to limit agricultural contamination of hydrologic systems. One of the strategies consists in changing agricultural practices (Arheimer et al., 2004). This can be associated with mitigation using wetlands (Zedler, 2003) and riparian buffer zones (Christensen et al., 2012), a successful strategy for reducing agricultural contamination of the recipient ecosystems. In the particular case of subsurface drainage of agricultural fields where runoff is limited and water from the soil profile flows through drain pipes, different techniques could be implemented to reduce nitrate transfer. Controlled drainage regulates water discharge by maintaining a water depth at the drainage outlet. This technique is largely applied in US agricultural catchments (Gilliam et al., 1979), but its application is successful only in flat areas. The bioreactor technique wasdeveloped by Robertson and Merkley (2009), in which the main drainage collector is directly connected to a wood chip-filled tank to stimulate denitrification (Schipper et al., 2010). This technique could be applied at a relatively small scale; however, from the hydraulics point of view it should be carefully designed to avoid uphill interactions. A recently developed method uses temporary flooding of riparian buffer zones (Jaynes and Isenhart, 2014). To enhance denitrification, the drainage water is driven through the soil beneath the riparian buffer zone. A hybrid solution, which uses the storage capacity and a soil buffering filter by infiltration of stored water (Nedelec et al., 2010), has not been applied yet at field scale.

Last, a constructed wetland (CW) is an economically and ecologically efficient tool to manage non-point source pollution and particularly excessive nitrate (NO_3^-) input (Kadlec and Knight,

* Corresponding author.
E-mail address: julien.tournebize@irstea.fr (J. Tournebize).

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1996; Birgand et al., 2007; Mitsch and Gosselink, 2007; Tanner and Kadlec, 2013). CWs can improve water quality as well as enhance biodiversity and contribute to flood abatement depending on how they are positioned in the landscape (Mitsch and Gosselink, 2007; Zedler, 2003; Moreno-Mateos et al., 2008b, 2010; Thiere et al., 2009; Passy et al., 2012). The capacity of CWs to release nitrate depends on environmental variables (pH, temperature, carbon, sources, pollutant concentrations) and wetland design (volume, depth, plant species) (Mitsch et al., 2001; Braskerud, 2002; Arheimer et al., 2004; Kadlec and Robert, 2005; Tanner et al., 2005; Kovacic et al., 2006; Moreno-Mateos et al., 2008a,b; Woltemade and Woodward, 2008; Thiere et al., 2011).

Denitrification is the main process by which nitrate is removed from wetlands (Bastviken et al., 2009; Birgand et al., 2007; Tanner et al., 2005). Denitrification occurs under suboxic to anoxic conditions where anaerobic bacteria reduce nitrate and reduce nitrite to gaseous nitrogen (N_2) (Fennel et al., 2009; Seitzinger et al., 2006). In CWs, these conditions occur close to sediments, indicating that the denitrification activity is higher in the benthic zone (Christensen et al., 1989; Ishida et al., 2006; Thiere et al., 2009).

The end-product of denitrification is N_2 gas; however, if the reaction does not proceed to completion, N_2O gas is produced and released into the atmosphere as a greenhouse gas (Firestone et al., 1980; Knowles, 1982). According to earlier IPCC statements, N_2O emission from agriculture is controlled only by the amount of N added as fertilizer, so N_2O travels from fields to groundwater and rivers and the construction of wetlands does not increase the amount of N_2O produced (IPCC, 1997). Unlike the IPPC, Groffman et al. (2000) consider that CWs can improve or damage regional N_2O budgets if the N_2O/N_2 ratio is modified during denitrification. Also, the last IPCC Wetland Supplement (IPCC, 2014) considers treatment wetlands and wet riparian zones as potential sources of N_2O.

The aim of this study was to observe the effectiveness of an original buffer system playing the role of a CW in removing nitrate from agricultural drainage water in an intensive agricultural catchment located in the Ile-de-France region of France during a long period from 2005 to 2013. The first step was to establish a nitrate budget at the catchment and CW scales. Eight years of monitoring data were analysed with regard to several hydrologic and chemical variables. The second step was to understand buffer system's effectiveness and verify in the laboratory whether denitrification occurs by incubation of buffer system's sediments and N_2O production. One of the goals was to show whether or not buffer system's implementation was advantageous at the catchment scale.

2. Materials and method

2.1. Site description

The man-made pond and reservoir is a buffering system functioning as a typical free water surface constructed wetland system. The whole system is referred to as a constructed wetland (CW). It is located in Aulnoy, 70 km northeast of Paris (France), and is part of the Orgeval catchment (Fig. 1), which belongs to the French environmental research observatory network (GIS ORACLE www.GIS-ORACLE.irstea.fr) (Anctil et al., 2009; Billy et al., 2010, 2011, 2013; Garnier et al., 2014). The climate is oceanic temperate, with a mean annual temperature and precipitation of 12 °C and 700 mm, respectively. The 33-ha agricultural catchment is situated in the sedimentary Paris Basin. The upper Brie Formation, tertiary siliceous and marly limestone, is covered by quaternary loess deposits (Bricon and Canipelle, 1963), enriched in clays and sands, resulting in low permeability and waterlogged soil during winter. The agricultural land is subsurface-drained with perforated pipe installed 10 m apart and buried 0.8–1 m deep to enable soil cultivation during wet periods. Cereals (corn, maize), legumes (horse bean, pea, alfalfa), sugar beet, and rape seed are the dominant crops grown in the region. The agricultural catchment is managed by two farmers. Nitrogen is applied according to usual agricultural practices between the end of February and the beginning of April. In 2011, one farmer converted 30% of the catchment's plots to organic farming.

The buffering system in the study site comprises a shallow pond (50 cm deep) and a reservoir (3 m deep) used for irrigation when necessary (Fig. 1). The pond and reservoir measure 860 and 3305 m^2, respectively, and a total estimated storage volume of 12,000 m^3. The ratio between the CW surface and the agricultural

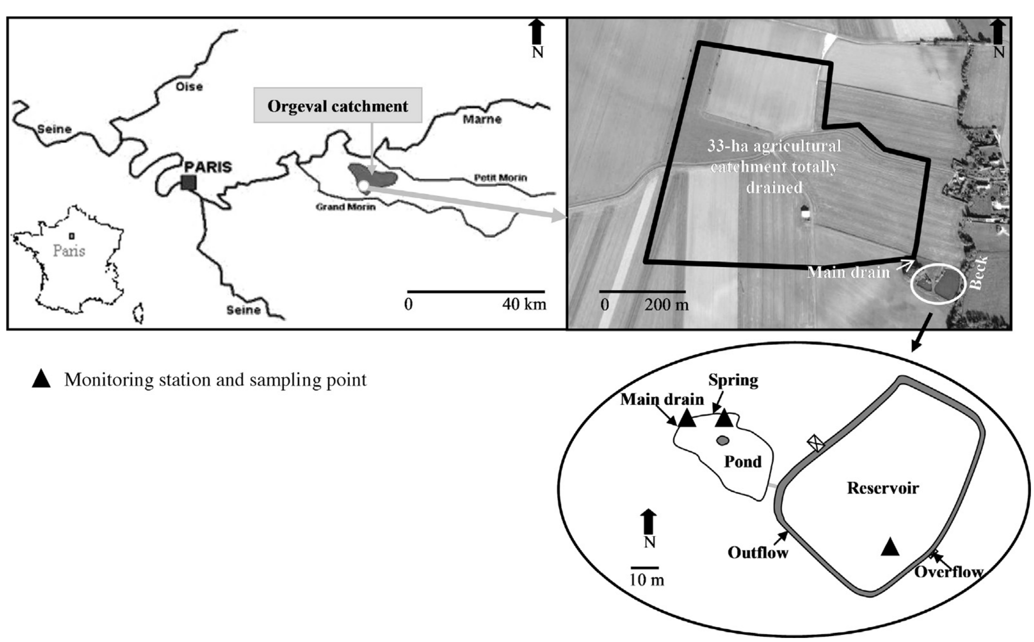

Fig. 1. Location of the subcatchment and the buffering system at the arterial network outlet.