Contribution of the sediment compartment to nutrient stocks and fluxes in a reservoir

Contribution du compartiment sédimentaire aux stocks et flux de nutriments dans une retenue hydraulique

Edwige Gautreau[1,2], Géraldine Nogaro[1], Emma Gouze[1], Florian Mermillod-Blondin[2], Laurence Volatier[2] , Pierre Marmonier[2]

[1]EDF - Recherche et Développement, Laboratoire National d'Hydraulique et Environnement (LNHE), 6 Quai Watier, 78401 CHATOU, France
[2]UMR-CNRS 5023, LEHNA, Université Lyon I, Campus de la Doua, 6 rue Dubois, 69622 Villeurbanne, France (contact : edwige.gautreau@univ-lyon1.fr)

RÉSUMÉ

Les retenues hydrauliques situées sur de grandes rivières peuvent constituer des zones d'accumulation de sédiments fins chargés en nutriments (azote et phosphore principalement) qui proviennent du bassin versant et, de ce fait, sont susceptibles d'engendrer des nuisances liées à l'eutrophisation (blooms de cyanobactéries, hypoxie, etc.) affectant la ressource en eau et ses activités récréatives (baignade, pêche, eau potable, etc.). L'objectif de cette étude est d'estimer l'évolution spatio-temporelle, qualitative et quantitative, des stocks en nutriments (azote et phosphore) dans les sédiments d'une retenue située sur l'Aude (Puyvalador, Pyrénées-Orientales) pour mieux comprendre leurs influences sur le fonctionnement biogéochimique du système. Des carottages de sédiment ont été réalisés à deux saisons (juillet et octobre 2016) sur 3 stations de la retenue présentant des caractéristiques contrastées (e.g. profondeur et positionnement par rapport au barrage). Les résultats montrent une hétérogénéité de la concentration en nutriments biodisponibles entre les stations et l'estimation de la diffusion moléculaire à l'interface eau-sédiment montre une faible contribution du compartiment sédimentaire dans les flux de nutriments de la retenue par rapport aux apports externes via les tributaires. Cependant la prise en compte du compartiment sédimentaire reste nécessaire en tant que réacteur biogéochimique où de nombreux facteurs influencent les flux de nutriment à l'interface comme la dynamique de l'oxygène dissous ou la présence de faune benthique.

ABSTRACT

Reservoirs located on large rivers can be preferential areas for the accumulation of fine sediments, which are usually loaded with nutrients (mainly nitrogen and phosphorus). These nutrients originate from the watershed and can lead to eutrophication problems (eg. cyanobacterial blooms, hypoxia) and affect water quality and recreational activities (eg. drinkable water, swimming, boating and fishing). The purpose of this study was to estimate the spatial and temporal evolution as well as the quantity and bioavailability of nutrient loads (nitrogen and phosphorus) in the sediments of a reservoir located on the Aude River (Puyvalador, French Pyrénées). Sediment cores were collected during two seasons (July and October 2016) in three locations with contrasted characteristics (eg. depth and location to the dam). Our results showed large differences in the concentrations of bioavailable nutrients among the studied locations. The estimation of the molecular diffusion across the water-sediment interface indicated a small contribution of the sediment compartment to nutrient fluxes compared with external inputs by the main tributaries. However, the influence of the sediment compartment needs to be taken into account as a biogeochemical reactor since many factors (e.g. dissolved oxygen dynamics, presence of benthic fauna) can greatly affect nutrient fluxes at the water-sediment interface.

MOTS CLES

Eutrophication, nutrients, reservoirs, sediment compartment, sediment interface, water

1 INTRODUCTION

Reservoirs located on large rivers can be preferential areas for the accumulation of fine sediments, which are usually loaded with nutrients (mainly nitrogen and phosphorus). These nutrients, originating from allochthonous inputs (catchments) and autochthnous inputs (primary production) can contribute to eutrophication problems (eg. algal blooms, hypoxia). Such alterations may have potential impacts on the use of water for drinking purpose or recreational activities. For these reasons, the assessment of P and N dynamics in reservoirs is crucial for understanding factors leading to eutrophication (Smith, 2003). The water-sediment interface can act as a source of nutrients for the water column but it has rarely been taken into consideration in eutrophication issues of reservoirs. Indeed, studies mainly focused on the role of autochthonous inputs by streams and rivers on reservoir eutrophication (Burger et al., 2007). However, studying the influence of the water-sediment interface on eutrophication needs to consider the spatial variability of bottom sediments within the reservoir. Thus, the purpose of this study was to estimate the spatial variation of nutrient loads and fluxes from sediments depending on their locations in the reservoir. We also compared fluxes calculated from the sediments to nutrient inputs from tributaries to evaluate their respective contributions to nutrient fluxes. Understanding this dynamism could support management decisions that potentially impact the sediment compartment of the reservoir (e.g. flushing, tidal range).

2 METHODS

The study was done in the reservoir of Puyvalador (42°38'N, 2°07'E) located on the Capcir Plateau in the Pyrenean mountains which is considered eutrophic according to Water Framework Directive (WFD) specifications. This reservoir has a mean volume and a maximum water depth of 10.1 million m^3 and 21 m, respectively. There are two main tributaries supplying water to the Puyvalador reservoir, the Aude River and the Galbe River. Previous data showed no vertical stratification of the reservoir for dissolved oxygen, temperature and pH (Rapport DCE de Puyvalador, 2014). During the present experiment, sediment cores up to a length of 10 cm were collected at two seasons (July and October 2016) in three stations contrastingly influenced by tributaries. Station A is located in the reservoir downstream to the Aude River whereas the station E is located downstream to the Galbe River. The third station, called C, is located at the deepest point of the reservoir, and is not directly influenced by the two tributaries. Immediately after collection, sediment cores (3 cores per station for each date) were sliced at 2 cm intervals in the field. For each slice, grain size distribution was measured by laser diffractometry (Malvern Mastersizer 2000G). Nutrient pools (NH4, NO_x, PO_4) were estimated in three ways: the total content (N,P), the water soluble fractions in pore-water after a centrifugation step, and the extractable fractions using NaOH for PO_4 removal and KCl for NH_4 and NO_x removal. Following these analyses, we tested the influences of location (n= 3 stations), sediment depth (n= 5 first core slices), and date (n=2) on nutrient quantities using a three way-ANOVA. For these analyses, the normality and the homoscedasticity of the residues were verified using the Shapiro–Wilk test and the Bartlett test, respectively. When significant results were obtained, Tukey post hoc tests were performed to evaluate which locations, months and/or sediment depths differed. In addition, the concentrations of N-NH_4+, N-NO_3^- and P-PO_4^{3-} in pore water (mean of the 3 first sediment layers) and in water column were used for estimating molecular diffusion through the water-sediment interface according to Fick's law.

3 RESULTS AND DISCUSSION

For all measured variables, we obtained comparable results between July and October. Sediment grain size analyses showed that the volumetric proportion of fine particles (< 63 µm) was significantly higher in station C than in the two other stations (Figure 1A for July, 3-ways ANOVA, $p < 0.001$, location effect). This result indicates that station C located in the central area of the reservoir constitutes the main area of fine particle sedimentation. Despite differences in grain size distributions among stations, we did not detect marked differences in total P and N among stations (Figure 1BC for July). In contrast, the concentration of extractable NH_4^+ was around 3-fold higher in sediments of station C in comparison with stations A and E (Figure 1D, 3-ways ANOVA, $p < 0.001$). The same trend was observed for NO_x^- concentrations despite a high variability with depth (Figure 1DE). Thus, sedimentation of fine particles could explain the highest concentrations of extractable N in station C. Despite comparable concentrations of total phosphorus among stations, the concentrations of extractable phosphorus were lower in station E than in stations A and C (Figure 1F, 3-ways ANOVA, p < 0.001). It is also worth noting that the comparable concentrations of extractable P in stations A and C indicate that P availability in sediments was not only due to sedimentation processes from the water column. According to measurements of extractable nutrients, diffusion rates estimated by Fick's law from nutrients measured in pore water indicated significant differences among stations (3-ways ANOVA, $p < 0.001$ for NH_4^+ and $p < 0.001$ for PO_4^{3-}).

Station C had a higher contribution to N and P diffusion rates from sediment to water column than station A and station E. Based on results from station C, we estimated maximal nutrient fluxes from sediments of 4.5 kg/ha/year of N and 0.5 kg/ha/year of P. In comparison, analyses made on tributaries (concentrations of nutrients and flow rate) gave external input estimations of 125.5 kg/ha/year N and 21 kg/ha/year P in the period from June to October 2016. Thus, the contribution of internal loading of nutrients from sediments by diffusion was more than 20-fold lower than external loading of nutrients by tributaries.

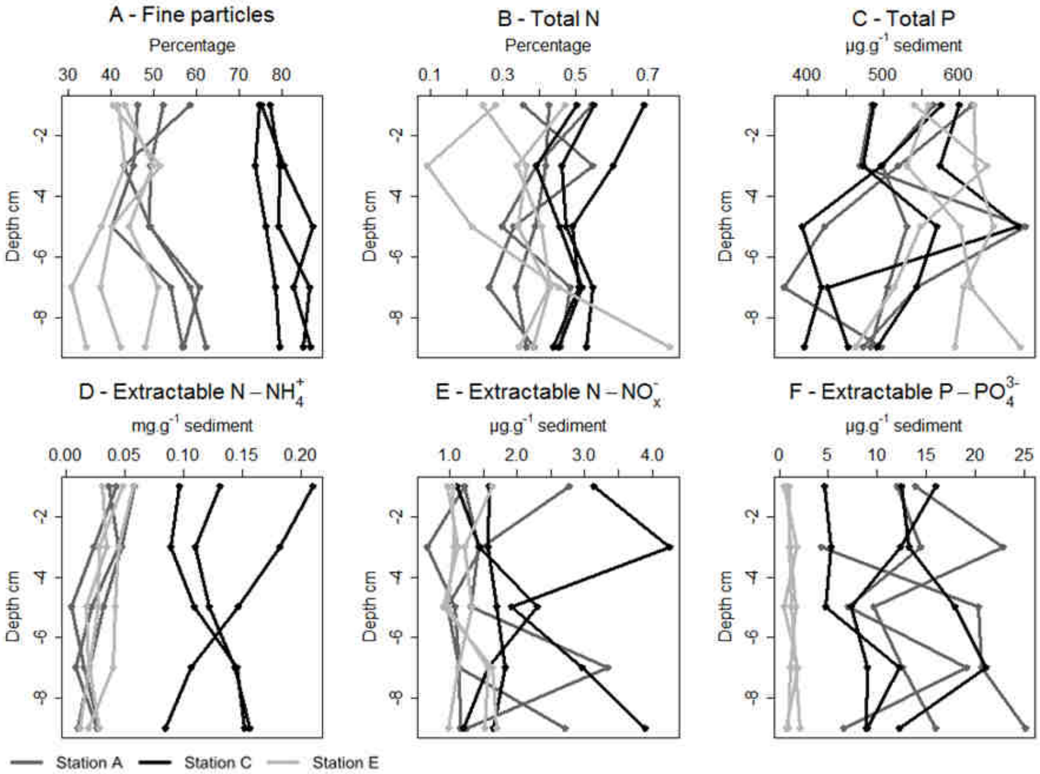

Figure 1: Vertical profiles of A/ the volumetric percentage of fine particles (< 63 µm) ; B/ the percentage in mass of total N ; C/ the total P ; D/ the extractable N-NH_4^+; E/ the extractable N-NO_x^- ; and F/ the extractable P-PO_4^{3-} measured at the three stations in July

4 CONCLUSIONS

Station C, which constitutes the main sedimentation area of fine particles among stations, had the highest contribution to nutrient recycling from sediments. However, the molecular diffusion across the water-sediment interface suggests a small contribution of the sediment compartment to nutrient loading compared with external inputs from tributaries. Nevertheless, many factors other than molecular diffusion, such as dissolved oxygen dynamics or the presence of benthic fauna, can also greatly influence nutrient fluxes at the water-sediment interface. These factors need to be considered in future studies to obtain more realistic estimations of the contribution of the sediment compartment to nutrient dynamics in reservoirs.

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