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Modelling of dissolved inorganic phosphorus transfers in the heavily dammed Mississippi River basin

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During the past century, the rapid acceleration of anthropogenic phosphorus (P) delivery to surface freshwaters has fueled massive downstream eutrophication problems. These additional P inputs have increased P exports to global estuaries, and retention in river networks. An increasing number of studies have been highlighting that this accumulated P can be re-mobilized on the long term, delaying the beneficial effects of water quality conservation measures. Since different P forms exhibit different in-stream behaviors, and have varying ecological impacts, a major challenge is to understand their driving transfer and transformation processes in watersheds.

The Mississippi River basin (MRB) is a relevant example of human-impacted watershed. It naturally transports large sediment loads, and receives high anthropogenic P inputs, essentially from fertilized croplands. With 1000's of dams throughout the basin, water, sediment and P transfers are highly affected by reservoir trapping. Freshwater nutrient export from the MRB to the northern Gulf of Mexico has been contributing to the spread of the largest "dead zone" in the entire western Atlantic Ocean. Here, we investigate the controlling processes of P fluxes and speciation throughout the basin, with a stronger focus on its most readily bioavailable form (and therefore most likely to affect eutrophication risk), i.e. dissolved inorganic P (DIP). Therefore, we developed the IMAGE-DGNM framework, which couples global, spatially-explicit hydrology and integrated assessment models with process-based biogeochemistry in surface freshwaters. The dynamic in-stream module calculates advection from headwaters to estuaries, particle dynamics, P cycling in the water column and in bed sediments, and exchanges between these compartments. After validating the model against suspended sediment, total P and DIP measurements at different USGS stations, we calculate P budgets for the whole MRB for the period 1970-2000.

In this timeframe, inputs of all P forms to surface freshwaters in the MRB have decreased. In-stream sedimentary and biogeochemical processes not only reduce the amount of P reaching the estuary, but also modify its speciation. Indeed, even though DIP accounts for 18-22% of the total P inputs to the river network, it constitutes 30-43% of that reaching the northern Gulf of Mexico, due to low DIP retention along the river network. DIP sorption to particles is overall counterbalanced by mineralization of organic matter in the water column and in bottom sediments. When looking at the specific role played by reservoirs, we show that, while they aid in net P retention, they serve as DIP sources due to the transformation of legacy P in sediments. As a result, between 1970 and 2000, DIP retention has decreased, while particulate P retention has risen. The continuation of this trend into the future may lead to a net DIP production in the MRB. This shows the necessity of accounting for benthic dynamics and P re-mobilization processes, generally lacking in current large-scale P budgets. This will help better evaluate the effect of pollution mitigation strategies over time, especially in the context of booming dam construction over the globe.