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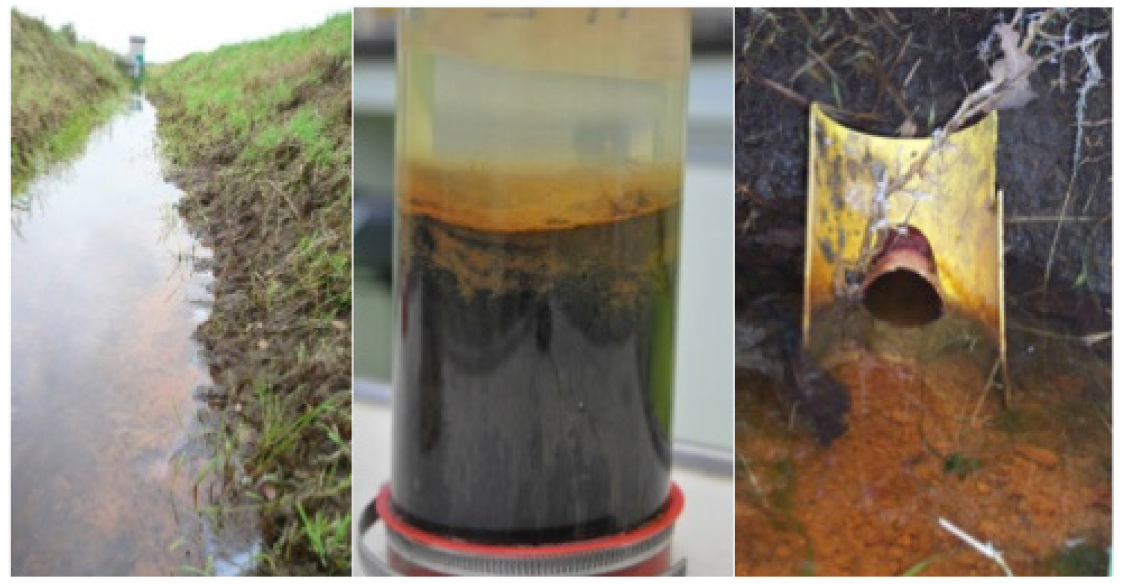
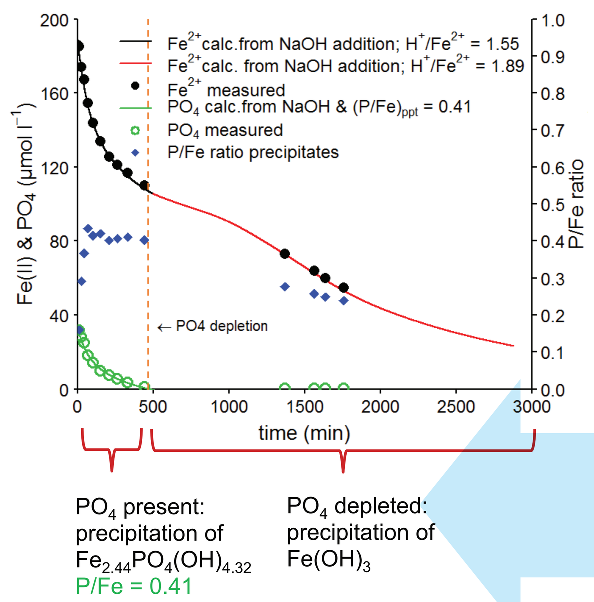
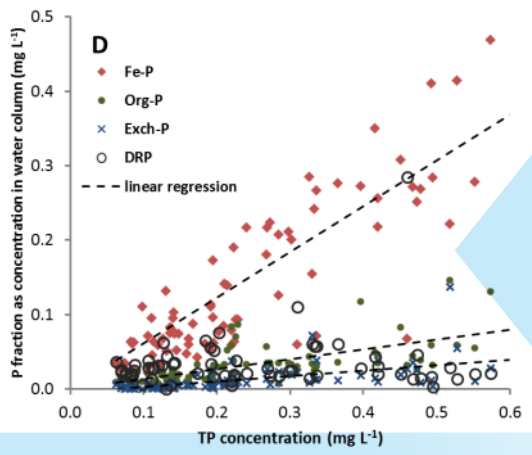
Building Towards a Model for Iron-controlled Phosphorus Transport in Lowland Catchments



Orange brown iron oxide precipitates: deposited at the bottom of a drainage ditch in the eastern part of the Netherlands (left), at the top of a ditch sediment core sampled in the western part of the Netherlands (middle) and from a drain tube (right).



Aeration experiments with Fe(II) and PO_4 containing solutions. A pH stat device was used to maintain constant pH and to record the H⁺ production during Fe(II) oxidation. This enabled us to monitor the reaction progress and stoichiometric ratios between H⁺ production and Fe(II) oxidation.



Concentration of P fractions versus total P concentration (submitted).

The release of P to surface water following P leaching from heavily fertilized agricultural fields to shallow groundwater and the extent of P retention at the redox interphase are of major importance for surface water quality. We studied the role of biogeochemical and hydrological processes during exfiltration of groundwater and their impact on phosphorus transport in lowland catchments in the Netherlands.

Biogeochemical controls

A field campaign on P speciation in surface waters draining agricultural land showed that the total-P concentration is strongly dominated by iron-bound P. On average, of the total-P concentration in the water samples was iron-bound particulate P. After the turnover of dissolved P to iron-bound particulate P, the P transport is controlled by sedimentation and erosion of suspended particulate matter.

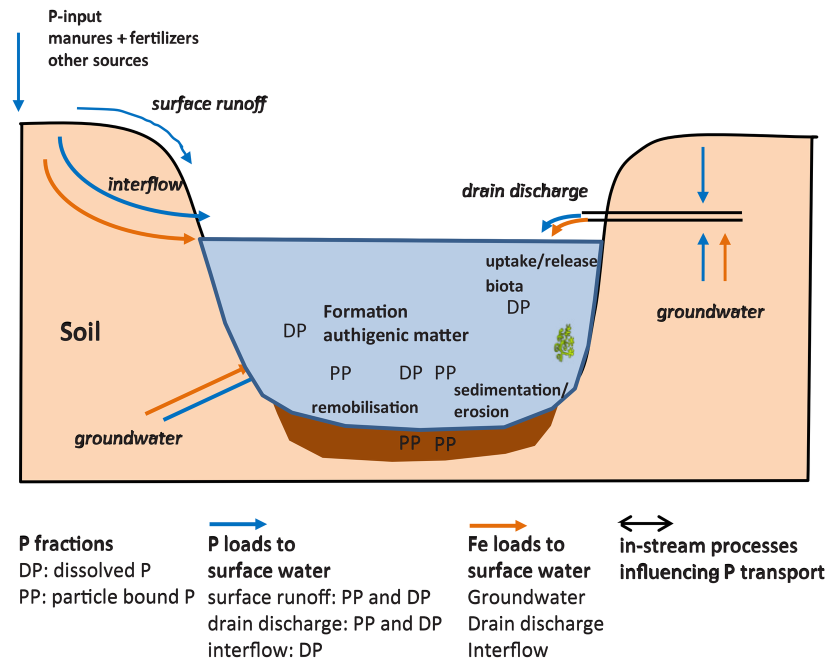
Chemical precipitates derived from groundwater-associated Fe(II) seeping into the overlying surface water thus contribute to immobilization of dissolved phosphate and, therefore, reduces its bioavailability.

Aeration experiments with Fe(II) and phosphate-containing synthetic solutions and natural groundwater showed that Fe(II) oxidation in presence of phosphate leads initially to formation of Fe(III) hydroxyphosphates precipitates until phosphate is near-depleted from solution. The mobility and ecological impact of P in surface waters in lowland catchments like polders is thys strongly controlled by the exfiltration of anoxic Fe(II)-bearing groundwater.

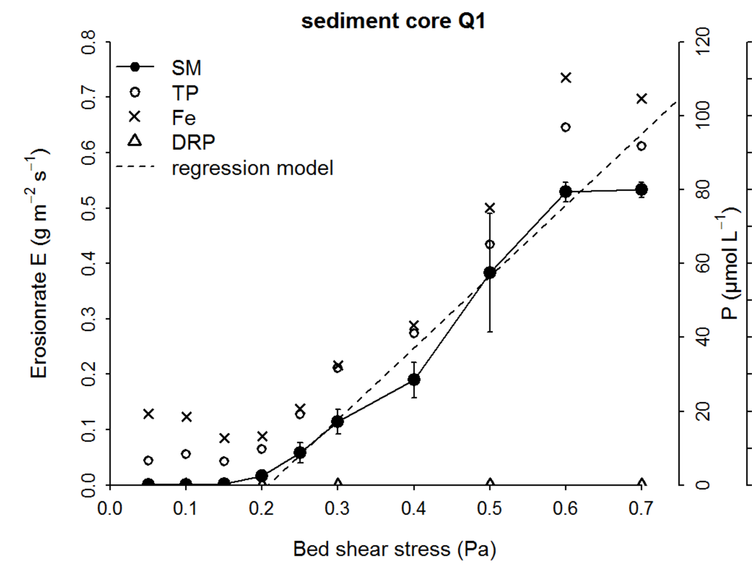
Hydrodynamic controls

After the turnover of dissolved P to iron-bound particulate P, transport of P in catchments or polders is controlled by sedimentation and erosion of suspended particulate matter. Hydrodynamic resuspension of P stored in bed sediments of watercourses is commonly considered to be the main transport mechanism in lowland catchments. A combination of erosion experiments with undisturbed bed sediment core and a hydrodynamic model that calculates bed shear stresses in watercourses revealed contrasting insights.

The geographic setting of a polder is, with a dense network of drainage ditches and water flow that is controlled by weirs and pumping stations, as such that flow induced bed shear stress in watercourses seldom exceeds the critical shear stress for erosion. This implies that erosion of bed sediment is not a major process controlling P transport in polder catchment. Polders can thus be considered as a comprehensive peak flow control system that mitigates P loads from agricultural fields to downstream vulnerable water systems.

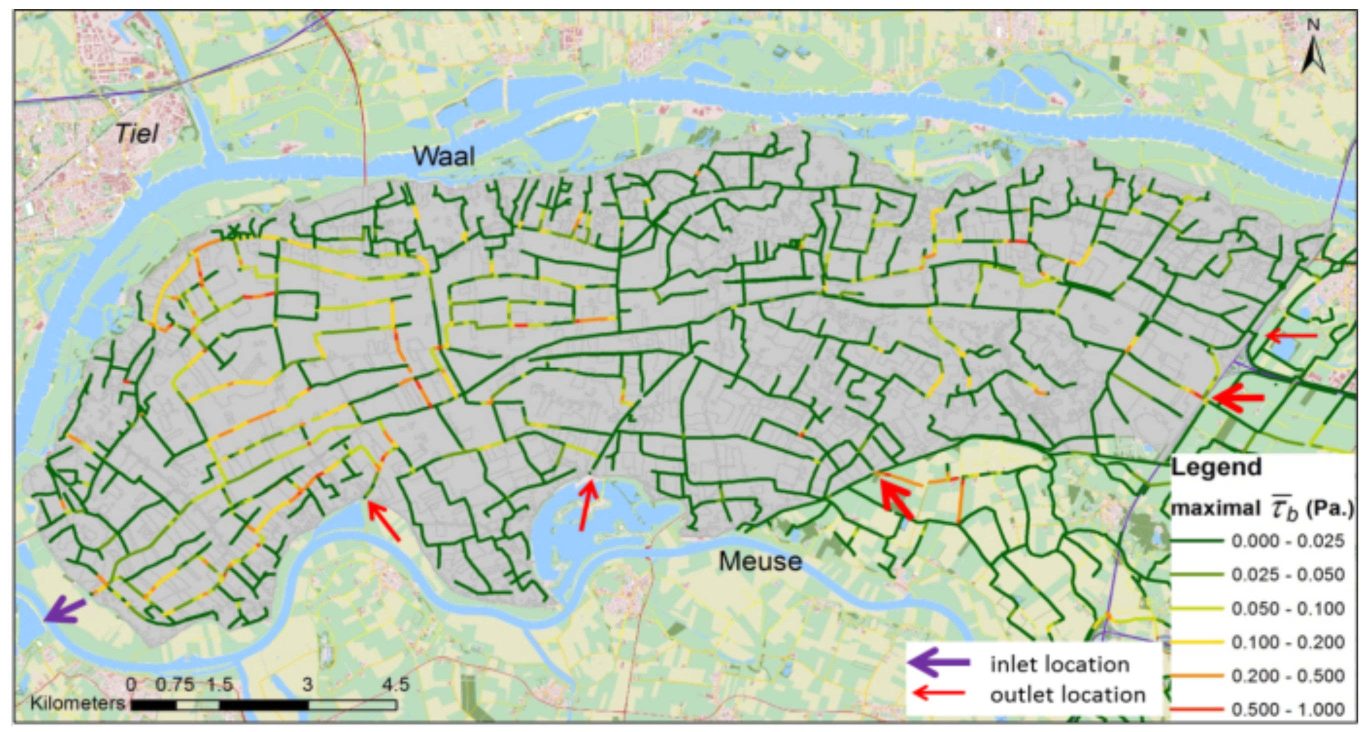


Main transport pathways of P loads from diffuse sources to surface water and in-stream processes controlling P transport in flowing surface waters.



< Erodibility of drainage ditch sediments represented as suspended particulate matter and associated total P and Fe concentrations as function of bed shear stress.

Maximum bottom shear stress in ditches and channels of the study area Quarles van Ufford during the period from March 2004 to April 2005 (submitted).



Conclusions

Discharge of Fe-bearing groundwater in combination the limited water flow in artificial and strongly managed watercourses reduce the environmental risk caused by P loads from diffuse agricultural sources. Furthermore, we hypothesize that a significant fraction of the P load that leaches from soil to surface water in polder catchments is converted back to the soil by dredging and thus that P recycling is more effective than expected.

Publication related to this research
Van der Grift et al., 2014. Iron oxidation kinetics and phosphate immobilization along the flow-path from groundwater into surface water. Hydrol. Earth Syst. Sci. 18, 4687-4702.
Van der Grift et al., 2016. High-frequency monitoring reveals nutrient sources and transport processes in an agriculture-dominated lowland water system. Hydrol. Earth Syst. Sci. 20, 1851-1868.
Van der Grift et al., 2016. Fe hydroxyphosphate precipitation and Fe(II) oxidation kinetics upon aeration of Fe(II) and phosphate-containing synthetic and natural solutions. Geo. et Cos. Acta 186, 71-90.

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