In-situ measurement and simulation of dissolved oxygen and nutrient transfer across the sediment-water interface of River Neckar, Germany

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Abstract: A benthic chamber was developed and used to gain representative rates of oxygen and nutrient transfer across the sediment-water interface at various locations along the lock-regulated River Neckar. The results were independently validated by a 1D biogeochemical sediment model, including sediment solute fluxes.

Key words: Sediment Oxygen Demand (SOD), nutrient transfer, early diagenesis, benthic chamber, biogeochemical sediment model

Introduction

River Neckar is a lock-regulated river, draining a densely populated watershed of 14.000 km^2 in south-west Germany. Bottom sediments within the river reservoirs are mostly fine grained (silty loam) and usually contain high proportions of organic matter. Consequently, these sediments are a major sink for dissolved oxygen (DO) and play an important role in the transport an fate of nutrients and contaminants (Song and Müller, 1999, Haag, 2003).

To further investigate the sediment-water interactions, we developed a benthic chamber to measure the solute transfer in-situ and a biogeochemical sediment model to simulate the processes relevant processes and fluxes within the sediment.

Methods and materials

The in-situ benthic chamber is schematically depicted in Figure 1. The system is made up of the chamber, a variable set of tubing to connect the inflow and the outflow end of the chamber, a controllable pump, a flow meter, and a set of probes (DO, water temperature, pH, conductivity). The chamber has an opening at the bottom (0.05 m^2), a vertical cutting edge, and exterior flanges.

The measurement principle, applied at various locations along River Neckar, is similar to other batch systems (Haag, 2003): The chamber is pushed into the sediment, with the flanges preventing excessive penetration. The ambient water is circulated through the system. Nutrient concentrations within the system are measured at the start and at the end of an experiment, whilst DO content is continuously recorded. Sediment Oxygen

Short scientific paper

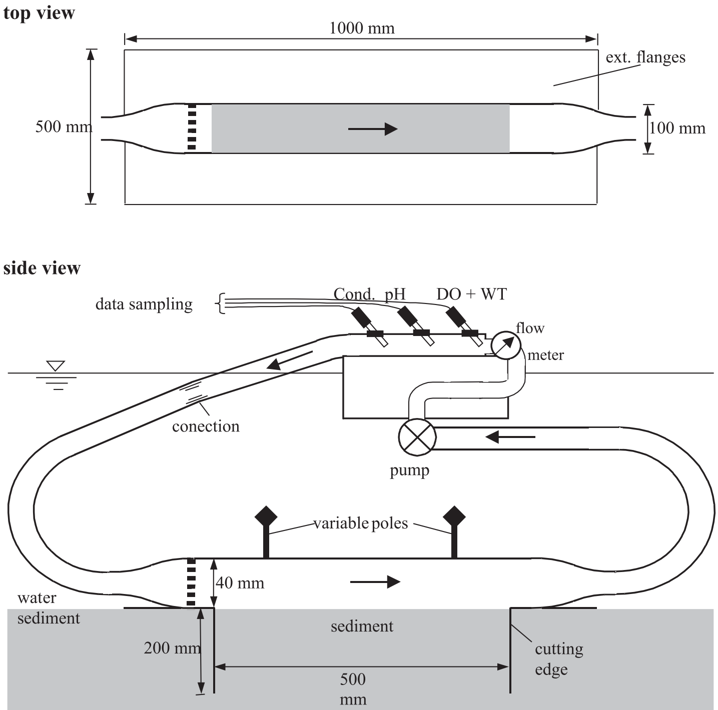

Figure 1. Schematic sketch of the in-situ benthic chamber.

Demand (SOD) and nutrient fluxes are calculated from the time course of concentrations, the known volume, and the known sediment surface area. DO loss due to water bound BOD is taken into account. Photosynthesis is prevented by darkening the system. In addition, two sediment samples were taken to determine the BOD rate of suspended sediment samples.

We also developed a 1D mechanistic model of the relevant biogeochemical processes within the sediment body and the associated solute flux. Beside the processes depicted in Figure 2, this model also accounts for the oxidation of the reduced products of early diagenesis (e.g. nitrification), the respiration of benthic animals, and equilibrium of dissolved methane with pure methane gas bubbles. Details of the model and its theoretical grounds, the governing equations, and the parameters are given by (HAAG, 2003). Parameter values were first estimated on the basis of literature values (DITORO, 2001), and then calibrated by using the fluxes measured with the benthic chamber and vertical concentration profiles recorded by SONG, MÜLLER, 1999.

RESULTS AND DISCUSSION

The parameter values of the biogeochemical sediment model could be adjusted within a physically meaningful range in a way that the model was able to describe both, the

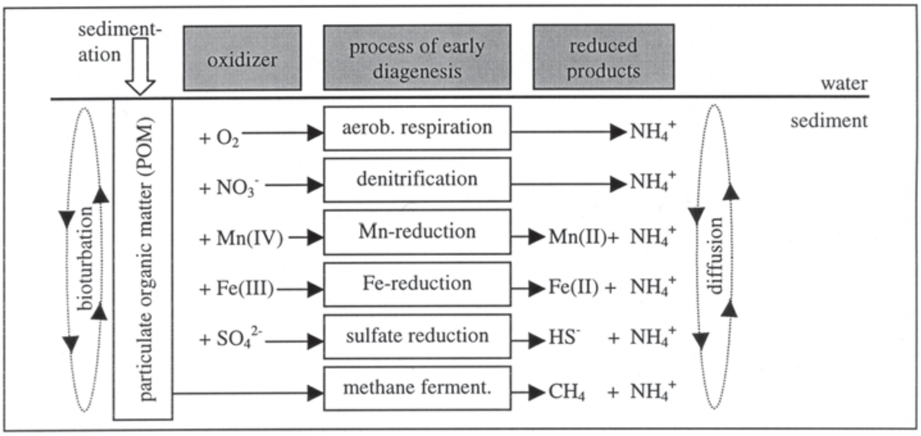

Figure 2. Some of the processes considered in the mechanistic biogeochemical sed. model.

fluxes measured with the benthic chamber and vertical concentration profiles provided by (SONG, MÜLLER, 1999). This implies, that the concept underlying the numerical model is broadly correct. Combining the results of the model and the in-situ experiments shows that the measurements with the benthic chamber can be evaluated using zero-order kinetics.

Table 1 summarizes solute flux rates which were considered representative for typical River Neckar sediments (positive fluxes are from sediment into water). In particular the fine grained sediments are relevant DO sinks. Whilst nitrate flux is negative, ammonium is released from the sediments. Hence, denitrification within the suboxic layer obviously dominates over nitrification in the oxic layer. Also note that phosphate is (temporally) taken up by the sediment. This is most likely due to a thin oxide-/hydroxide-layer close to the sediment surface, efficiently trapping phosphate from the sediment body an the water column. However, it could be shown experimentally, that upon eroding this superficial layer, phosphate is released into the water column (HAAG, 2003).

It was also found that SOD generally increases with the square root of the BOD measured for suspended sediment samples, which is consistent with model results. This general behavior is influenced by the density of benthic macrofauna. SOD increases with increasing macrofauna density because

Table 1. Solute fluxes across the sediment-water interface of River Neckar.

		silty loam	loamy sand
J_{DO}	(in g/m^2/d)	-1.4 ... -1.7	-0.7 ... -0.9
J_{NH4-N}	(in g/m^2/d)	0.2 ... 0.5	~ 0.01
J_{NO3-3}	(in g/m^2/d)	-0.35 ... -0.70	~ -0.20
J_{PO4-P}	(in g/m^2/d)	-0.025 ... -0.055	-0.001 ... -0.016

of respiration and enhanced effective diffusion due to bioturbation.

The results gained here were successfully used for large scale water quality modeling (HAAG, 2003). Moreover, the biogeochemical sediment model may be used to assess long-term effects of changing environmental conditions upon SOD and the fate of nutrients. It may also be extended to simulate the fate of contaminants, whose fluxes are associated with early diagenesis of sediments SONG, MÜLLER, 1999, DITORO, 2001).

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