Considerations in modeling the sediment–water exchange of phosphorus

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Key words: sediment, water, phosphorus, models, temporal scales, spatial scales

Abstract

The potential to release accumulated phosphorus from sediments has been the major motive to study and to model the fate of this nutrient in sediments.

For the dynamics of the sediment–water interaction the sizes of the pools involved and the rates of conversion/transport from one pool to another are of primary interest. As the sediment pools for phosphate are generally much larger than the pools in the water column, a rather slow adjustment of the sediment to management measures will occur. For the analysis of management measures it is obvious that the gradual change in sediment composition must be taken into account. Only for rather short periods the sediment composition can be assumed to be constant; this may be appropriate for studies of e.g. the annual cycle.

The sediment–water interaction is a complex resultant of physical, chemical and biological processes, including:

- physical processes: advection due to seepage or consolidation, pore-water diffusion, transport and mixing of solids by resuspension, sedimentation and bioturbation.
- chemical processes: adsorption and desorption, dissolution and (co)precipitation, inclusion.
- biological processes: mineralization of a wide range of organic compounds by various (micro)organisms, each with their own nutrient requirements and electron acceptors.

Aspects which are discussed and need to be considered in application of a model in research or management are the level of aggregation and detail that is required and may still be practical, the spatial and temporal scales which are applicable for the processes mentioned and their influence upon the numerical dispersion and model stability, the availability of data for calibration/validation and the resolution of the analytical techniques. These aspects are not independent however.

Frequently models are not functional because they contain details which are either unnecessary or suggest a feigned accuracy which is not justified by analytical and experimental resolution of system characteristics.

Introduction

The potential to release accumulated nutrients or pollutants from sediments has been the major motive to study and to model the fate of these substances in sediments. Internal loading of phosphate will sustain primary production and might delay the effects of restoration measures. Therefore, much of the research on eutrophication has been focused upon the role of sediments in the cycling of nutrients, see e.g. Baccini (1985).

The interaction between sediments and over-
lying waters is reciprocal: the loading of the sediments with phosphorus – generally in a particulate form – from the overlying water is controlled by its cycling and incorporation in different trophic levels in the water column, but this is in turn affected by the rate of release from the sediments which in a complex way is related to the loading of the sediment and the subsequent accumulation, redistribution and speciation. Especially in a transitional phase, when reduced external inputs start to restrict the productivity, the interaction between sediment and water is of great interest. Actually, managers want to know at what level this transition will occur and what the role of the sediments will be in the long and short term. They therefore generally want guidelines or rather simple predictive models relating readily accessible variables, some of which can be controlled, to trophic indicators. Such models may exist, but do no justice to the complexity of the system or only within certain limits, e.g. for the specific water body on which the model has been calibrated. In research, often much more complex models are used as a tool to collect one's thoughts, to design and evaluate experiments, to integrate results of different scientific disciplines, and eventually to generalize these for management purposes. One of the main dilemmas in research is the level of detail and complexity that should be introduced in the description of the system. Too simple models have very little predictive value outside the conditions for which they were calibrated, and prediction in the most essential function of models. On the other hand, complex models are hard to calibrate and validate, if possible at all, and have a high demand for parameters, input data, initial and boundary conditions, time and expertise. Although not addressing the role of sediments specifically, the empirical lake loading models belong to the first category; when error analysis is used the information from such models can be properly weighed and considered in the lake management (Reckhow, 1979). An example of a model that tends to be rather rich in variables and parameters can be found in Kamp Nielsen (1975).

In this contribution some aspects pertaining to the scope and complexity of models are discussed with a view to the function of the model.

**Temporal scales**

Whereas is the water column autotrophic processes and grazing food chains predominate, sediments are characterized by heterotrophic transformations and a detritus food chain. Thus in the overlying water phosphate is incorporated in algae and other organisms in a particulate form, but in the sediments the inorganic phosphate is (in part) regenerated and subsequently released, stored and/or buried. The proportions of release, fixation and burial are of interest for different objectives, in which from a methodological and modeling point of view the time scale is the most important.

Short term objectives, with a time horizon of about one year, may be to analyze the seasonal variation in internal loading as an important attribute of predicting chlorophyll levels, oxygen conditions, habitat quality etc. Within a year the sediment matrix will be fairly constant except for the pool of non-refractory organic material. Consequently the adsorptive capacity of the sediment for phosphate varies mainly due to changes in redox conditions related to the temperature cycle and the course of organic deposition. This means that a reasonable prediction of internal loading within a year does not require a complete sediment mass balance, but should take into account transient storage in pools related to the mineralization and the seasonal deposition of particulate organic phosphate from the water.

The buffer of phosphate in the microbial mass is one of these potentially important transient pools (Montigny & Prairie; Petterson; Gächter; 1993). Iron associated phosphate also can vary strongly due to changing redox conditions (Caraco et al.; 1993) and more general by Froelich (1988), Lijklema (1977, 1980).

Besides the effect of redox conditions also the change in the ambient concentration of phosphate will affect the fraction adsorbed on Fe (III)-(hydr)oxides, e.g. Breeuwsma (1973) and Al-