

Multi-modelling approach for assessment of water quality in the Lower Havel, Germany

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Abstract: Complex water quality problems demand integrated solution approaches. The current work presents a multi-modelling approach to tackle water quality issues in the Lower Havel, Germany. The Lower Havel located in the northeast of Germany, near Berlin, is a region with several large shallow riverine lakes interconnected with river sections and artificial canals. The surface waters are contaminated by urban effluents discharged from six wastewater treatment plants from the municipal area of Berlin which serves a population of four million. The models HYDRAX and QSim were used to study eutrophication control viability by manipulating nutrients external loads. Namely, to investigate if reducing nitrogen plus phosphorus sources would contribute more to improve the trophic state in the Lower Havel than using the strategy of just reducing phosphorus sources. The results obtained show that, for the Lower Havel case, there is no significant improvement in trophic state when nitrogen and phosphorus loads are reduced simultaneously in comparison with only reducing phosphorus loads.

Keywords: *Water quality; Multi-modelling; Lower Havel; Eutrophication*

1 INTRODUCTION

The Lower Havel located in the northeast of Germany, near Berlin, is a region with several large shallow riverine lakes interconnected with river sections and artificial channels. There, human flow regulation and a naturally low slope are responsible for small flow velocities and discharges. With six urban wastewater treatment plants discharging treated effluents in the waterways, eutrophication is a water quality problem in the Lower Havel [Kneis 2007].

In freshwaters, phosphorus is usually pointed out as the limiting nutrient for phytoplankton growth [Vollenweider 1968, Schindler 1974]. Until now, efforts to control algae growth in the Lower Havel indeed focused mostly on phosphorus reduction. However, there has been a growing perception that just reducing phosphorus would not be enough to improve the ecological condition of this sensitive waterbody as demanded by the EU Water Framework Directive [The Council of the European Union 2000] and that a combined reduction of both nutrients, Nitrogen (N) and Phosphorus (P) could possibly give better results. Eutrophication control strategies that reduce only phosphorus have failed in a number of waterbodies [Havens et al. 2001]. Nevertheless, the effectiveness of nitrogen reduction measures to control algae growth is also far from certain since many cyanobacteria species can directly fix atmospheric nitrogen [Vitousek et al.

2002, Conley et al. 2009] and therefore they may counterbalance lower nitrogen loads. Based on the current scientific knowledge there are authors that strongly advocate a combined reduction of nitrogen and phosphorus to control eutrophication in freshwaters [Abell et al. 2010] while others are strongly against it and encourage only phosphorus control [Schindler et al. 2008]. Both strategies have stories of success and failures and depend on the intrinsic conditions of a particular waterbody.

In the current work we propose to investigate the feasibility of eutrophication control in the Lower Havel by manipulating simultaneously N and P loads through the use of an integrated multi-modelling approach. The use of this approach has several advantages, namely enabling comprehensive evaluation of this large and complex waterbody, the possibility of making future previsions and weighting contributions from different processes.

The conceptual integrated multi-modelling framework is presented in Figure 1.

2 MULTI-MODELLING APPROACH

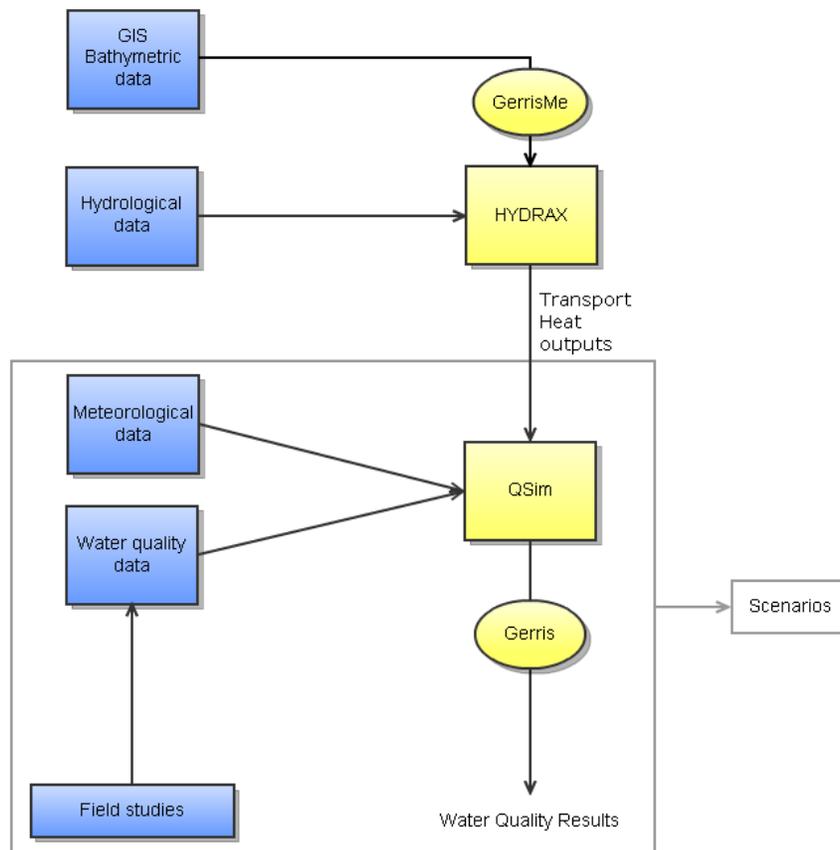


Figure 1. Conceptual scheme for the multi-modelling approach for assessment of water quality.

As a first step GIS and spatially interpolated bathymetric data are used to build a modelling domain geometry and to generate a numerical simulation grid using the GerrisME [Rüter 2010] tool. The outcome is used together with hydrological data to set up the hydrodynamic model HYDRAX [Oppermann 2010]. Modelling work proceeds by calibrating and running the water quality model QSim [Kirchesch and Schöl 1999]. HYDRAX model output plus information from field studies and meteorological data is used for that purpose. A final step involves the use of Gerris software to postprocess and analyze results. The different models are uncoupled and were used sequentially. Both, HYDRAX and QSim have previously been used

successfully to simulate hydrodynamic and water quality in the Spree, Elbe, Saar, Havel and Rhine rivers [Rode et al. 2007, Schöl et al. 2002, Becker et al. 2010]. The HYDRAX model solves numerically the shallow water equations for one dimension using a finite difference implicit scheme. Meteorological data plus hydrological data (daily discharges and water levels) was used to set up the model. QSim is a water quality model able to simulate the pelagic and the benthic compartments. The model includes a quasi-2D extension that allows simulation for stratified pelagic compartments. Apart from oxygen and nutrients species, the state variables include three groups of algae (cyanobacteria, diatoms and green algae), zooplankton, macrophytes and benthic algae. QSim rationale can be found in Schöl et al. (2002). QSim parameterization was supported by limnological field studies and by literature data. Water quality data for model initialization was obtained from Berlin water authorities. Meteorological data was provided by the German meteorological service (DWD). This multi-modelling approach allows to include important factors to evaluate the water quality, such as hydrology, morphology and hydrodynamic in the simulations [Lindim et al. 2011]. In non multi-modelling approaches these factors cannot be accounted for.

3 STUDY AREA

The Havel River is an entirely lowland, low-gradient river and one of the major tributaries of the Elbe River. It is located in the North-East German lowlands and covers a catchment area of 24096 km². The so called Lower Havel (Figure 2) is the section downstream the confluence of the rivers Spree and Havel in the western part of Berlin, covering a basin area of 13501 km². It presents a characteristic river-lake system behavior. Mean daily discharge of the Lower Havel at the next downstream gauge in Ketzin was 53 m³/s (period 2005-2010). However, average discharges have been decreasing since the 90's due to lower inflows from the river Spree and to climate change effects [Wechsung et al. 2008]. The average depth in the Lower Havel is 4 meters.

Together with its tributary, the Spree River, the Havel River drains the municipal area of Berlin and collects the urban effluents of roughly four million people [Heberer 2002]. It also serves as a source of drinking and process water and is heavily used for recreational and commercial navigation. Because of its multiple uses, eutrophication is a major water quality concern in the Lower Havel [Kneis 2007]. Phytoplankton can reach concentrations of up to 140 µg Chl-a/L, and intense growth of cyanobacteria is a common nuisance in late summer that can lead to restrictions for recreational use.

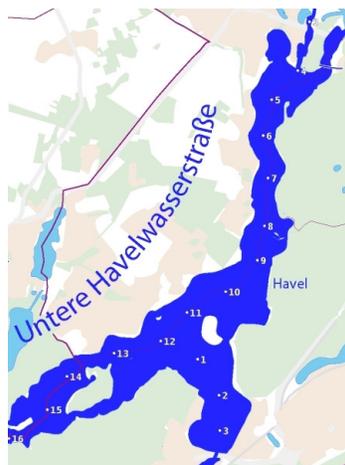


Figure 2. Map of the Lower Havel (52°27' N, 13°10' E) with water quality sampling stations and navigation kms. (Source: Doerrbecker, 2008. Reproduced under a CC License).

Water quality monitoring campaigns done by the Berlin water authorities took place every fortnight during 2005-2010. Sampling was done at surface waters at seven monitoring stations along the Lower Havel. Data collected included nutrients, dissolved oxygen, pH, transparency, Chl-a, conductivity, silicate, DOC and TOC. Experimental procedures were according to German Standard Methods [DEW 2007]. A vertical array of temperature loggers was fixed at one sampling station during the years 2008-2010 (except for the winter months when ice cap exists). The loggers were fixed at 1 m intervals.

4 RESULTS AND DISCUSSION

Previously calibrated models showing reasonable agreement with field measurements were used in the simulations. The models were initially used to simulate an ad-hoc reference scenario with the current status knowledge. Subsequently, different scenarios for external loads reduction were simulated, namely scenarios where N and P loads were reduced simultaneously and scenarios where only P loads were reduced.

Simulated scenarios results were compared and analyzed with the purpose to help decision makers to make adequate choices concerning the possible reduction of nitrogen sources as a way to control eutrophication in the Lower Havel. A representative selection of the simulated scenarios is presented in the current paper.

Figure 3 presents the simulated temporal evolution of nutrients and Chl-a for three different nutrient loads conditions in the Lower Havel. Black line represents the ad-hoc scenario results, blue line shows results for a 50% reduction of P and organic sources loads, and the red line presents results for a scenario where a 50% loads reduction of N and P, plus organic loads was applied.

Modelling results indicate that cutting 50 % of any type of loads would benefit the lower Havel most of the time. The benefits are similar regardless of the type of loads reduced (P alone or combined N+P). Figure 3 shows that less concentration of Chl-a is the outcome when the loads are reduced. This is particularly true for the spring algae blooms. However, there are some summer time intervals when this is not the case: For August 2006, July/August 2008, July/August 2009 and July 2010 (Figure 3) the combined reduction of N and P scenario (red line) leads to an adverse effect in eutrophication. The same holds true for the P only reduction scenario (blue line) for the period July and August 2008. The Chl-a concentrations for these periods are higher for the scenarios where loads were reduced than for the ad-hoc situation.

These situations seem to correspond to stratified periods during which P internal loads occur. P release from sediments in the Lower Havel lakes was observed by Schauer and Chorus [2009]. Furthermore, a large pool of P is stored in the sediments of the Lower Havel according to Kneis et al. [2006].

Figure 4 shows temperatures measured in the Lower Havel between 2008 and 2010 (for 2005-2007 no temperature profiles data exists). From Figure 4 it can be seen that the aforementioned summer time periods correspond indeed to periods of thermal stratification. In particular for 2010 a strong long term period of summer stratification could be observed in July that corresponds to a sharp response of Chl-a in the simulated N+P reduction scenario (Figure 3) - a fivefold increase in Chl-a concentration for the month of July when compared with the ad-hoc scenario.

P internal loads occur through desorption of P from sediments, which is a redox controlled process. After desorption, P is advectively or diffusively transported to the water column. The phosphorus remobilized in sediments is mainly bound to iron (III) oxy-hydroxides. Whenever iron (III) undergoes reduction in sediments, phosphorus is set free and diffuses to the water column. In aerobic sediments oxygen and nitrate will re-oxidize iron and dissolved P will either precipitate or be adsorbed at iron (III) compounds again. Therefore the presence of oxygen or nitrate will inhibit P internal loads, whereas in the absence of these two oxidants P will be released from the sediments. Schauer et al. [2006] refers to a N-NO₃ concentration threshold in sediments of 0.5 mg/L for the inhibition of P internal loads by nitrate.

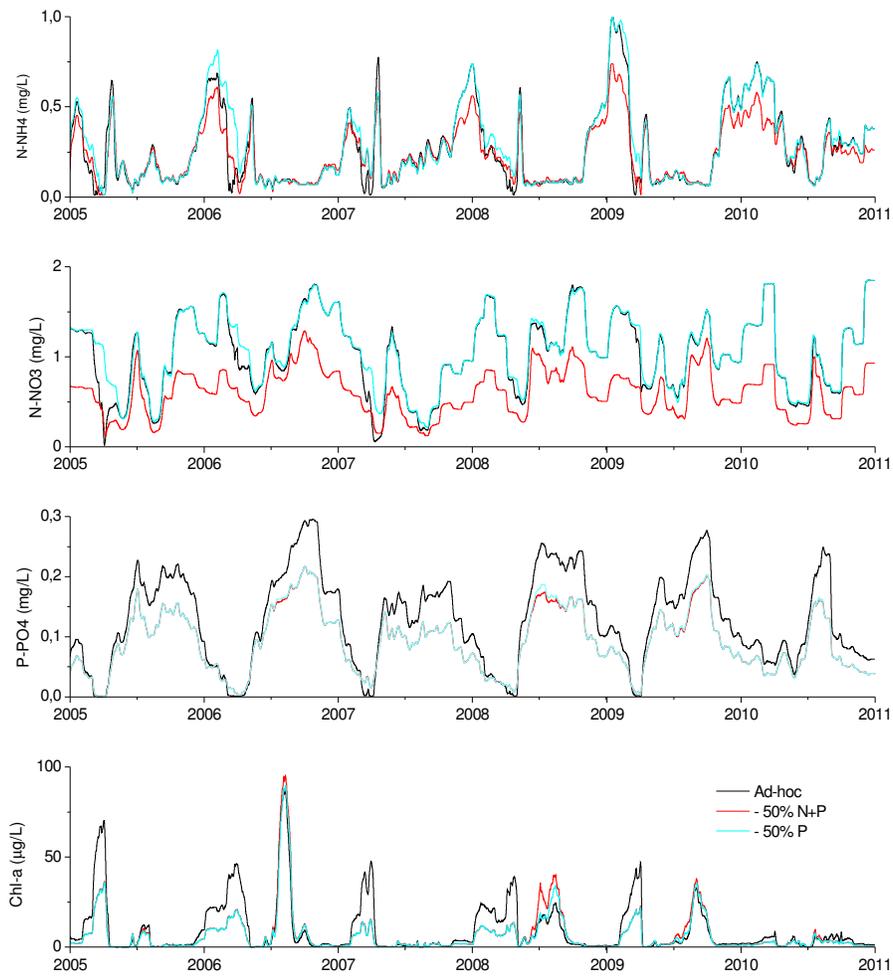


Figure 3. Nutrient loads control simulated scenarios for the Lower Havel. Simulated orthophosphate, nitrate, ammonia and Chl-a concentrations at Km 11 of Lower Havel. Black line - Ad-hoc scenario. Red line - Organic and nutrients (N+P) external loads reduction by 50%. Blue line - Organic and nutrients (P only) external loads reduction by 50%. Note that for orthophosphate and Chl-a the blue and red lines are sometimes coincident.

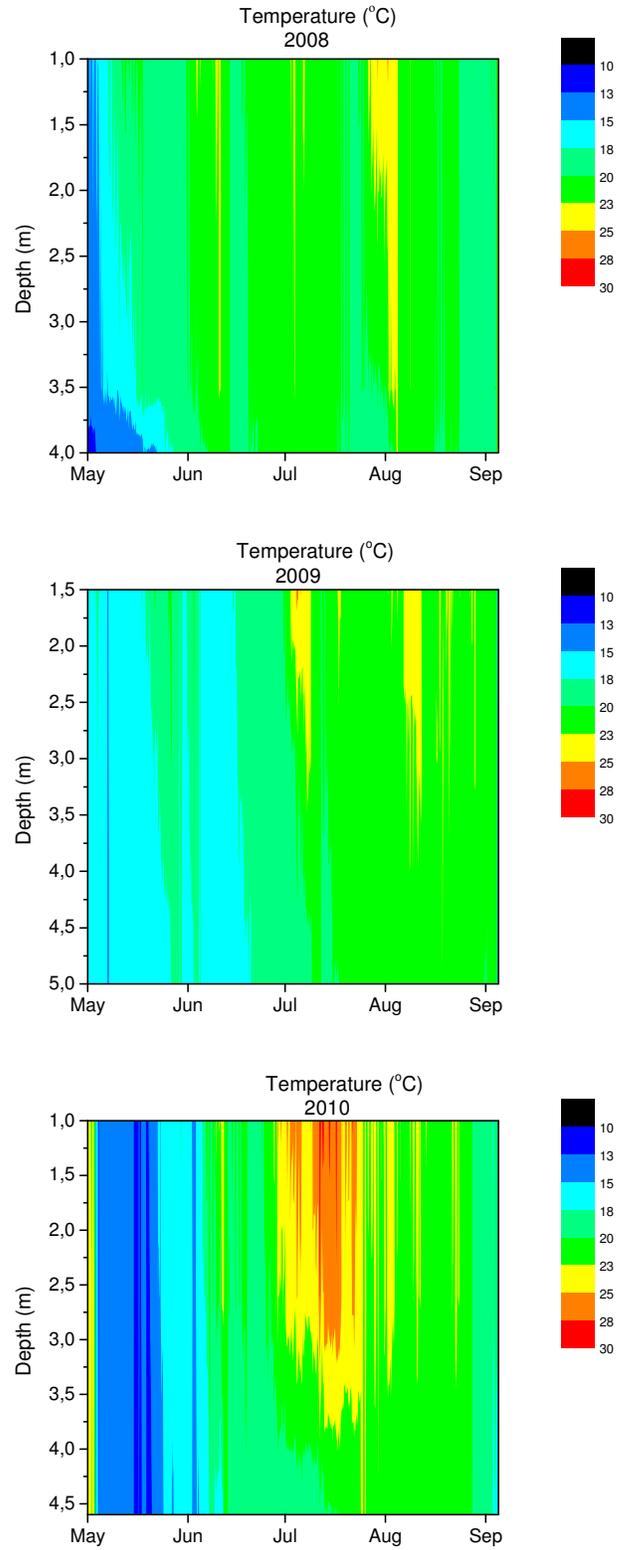


Figure 4. Daily averaged water temperatures (°C) in the lower Havel for 2008-2010.
Data loggers were fixed at 1 m intervals.

Oxygen and nitrate are consumed in the sediment to mineralize organic matter. In the absence of thermal stratification their levels at the bottom water are renewed by vertical transport and mixing in the water column. But in the above mentioned summer situations the thermal stratification will hinder vertical transport of oxygen and nitrate to the bottom. These oxidants will therefore be replenished from the sediment without renewal. Whenever their inhibition threshold limits are reached, P will be released from the sediment, ultimately resulting in the higher concentration of algae observed for these summer situations in Figure 3.

From Figure 3 it can be seen that the resulting Chl-a concentrations for these summer episodes is higher for the scenario where N+P loads were reduced than for the scenario where only P loads were reduced. Reducing the N loads is likely to lead to less nitrate presence in sediments and consequently to higher P internal loads. Thus, in the Lower Havel, when summer stratification occurs reducing N loads will possibly degrade the trophic state of the waterbody instead of helping to control eutrophication.

5 CONCLUSIONS

The multi-modelling approach proposed in the current work predicted algae and nutrient dynamics in the Lower Havel under different external loads conditions. This demonstrates the potential of integrating morphology, hydrology, hydrodynamic and water quality numerical tools to simulate eutrophication in waterbodies.

The water quality assessment performed with the multi-modelling approach suggests that a combined reduction of nitrogen and phosphorus external sources loads may not present advantages to control eutrophication over the reduction of phosphorus loads alone. In particular, for summer periods where thermal stratification occurs, reducing nitrogen loads to the waterbody may result in worsening eutrophication due to stimulation of phosphorus release from sediment.

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