Theme: Water Quality and Management

MIKE BASIN as a tool for development of detailed programmes of measures against eutrophication

A step towards implementation of the Water Framework Directive

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Abstract

The Water Framework Directive in Sweden has led to the production of a programme of measures, aided by the results of different analyses and modelling tools available on a national scale. The implementation of the proposed measures however needs a refined analysis of the different possible measures with regard to cost-effectiveness. The River Basin District Authority for the Southern Baltic Sea District has therefore started a participation-based modelling project, where in-data to a MIKE BASIN set-up has been discussed with municipalities, county administrative boards, farmers organisations and others. The main goal of the project is to provide a basis for the development of detailed programmes of measures on a water body level. Another goal is to assist water boards with the interpretation, analysis and evaluation of environmental monitoring data and programmes. Currently, 4 watershed models are set up, and one more is under development. After calibration, the model set-ups adequately describe nitrogen- and phosphorus transport from watersheds to the sea as compared to existing calculations. Comprising a module with the watershed model for calculation of the cost efficiencies of individual measures is under development.

Some problems dealing with calibration of phosphorus and to a lesser extent nitrogen concentrations in rivers remain. Methods for calculating the effect of different measures such as constructed wetlands and riparian buffer strips on nitrogen- and phosphorus transport have been developed and are currently implemented.

Introduction

The Southern Baltic Sea River Basin District is located in the Southeast of Sweden (Figure 1). Through the EU´s Water framework directive a River Basin Management Plan has been implemented and also a program of measures which gives guidelines for the measures to be taken in order to reach good ecological status in groundwater, coastal waters, lakes and rivers within the district.

Eutrophication has been identified as one of the main environmental problems within the district. It is caused by point sources like paper industries, water treatment plants and rural household wastewater facilities, and diffuse sources of which agriculture and storm water are the most important. – All coastal water bodies are in risk not to fulfil the WFD demands at the year 2015 (Figure 2).

The general measures as described in the Program of measures will have to be translated into concrete measures on a river basin scale. In order to meet the demands for good ecological status and cost-effectiveness it is important to be able to calculate the effect (change in nutrient concentrations) and economic consequences of the different measures and combination of measures on a spatial scale within a river basin. As a first step in this direction, a MIKE BASIN model was set up for hydrology and water quality (organic nitrogen, nitrate, ammonium and total phosphorus) in 4 pilot areas within the district (Figure 2).

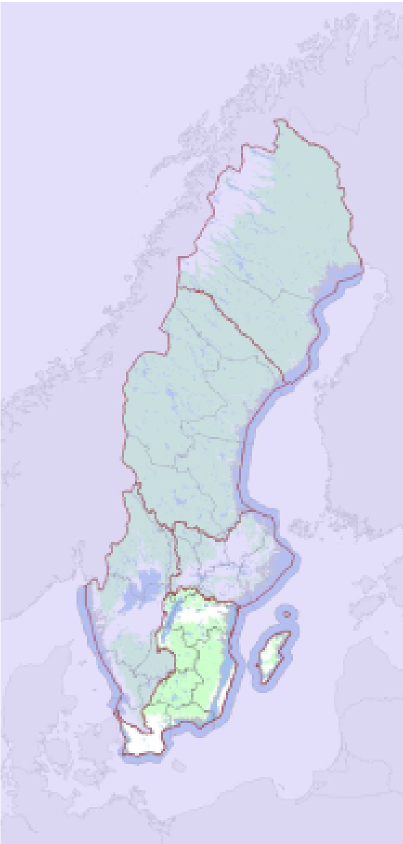


Figure 1 : The South Baltic Water District in Sweden

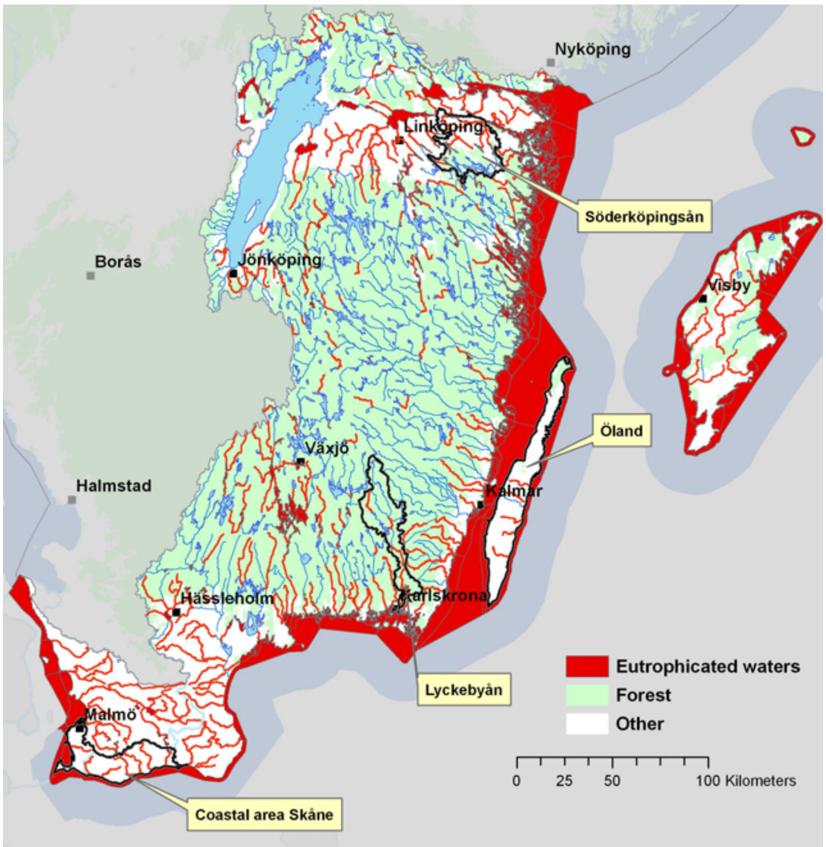


Figure 2: Eutrophicated waters in the South Baltic Water District. Pilot study areas in the District are indicated.

The pilot areas were selected to include sufficient variation in geographical position, nitrogen and phosphorus leakage, land-use, and type of coastal water (Figure 3 and Figure 4).

The main goal of the project is to provide knowledge-based information to local and regional authorities for the realization of detailed programs of measures for reduction of eutrophication in surface waters. Besides this main goal, the results from this project will be useful to prioritize applications for measures in national measure subsidy programs and the evaluation of national and regional measurement programs for eutrophication. Furthermore, during the different stages of the project, the involvement of local and regional authorities enhances knowledge and critical evaluation of available data on loads and concentrations as well as the modelling process.

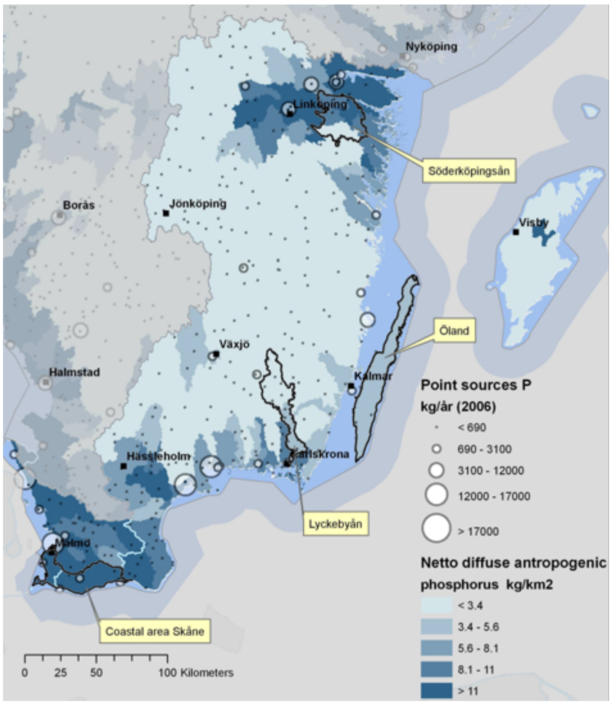


Figure 3: Net anthropogenic phosphorus leakage from diffuse and point sources in the Southern Baltic Sea RBD.

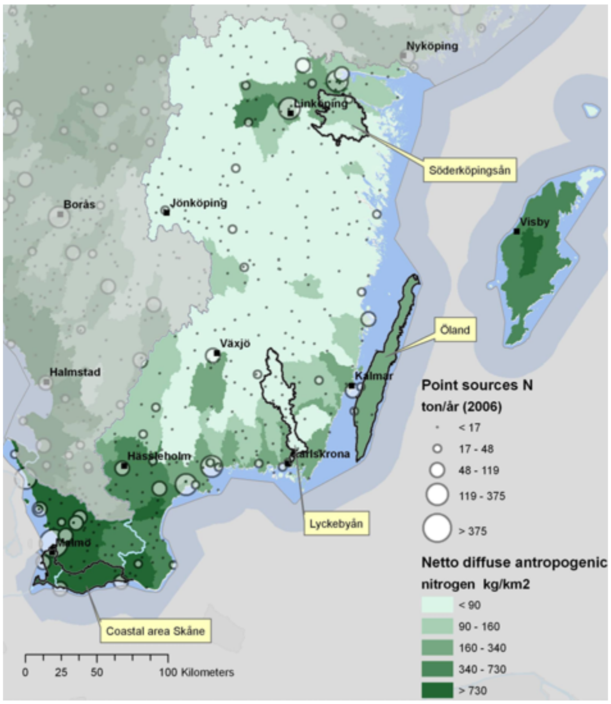


Figure 4: Net anthropogenic nitrogen leakage from diffuse and point sources in the Southern Baltic Sea RBD

Methodology

During all stages of the project, public participation is an important factor (Figure 5). The need for input data to the MIKE BASIN models insured a thorough base for discussion with local and regional authorities as well as other stakeholders in the pilot areas. It was attempted to reach agreement on how to handle the different sources for nutrient leakage in the pilot areas. During the mapping phase of the project, which includes the model set-up in MIKE BASIN, model principles and general methods were discussed with local stakeholders. Moreover, methods for determining the potential for different measures were discussed on this level. Need for measures, in terms of N- and P-reduction were based upon existing classification of nutrient status by regional authorities.

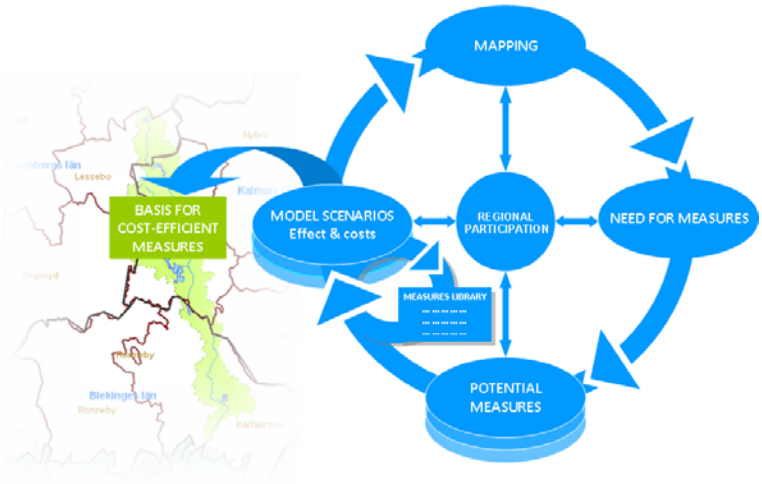


Figure 5: General methodology of the project. Model scenarios build on mapping of nitrogen and phosphorus sources, identification of the need for measures in terms of nitrogen and phosphorus, and the identification of potential measures and final calculation of the effect of those measures. During all phases of the project, public participation is an important factor.

Model approach

The MIKE BASIN model consists of 3 modules including a water balance module (WB), a water quality module (WQ) and a pollution load calculation module, the Load Calculator (LC). The WB module was applied to simulate the water balance in terms of daily or weekly discharges in rivers and lakes based on simulated rainfall runoff at sub-catchment level. Rainfall runoff was simulated using the optional rainfall runoff model, NAM, for each sub-catchment based on monitoring data of precipitation, evaporation and temperature. The WQ module was applied to simulate the average weekly concentrations of nitrogen and phosphorous in rivers and lakes considering both dilution and transformation/retention processes. The LC module was applied to quantify the point and nonpoint sources of nitrogen and phosphorous at sub-catchment level considering the within catchment retention and transport of pollutants.

Model set-up

The MIKE BASIN model was set-up for four areas: Söderköpingsån (882 km^2), Öland (1354 km^2), Coastal area in Skåne (878 km2) and Lyckebyån (810 km^2) (Figure 2). The detailed method for model set-up is exemplified for only one area, Söderköpingsån.

For Söderköpingsån, hydrology was modelled using meteorological data from 6 rainfall and 1 temperature station. A digital elevation model was obtained from the Swedish mapping, cadastral and land registration authority and applied for sub-catchment delineation and within sub-catchment flow distance calculations. River network, lake descriptions and sub-catchments were based on data from the Swedish Meteorological and Hydrological Institute (SMHI) and applied as the basis for model discretisation.

Nutrient loads were based on the results from the 2005 national survey on nutrient loads from Sweden to the Baltic Sea for the year 2006 (Swedish Environmental Protection Agency, 2009). For three types of sources, modifications were made compared to this national survey.

- Nutrient loads from rural household wastewater facilities were included as point sources. Geographic position of households and information on type

of treatment were kindly provided by the municipalities in the respective areas.
- Additional data, with higher time resolution as compared to the national survey data (Swedish Environmental Protection Agency, 2009), on N- and P-loads from wastewater treatment plants were collected from municipalities.
- Nutrient loads from agricultural lands were calculated as in the national survey (Swedish Environmental Protection Agency, 2009), but data on soil texture were modified after discussion with local and regional authorities according to SMED (2009).

Calibration

The model set-ups were calibrated against available data for hydrology and water quality. For example, in Söderköpingsån area 2 flow time series, and 6 water quality time series were used for calibration. For the hydrological model in cases where no discharge measurements were available (Skåne coastal area), simulated discharge obtained from national models (SMHI) were used for calibration. In general the calibration of the hydrological models was done covering a period of approximately 10 years. The primary focus of the calibration was first of all to insure that the overall water balances were simulated satisfactory and secondly that especially the flows during high flow periods were as accurate as possible. The latter is especially critical for achieving a good calibration of point source loads.

For the water quality model (and the pollutant load calculation) if possible, calibration in general were done covering a period of approximately 3-4 years around the year(s) of which data of pollutant loads originated. The primary focus of the calibration was first of all to insure that the simulated concentrations during the high flow periods coincided approximately with actual measurements since these periods are far the most important periods for the total annual transports of N and P. Only secondarily low flow concentrations were calibrated and only for larger rivers.

Measures

There are no ready-to-use functionalities for simulating different measures in MIKE BASIN. In this project the general basis for simulating measures in MB has been modification of N- and/or P loads or modification of soil retention processes. A number of methods for calculating the effect of different measures has been developed and is currently under evaluation:

- Point sources
    - The estimated actual treatment efficiencies from rural household wastewater vary from 10 to 90% and is generally hard to determine in practice. Nonetheless, scenarios were run where these treatment efficiencies were assumed to be at least 50% for phosphorus, and 25% for nitrogen, which corresponds to the minimal treatment efficiency of an approved treatment facility. Also, a scenario was run where 90% of total phosphorus and 45% of total nitrogen was removed before waste water reached within the treatment facility.

This corresponds to the average treatment efficiency of the best available technique. Also, the effect of a general phosphate ban in washing powder (introduced in Sweden 2008) was simulated. In individual cases, already planned connection of rural household wastewater facilities to waste water treatment plants was simulated. Effects of different treatment efficiencies were simulated by changing the N- and P-leakage for each point source.
    - Larger waste water treatment plants in the River Basin District typically have a cleaning efficiency of 96 % for phosphorus and 60 % for nitrogen. The effect of improved techniques, and therefore higher efficiencies was simulated by changing the loads from these point sources.
- Diffuse sources
    - The effect of constructed wetlands on nutrient removal was modelled using a custom made program that interacts with MIKE BASIN. Wetlands were positioned in the river basin according to existing wetland construction plans. Alternatively, when insufficient information was available, wetlands were positioned randomly, taking into consideration the hydraulic load of the wetland. For simulating the retention of nitrogen and phosphorous in wetlands a small program were developed to include wetland retention processes during the MIKE BASIN simulation. Retention processes were included as described in Arheimer and Wittgren (2002) and Tonderski et al.(2005). Where available, upstream drainage area estimations from field-surveys were used and included in the sub-catchment specification in MIKE BASIN. Alternatively, the corresponding upstream drainage area was delineated based on a digital elevation model.
    - The effect of buffer strips on phosphorus run-off from agricultural land was simulated through manipulation of the distance decay grid which describes the distance from nutrient source to the closest water body using an elevation model. The grid was manipulated assuming that retention of particulate phosphorus in surface run-off is between 27 and 97 %, as was obtained from studies of different types of buffer strips in the Nordic Countries (Uusi-Kämppä 2000). The width of the agricultural land that runs off via buffer strips was assumed to vary from 0 to 50 meters distance from water bodies.

Public participation

During the model set-up phase of the project, a close cooperation was established with local and regional authorities, as well as agricultural organisations within the pilot areas in a number of meetings. Experts from the different organisations were informed and involved in discussion about the modelling project, which data were required, and the different scenarios that were planned. Meeting minutes are administrated at the RBDA homepage. During the ongoing model simulation phase of the project, outcome of simulations are published on the RBDA home page, and discussed in detail with regional authorities and agricultural organisations.

Results and discussion

At this stage in the project, water quality models have been successfully set-up and calibrated for 4 pilot areas in the RBD, and is under construction for a fifth.

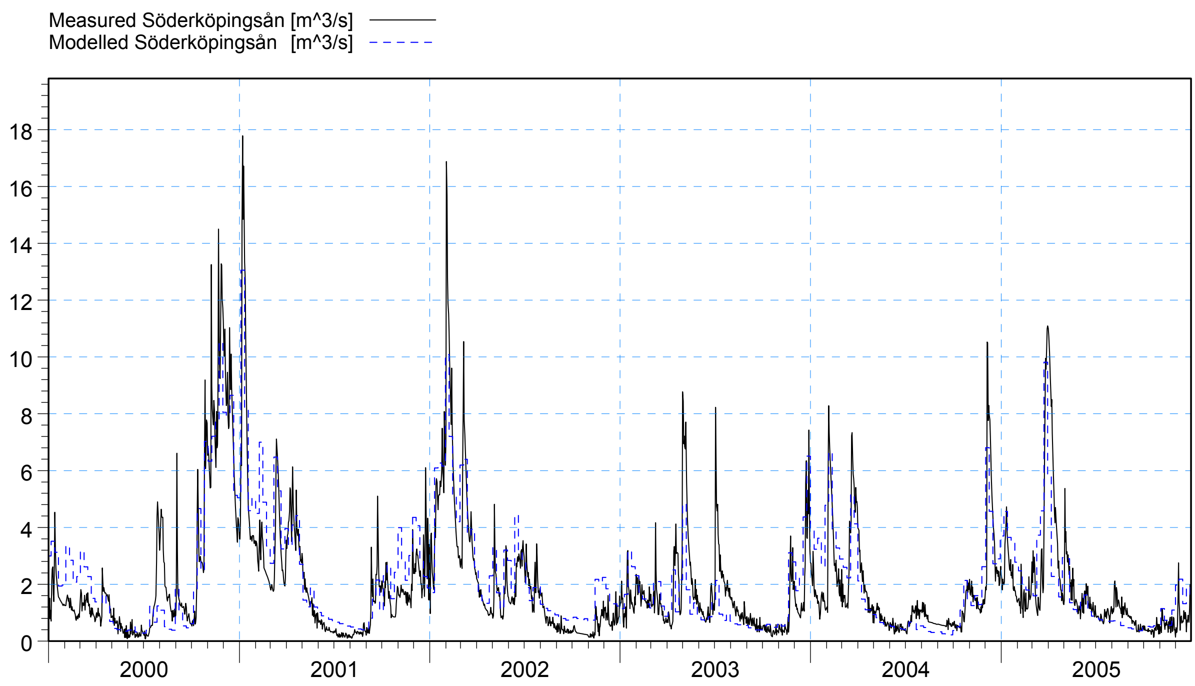
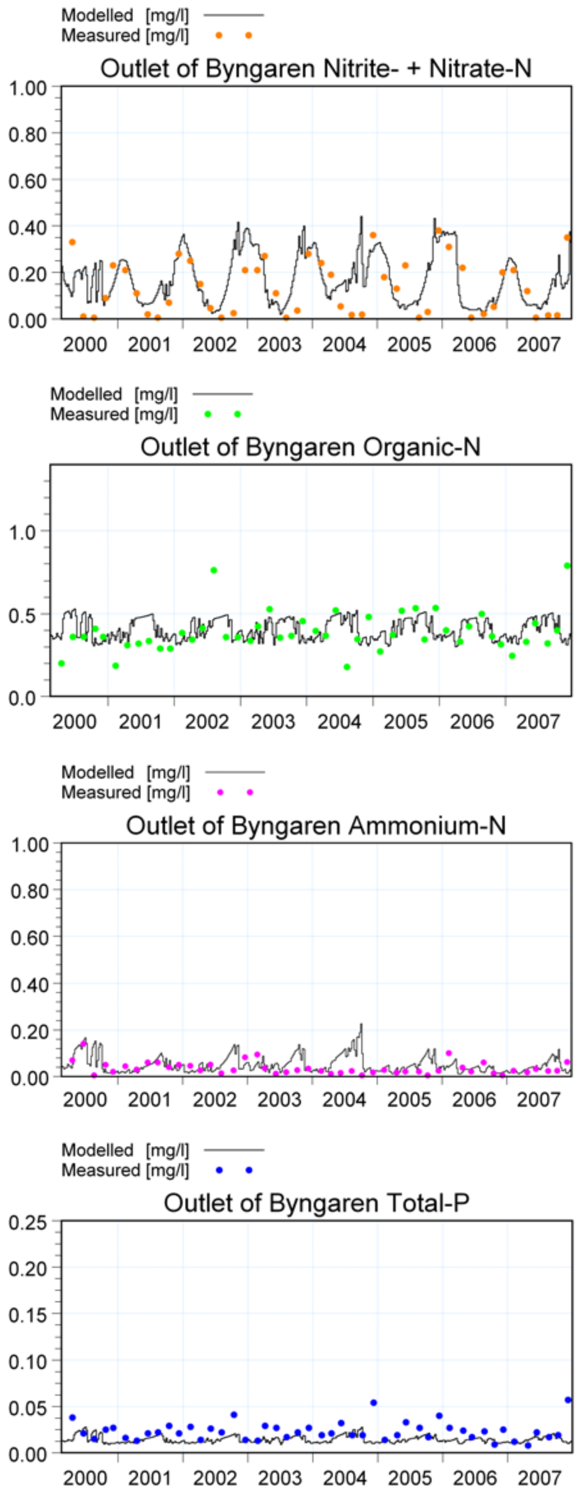


Figure 6: Flow calibration at the downstream hydrology station in the Söderköpingsåns catchment area.

Data availability was usually good for modelling hydrology, although no measurements were available for calibration in one pilot area. Data availability for modelling nitrogen and phosphorus loads was good to moderate. Soil texture data in agricultural land were critical for model results in some areas. Information on rural household wastewater loads varied depending on municipality, and is critical for calculating loads in areas with low agriculture activities and high densities of rural households. Nitrogen and phosphorus concentration measurements for water quality calibration was usually available sufficiently both over time and space. Nevertheless, in coastal areas (Öland and Skåne) there were small streams with limited or no measurements.

Water balance calibration was usually good in larger rivers, where most of the measurements where available (for example see Figure 6).

In general, best agreement between modelled concentrations and measurements was obtained for nitrate+nitrite-N. Typically, variation in organic N and total-P could not be explained with modelled results. On the contrary, variation in modelled ammonium-N concentrations was higher than measured concentrations (example Söderköpingsån, Figure 7 and Figure 8). For small coastal catchment with no discharge measurements and rivers running dry during summer (Öland and Skåne pilot areas) calibration of N and P could not be done satisfactorily (data not shown). In these rivers, model concentrations of N and P during summer were higher than expected especially in areas with many rural households. This did not affect the calculated transport of nutrients proportionally, due to the very low flows during those periods.



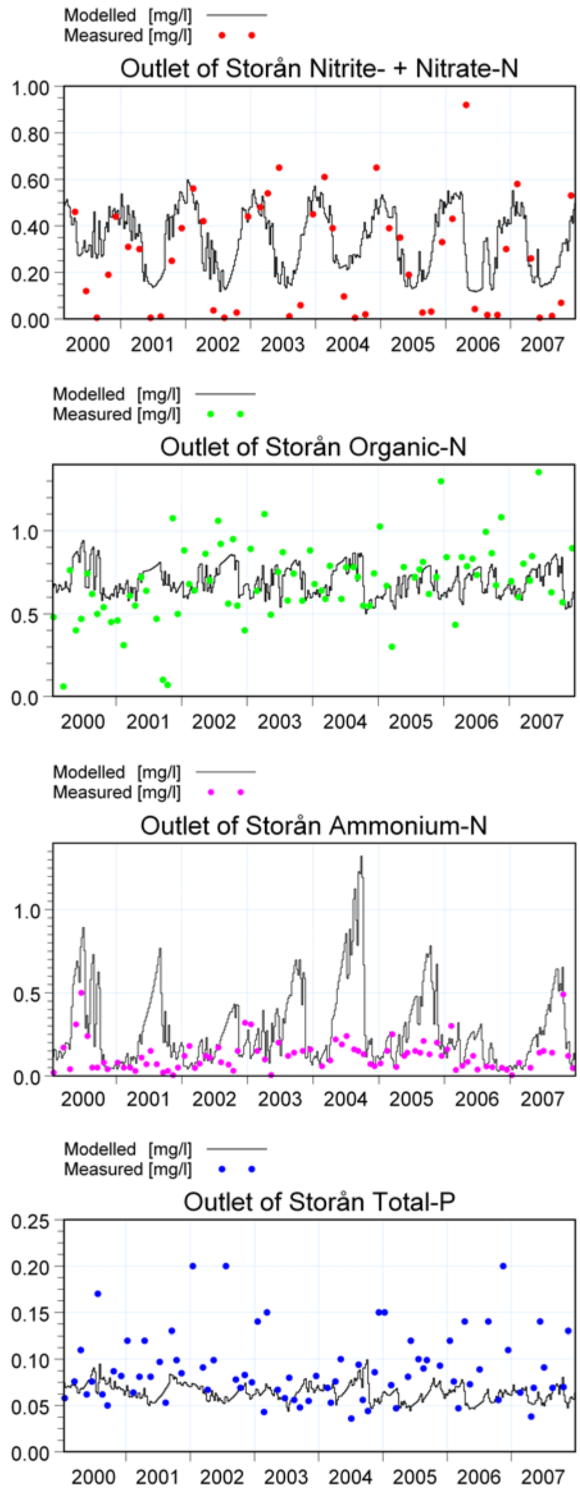


Figure 7: Calibration of NO_x^-N, organic N, ammonium-N, and total P at the upstream station in Söderköpingsåns catchment area.

Figure 8: Calibration of NO_x^-, organic N, ammonium-N, and total P at the downstream station in Söderköpingsåns catchment area.

The interpretation of the results is highly dependent on the available/used in-data for the model. In this case much of the source-data is described as yearly mean values (eg. kg/year). Hence the results from this project/study should only be interpreted as yearly transports and/or yearly changes in total- N and P transports. For this reason, calibration results were judged to be satisfactorily, despite some problems with the calibration of nutrient concentrations.

Possible improvements to the set-ups are dependent on future availability of improved input data. The need for improved input data varies between the different pilot areas but concern in general topography (elevation model, description of ditches), source distribution (soil texture data, rural households wastewater) but also improved spatial distribution of nutrient measurements for calibration and validation of modelled concentrations.

Methods for calculating the effect of a number of measures have been tested, but have not been applied fully at this stage. Currently, model runs are being done, and communicated with regional and local stakeholders. The possibility to reliably model N and P leakage from different sources, and to estimate the effect of the different measure was estimated based on our experiences so far (Table 1).

Table 1: Qualitative assessment of the availability of model input data, available data on realistic measures against eutrophication, and applicability of MIKE BASIN for calculating the effect of measures in our pilot areas.

Source		**Effect of measures**		
	Available information for modelling of source load		**Available data**	**Technical solution in MB**
Point sources				
Rural household wastewater	+/-	Improved technique	+/-	+
		Phosphate ban detergents	+	+
		Connection to WWTP	+	+
Waste water treatment plants	+	Improved technique	+	+
Diffuse sources				
Agriculture	+/-	Constructed wetlands	+/-	+*
		Buffer strips	-	+

*Custom-made solution for calculation of wetland N- and P-retention was made by DHI

Generally, measures concerning point sources were most feasible to calculate assuming that there is information on how better techniques will affect the cleaning efficiency of municipality and rural households wastewater treatment plants. The ability to calculate effects of constructed wetlands is mostly dependent on the description of the upstream area. Moreover, there seem to be a general better predictability of the retention of nitrogen as compared to phosphorus (Arheimer &Wittgren 2002, Tonderski et al. 2005). There are also improvements to be done concerning the selection of different measures and their effectiveness. The different measures which have been simulated so far in this project are relatively well-documented. Other measures such as alternative ploughing methods, manure application and measures concerning urban storm-water have been planned, but so far the available information for simulating these measures is insufficient.

The level of ambition in the Water Framework Directive is high. In the South Baltic Water District there are 1623 water bodies. The lack of measurements in many of them, and the demand of resources it will take to follow up these waters highlight the need of model results and a critical understanding of them. Apart from an increased base for cost efficient measures this project is also expected to aid the RBDA with important model experience. The involvement of different stakeholders is likely to increase the acceptance of the model results including their uncertainties.

Table 2: Expected benefits of the project.

Expected benefits	**Local stakeholders** Municipalities, water boards etc.	**Regional stakeholders** County administrative boards	**RBDA**
Urban planning	+		
Permission and inspection *Rural households, industries etc.*	+	+	
Data awareness *source data, measurements etc in the area*	+	+	++
Acceptance of model results *Loads and effects of measures*	+	+	+
Modelling competence *Critical evaluation of model results*		+	++

The results from this project are expected to be beneficial for both local and regional stakeholders such as municipalities and county administrative boards (Table 2). The outcome of scenario calculations may serve as a priority base for ongoing planning, permission and inspection by local and regional authorities. Furthermore, the awareness of the data that actually are available in the pilot areas provides water boards and authorities with tools for further planning of environmental monitoring. Moreover, discussion of in-put data, measurements and model design and results will improve the overall acceptance of the model results. Finally, increasing RBDA modelling competence is important for further development of tools to be used for future management plans and programs of measures.

Future aims and plans

The programmes of measures prepared by the river basin district authority are required to provide adequate economic analyses and cost effectiveness of the programmes is one of the main objectives. These required analyses are usually very complex – both in terms of data analysis, calculations, interpretation and communication of results. The river basin district authority is thus trying to develop an economic-hydrologic model that may act as a decision support system (DSS) in combination with other information to analyse possible combinations of measures with regards to localisation, effects, costs, benefits, etc. This type of DSS may function combined or independent with the Mike Basin models depending on the preferred functionality and complexity of the system.

A prerequisite for setting up an economic-hydrologic model is a sufficiently comprehensive library of measures that can be used as in-data in the model. Such a library of measures should include both effects and costs of measures. The effects of measures in the library may be derived from previous studies and/or results from Mike Basin modelling as outlined above. Currently there exist various libraries of water related measures kept by different government authorities and research institutions in Sweden and abroad, but joint efforts are necessary in order to achieve more reliable and agreeable estimates of possible measures and their effects and costs.

The river basin district authority's requirements for a possible future decision support system are primarily that it (a) may utilize input from a library of measures that is possibly kept externally, (b) provides a geographic interface that enables the user to e.g. analyse localisation of measures, (c) is user friendly and preferably accessible through the www, and (d) that it provides results that can be used to evaluate and compare cost efficiency of combinations of measures as well as individual measures at their location.

Acknowledgements

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