

River Water Quality Management for the Senne River Basin (Belgium)

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Abstract: The paper presents an integrated methodology and simulation models for the evaluation of pollution abatement plans for river basins, according to the environmental quality objectives/environmental quality standards philosophy (EQO/EQS). Emissions from waste water treatment plants, industry and agriculture are hereby taken into account. The pollution abatement plans for the Senne River basin (Belgium) are evaluated using the methodology. The results show that the application of the actual plans will be insufficient to reach the objectives of the EU Water Framework Directive.

Key words: integrated modelling, Senne river, pollution abatement plan, EU Water Framework Directive

1. INTRODUCTION

The Senne river basin (Belgium), with an area of ca. 1000 km² and an average flow of 9m³/s at the outlet, receives the waste water ca. 1.4 million inhabitants, including those of the capital Region of Brussels. The domestic effluents exceed the river flows during dry summer periods and – at present – a mere 20% of the domestic wastewater is treated. The hilly surrounding areas are mainly cultivated and considerably manured, while the soils are very erosive. Many parts of the river are canalised and around Brussels the river is completely covered. It is thus wondered that the river is biologically more dead than alive. The situation is far from what is imposed by the European Directives, and in July 2000, the European Court of Justice stated that Belgium had failed to implement European rules for the treatment of household and industrial water waste runoff in the Brussels region (European Court of Justice, 2000). Prior to the voting of the EU Water Framework (WFD) in December 2000, the authorities of the Walloon, Flemish and Brussels Capital regions established pollution abatement plans, with the objective to reach fish water quality in the receiving waters. Although the WFD is based on a compromise between an emission based approach of the water quality problems and the environmental quality objectives/environmental quality standards philosophy (EQO/EQS), it is clear that reaching the in-stream quality objectives is essential for the new EU policy. An evaluation of the former plans for the river Senne, in view of the new EU policy should therefore be carried out. This study elaborates an integrated methodology for the evaluation of pollution abatement plans for river basins, taking the Senne river as a case study. A holistic approach, including all types of pollution sources is hereby essential. A new simulator -ESWAT- was developed to this purpose. ESWAT allows for an integration of all the waste sources and includes an in-stream river water quality module. It also allows for long time simulations (decades), making it possible to consider a large variation of possible combinations of hydrometeorologic and emission factors that can lead to critical quality conditions. The study focuses on variables that cause acute toxicity, i.e. dissolved oxygen and ammonium/ammonia.

2. THE SIMULATORS

To perform the analysis of the water quality of the Senne river, two simulators have been used. ESWAT, for the simulation of the flows and the diffuse pollution generated by the rural areas and

for the simulation of the in-stream water quality processes and KOSIM, for the simulation of the flows and pollutant loads of the urban areas.

2.1 ESWAT

ESWAT is an extension of the free shared codes of the SWAT98 simulator (Arnold et al., 1998). Being mainly focussed on diffuse pollution problems, SWAT98 had to be adapted in view of an integrated modelling, including urban drainage impacts (van Griensven and Bauwens, 2001).

Because sub-daily processes - such as algae respiration or combined sewer overflows- can determine the river water quality, the original SWAT-simulator was modified to perform calculations on a sub-daily time step. An hourly time step is used for the simulation of water, erosion, nutrients, pesticides and river quality processes. The reduction of the time step required an adaptation of the river routing procedure but also allowed for the inclusion of a sub-hourly infiltration module.

To account for the impact of combined sewer overflows (CSO) and waste water treatment plants (WWTP) emissions, dynamic point sources were included in the river simulation module as boundary conditions. The latter are thus not explicitly modelled by ESWAT, but can be accounted for by input files, generated by other models or measurements.

An hourly river water quality module was developed, based on the equations of QUAL2E (Brown and Barnwell, 1987) but using the chemical oxygen demand (COD) instead of the biological oxygen demand (BOD). A fast and a slow COD class are distinguished, to account for different compositions of the organic matter and thus of the COD degradation rate. In the original QUAL2E, the sink and release of pollutants at the level of the river bed are dissociated. In order to close the mass balances, new state variables had to be introduced for the river bed. Also denitrification and phosphate adsorption/desorption processes have been included.

More details about these extensions of ESWAT can be found in van Griensven and Bauwens (2001).

2.2 Kosim

Continuous time series of flows and pollutant loads from the various urban drainage basins are computed with KOSIM (Harms and Kenter, 1987), using a 10-minute time step for the simulations.

KOSIM simulates the following processes: (1) dry-weather flows, (2) dry-weather pollutant loads, (3) storm flows and (4) storm pollutant loads.

Dry-weather flows are computed based on a daily water consumption per inhabitant-day and the population density of each drainage basin plus infiltration inflow. Concentrations of pollutants in the wastewater allow for the calculation of the pollutant loads.

Storm-runoff volumes are computed as the sum of the runoff from impervious and from pervious areas. The calculation of the runoff from impervious areas accounts for a time-dependent runoff coefficient, as a function of the degree of filling of the depression storage, and a surface runoff routing based on the Nash cascade concept. Pollutant loads in storm runoff are computed by assuming pollutant concentrations for the rainfall. Sedimentation and resuspension are also accounted for in a simplified way.

The resulting hydrographs and pollutographs are routed through the combined-sewer system using the hydrograph-translation method with a specified routing delay time that varies among basins. The network can contain structures such as reservoirs, pumping stations and overflow structures, but should be dendritic.

3. THE SENNE RIVER BASIN

The hydrographic basin of the Senne, with an area of 1011 km², is located in the Scheldt basin in Belgium. From its sources, it runs through the Walloon (564 km²), the Brussels (162 km²) and the Flemish Region (286 km²), to reach its outlet in the river Dijle in Mechelen, 70 km northward (Fig.1). The river has an average flow of 9 m³/s at the outlet. The velocities during base flow are in the order of 0.2 - 0.4 m/s. The predominant land uses in the basin are agricultural (48%) and urbanised (38%) land. Pasture land and forest account for 8 and 6% respectively. The predominant soil type is loam.

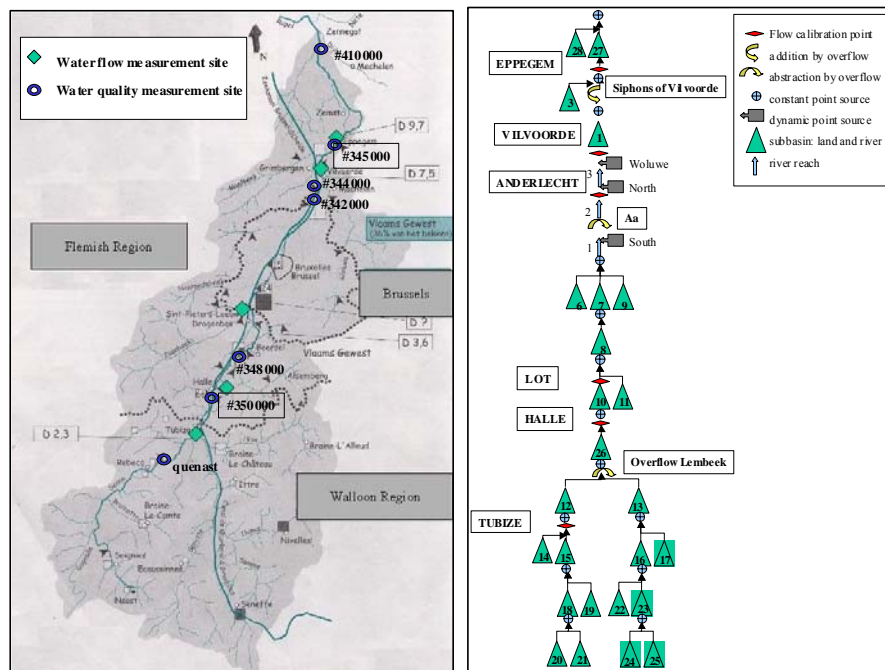


Figure 1. Map of the Senne river basin with the location of the calibration sites (left) and the structure of the Senne river model (right)

Parallel to the Senne runs the canal Brussels-Charleroi. The canal is fed by former tributaries of the Senne (Hain and Samme; 222 km²). Three overflows, with a total maximum capacity of 105 m³/s, divert water from the river to the canal during floods, to avoid flooding in Brussels. Downstream Brussels, at Vilvoorde, part of this flow is redirected to the river. The latter overflows also have a major impact on the water quality issues, as large amounts of sediments and pollutants settle in the canal during these events, while relatively clean water is then recharged to Senne downstream.

4. THE MODEL

The ESWAT model of the Senne (Fig.1) consists of 28 subbasins, as delineated with the ArcView interface of the SWAT. This number was reduced to 25, after subtraction of the subbasins that drain directly into the canal. The subbasins were further subdivided in Hydrologic Response Units, being specific combinations of soil type and land use. In total, 124 HRU's have been used.

ESWAT was also adapted, to allow for flow divisions at the overflows to the canal. This was achieved by defining a critical flow at which the structure starts to function and by a (constant) partitioning of the excess flow between the river and the overflow.

Within the ESWAT model of the Senne, the urban area covered by the subbasins in the Brussels Region and small parts of the Flemish Region, have been replaced by KOSIM models. The latter thus provided dynamic point sources for the ESWAT model. For information about the Senne model, it is referred to Bauwens and van Griensven (2002) and for the KOSIM models to Demuyne et al. (1993), Fronteau et al. (1996) and to Bauwens et al. (1997).

5. THE CALIBRATION

The integral model has been calibrated against water quantity and water quality using daily observation at several locations along the river for the period 1996-1997 (Fig. 2). The calibration included 63 parameters to optimise the curve fitting for the water quality outputs of ammonia, DO, Kjeldahl N and total COD at the sites #350000, #348000, #345000, #344000, #341000, at Quenast and with the water flow output at Halle and Vilvoorde. For all these outputs, an objective function was determined based on the mean square error. These objective functions were transformed by a normalisation in a probabilistic scale before being summed to a Global Optimisation Criterion. This procedure allows an equal participation of the objective functions in the calibration procedure. More information on this procedure, can be found in van Griensven et al. (2002) and van Griensven and Bauwens (2002).

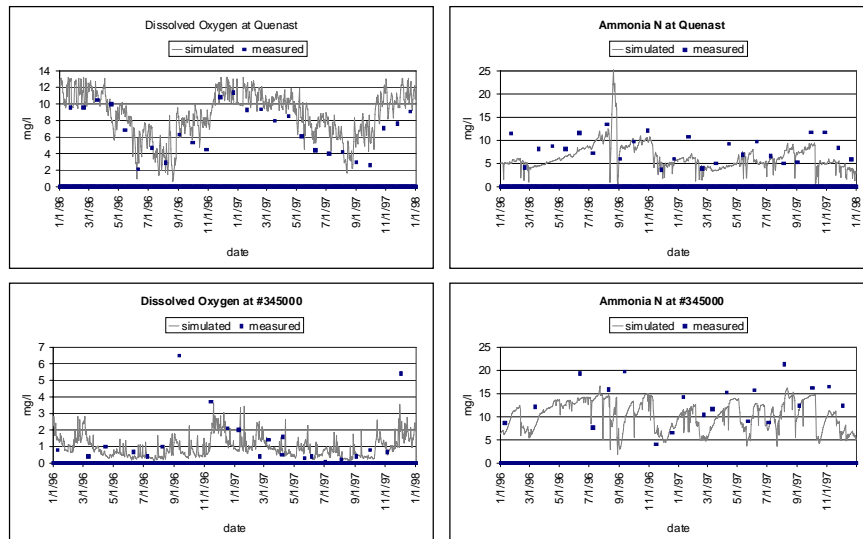


Figure 2. The comparison of the measured and calculated oxygen and ammonia concentrations at Quenast and #350000

6. THE SCENARIOS

Three scenarios run for the Senne model using the model set-up and weather data from the period 1996-1999. The constant point sources and the KOSIM outputs were adapted against the waste water treatment efficiencies (Fig. 3). The constant point sources use constant efficiencies while for the KOSIM results, different efficiencies are applied to the dry weather flow, and the water exceeding 2.5 or 5 times the dry weather flow. These efficiencies are in accordance to the technology of the WWTP, where the WWTP before 2002 are less efficient and often lack tertiary treatment.

The water quality of the Senne river is simulated for a baseline scenario (Sc0), being the situation for which the model was calibrated, for the actual situation (Sc1) and for the future situation (Sc2).

The baseline scenario corresponds to the year 1996 when no relevant treatment of domestic wastewater took place (only around 1% treated): all 1.4 million inhabitants discharge directly to the Senne river. The scenario Sc1 includes all operational activities for wastewater treatment of the 3 Regions in the year 2001. The scenario accounts for the activation of the WWTP Brussels South at around 70 % of its capacity or the treatment of quarter of a million inhabitants. Sc2 represents all the planned activities for wastewater treatment by the 3 Regions, corresponding to the treatment of ca. all the 1.4 millions of inhabitants. The latter plans should be operational by the year 2005.

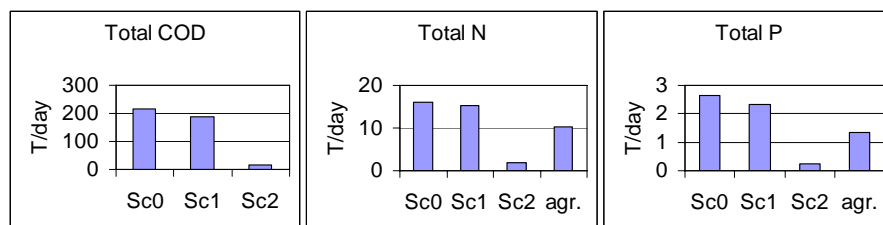


Figure 3. Emission loads for the point sources for Sc0, Sc1 and Sc2 compared to the diffusive loads by agriculture (agr.)

To account for the impact of the WWTP treatment efficiencies in accordance with the technology of the WWTP were used (Table 1). The resulting pollution loads for the different scenarios are shown on Fig. 2. For all scenarios, the model set-up for 1996 (Fig. 1) and the weather data for the period 1996-1999 were used.

Table 1. Treatment efficiencies for the North treatment station

	COD	N	P
North station; flow < 2.5 DWF	83-95 %	80-90 %	83-95 %
North station; flow between 2.5 and 5 DWF	40 %	50 %	40 %
South station; flow < 2.5 DWF	80-90 %	57-65 %	75 - 85%
South station; flow between 2.5 and 5 DWF	40 %	50 %	40 %

7. RESULTS

Simulation results for the different scenarios, upstream (location 348000) and downstream (location 345000) of Brussels, are shown on Fig.4.

While a future improvement of the oxygen concentrations is observed upstream of Brussels, the situation remains critical especially during the summer periods. The poor improvements are partly due to the fact that in the upstream part of the basin, the erosion and the diffuse pollution from the agricultural areas remain high, resulting in high ammonia concentrations and oxygen depletion by the nitrification processes.

Downstream of Brussels, there is a clear improvement in water quality with a significant drop in the pollutant concentrations and an increase of the oxygen concentrations. However, even though the COD pollution is reduced by more than 90%, the efforts to treat domestic wastewater are not translated into a "good" water quality status. During long periods there is a strong violation of the standard for dissolved oxygen. The latter is mainly observed during high flow periods, thus when untreated wastewater is discharged directly to the river as combined sewer overflow.

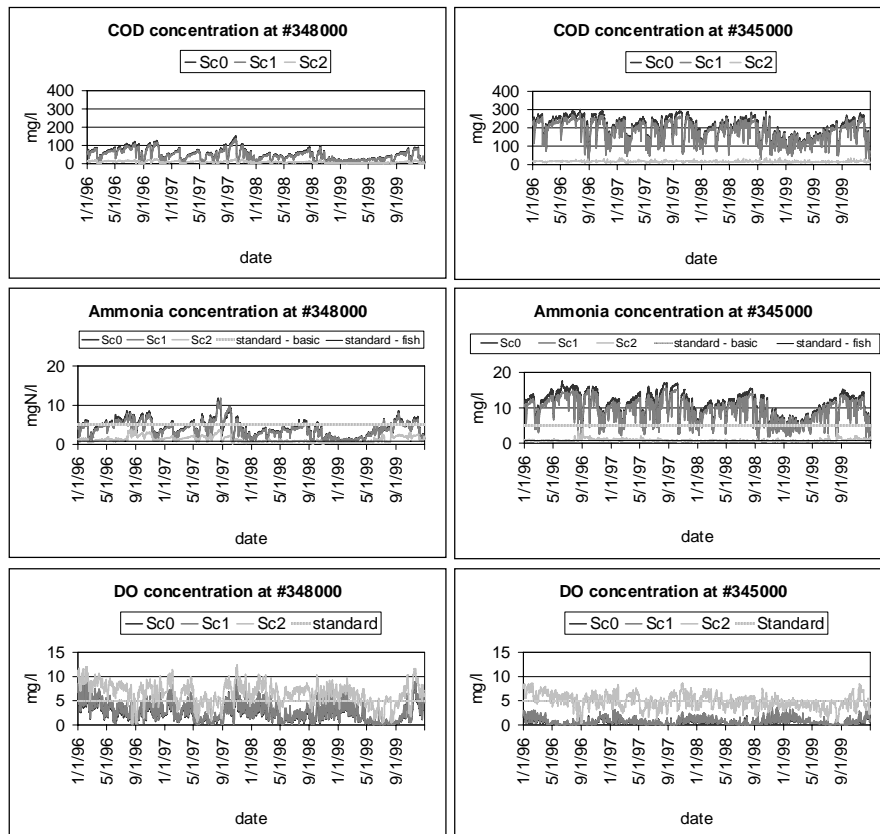


Figure 4. Results for the water quality simulations for the Senne river

8. CONCLUSIONS

The simulations illustrate that the goals of the EU Water Framework Directive will be difficult to achieve in areas with high environmental pressures, due to the high inhabitant density and/or intensive agriculture. The latter is definitively the case for the Senne river, for which the wastewater flow may exceed the river flow during dry periods. Under such circumstances, the mere application of the former EU directives on urban wastewater treatment and on diffuse pollution are shown to be insufficient to reach a good ecological status or even a good ecological potential. Additional measures will thus be necessary. These include measures to reduce the input of agricultural pollution – as it is observed that the future nitrogen and phosphate emissions from agriculture will exceed those of the domestic wastewater - and measures to reduce the impact of the combined sewer overflows.

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