Development of a planning instrument for CSO management – Cooperation of research, water utility and public water authority in the city of Berlin

Développement d'un outil de gestion intégrée des rejets issus de réseaux unitaires - Coopération entre recherche, compagnie des eaux et pouvoirs publics à Berlin

Kai Schroeder*, Pascale Rouault*, Andreas Matzinger*, Hauke Sonnenberg*, Bernd Heinzmann**, Erika Pawlowsky-Reusing**, Dörthe von Seggern***

* Kompetenzzentrum Wasser Berlin, Cicerostr. 24, 10709 Berlin, Germany (kai.schroeder@kompetenz-wasser.de)

** Berliner Wasserbetriebe, 10864 Berlin, Germany

*** Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin, Brückenstr. 6, 10179 Berlin, Germany

RÉSUMÉ

Un outil de gestion des rejets provenant du réseau d'assainissement unitaire est actuellement en cours de développement à Berlin, Allemagne. Le projet a pour but, d'une part, de mieux comprendre l'impact des rejets par temps de pluie sur l'état chimique et écologique des rivières de plaines à faibles débits ; d'autre part, d'évaluer l'efficience des mesures de contrôle de ces rejets prises en conséquence. Une fois achevé, cet instrument basé sur des modèles numériques permettra à la Compagnie des Eaux de Berlin et à l'Autorité responsable des rivières d'analyser différentes stratégies de maitrise des rejets. Ainsi, afin de répondre à leurs besoins respectifs et d'assurer un transfert efficace des résultats, une structure spécifique au projet a été mise en place. A travers leur implication directe dans la conduite de projet, ainsi que dans la réalisation et la présentation du travail technique et scientifique, les utilisateurs finaux peuvent orienter le développement du projet et fournir les données techniques propres à la situation locale. Les premiers résultats attestent l'importance des impacts des rejets du réseau d'assainissement, dans le cas du système fluvial de Berlin, ainsi que la nécessité de mesurer des données supplémentaires pour permettre l'ajustement, le calibrage et la validation des modèles.

ABSTRACT

To gain better understanding of the impact of combined sewer overflows (CSO) on the chemical and ecological status of lowland rivers and to evaluate the effect of CSO control measures a planning instrument for impact-based CSO management is being developed in Berlin, Germany. After completion the model-based planning instrument will be used by the Berlin water and wastewater utility and the water authority for scenario analysis of CSO management strategies. To adapt the planning instrument to their respective needs and to guarantee an efficient transfer of the results a specific project structure was established. Through direct participation in project management, technical and scientific work as well as demonstration the end-users can influence the development and provide technical input on local issues. First project results show the relevance of CSO impacts compared to the background condition of the Berlin river system and the need for additional measurements to provide data for model adaptation, calibration and validation.

KEYWORDS

CSO, impact assessment, modelling, surface water quality, water framework directive

1 INTRODUCTION

Today, we face an increasingly acute and complex situation in water resource management. Urban areas, where over half of the world's population is living, are under particular pressure. Increasingly, in urban water resource management the consideration of stormwater impacts on water resources gains in importance (UBA 2006, USEPA 2000). Among stormwater discharges the impact of combined sewer overflows (CSO) plays an important role. Major impacts are long term accumulation of nutrients, suspended solids or toxic substances and short term aesthetic, toxic and hygienic implications (House et al. 1993). The dynamic character of the discharge events lead to particular stress on the water bodies. The situation is worsening with increasing urbanisation and accordant land use and land sealing. According to UNESCO (2006) one of the major problems of the industrialised countries is an insufficient capacity to cope with increased volumes of rainwater, causing frequent spills of combined sewer overflows and jeopardizing the quality of receiving water bodies. Consequently, CSO control will be an important component in reaching the good chemical and ecological status of the surface water bodies as demanded by the EU water framework directive (WFD, EU 2000).

In Berlin, Germany groundwater abstraction, drinking water supply and disposal of treated wastewater is carried out within the same metropolitan area. Due to low runoff rates the receiving rivers Spree and Havel are very sensitive with a significant risk of eutrophication. The situation is exacerbated as these rivers are dammed for shipping. Therefore, strict requirements are stipulated by the public water authority (Berlin Senate Department of Health, Environment and Consumer Protection) for the emissions from the urban wastewater system into these sensitive water bodies (Sen Stadtentwicklung 2001). A combination of measures is necessary to reduce pollution load from the wastewater system and in particular nutrient loads. The measures include both, upgrading wastewater treatment and rehabilitation of sewer networks. One focus of measures is on stormwater management and treatment within the separate and the combined sewer system.

The review of the environmental impact of human activity on the Berlin water courses according to WFD (Article 5) showed the specific adverse effect of CSO (Sen Stadtentwicklung 2004). Most relevant are acute effects on aquatic organisms from (i) increased levels of unionised ammonium (NH_3) through ammonium input and (ii) low levels of dissolved oxygen (DO) through the input of degradable organic components, which lead to DO consumption.

A pollution control plan will be carried out until the year 2020 leading to an enlargement of the storage volume of the combined sewer system by 100 %. To gain better understanding of the impact of CSO on the chemical and ecological status of the receiving water and to evaluate the effect of planned CSO control measures, a standardised methodology and a planning instrument for impact-based CSO management is being developed. The development is carried out within the project MIA-CSO (Monitoring, Modelling and Impact Assessment of Combined Sewer Overflows) in cooperation between Kompetenzzentrum Wasser Berlin (research centre), Berliner Wasserbetriebe (water and wastewater utility), Berlin Senate Department of Health, Environment and Consumer Protection (surface- and groundwater management and public water authority) and the engineering company Dr. Schumacher Wasser und Umwelt.

The objective of this paper is to introduce the structure of the planning instrument and the cooperation between the stakeholders involved in the development process. Finally, results from the first project phase are given and open questions are discussed.

2 DEVELOPMENT OF THE PLANNING INSTRUMENT

2.1 The impact-based approach

Usually, planning and design of pollution control measures for combined sewer systems are based on emission thresholds like annual loads of specific pollutants, annual overflow volumes or overflow frequencies. In contrast to the classical approach of sewer emission thresholds, impact-based approaches focus on possible effects of CSO on the receiving surface water and its aquatic organisms. Impact-based guidelines aim at deriving locally adapted measures to minimise CSO impacts to surface waters. Thanks to this local approach, potential protection measures can be planned dependent on the state of a specific river, reservoir or lake.

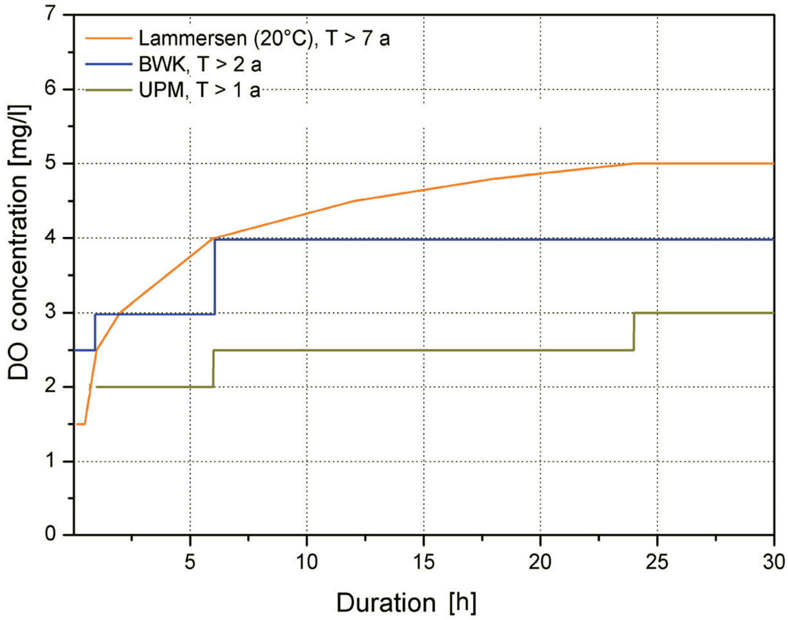

Figure 1: Critical DO concentrations subject to event duration for rare events (recurrence interval T > 1 a for UPM, T > 2 a for BWK and T > 7 a for Lammersen). For the UPM values (FWR 1998) NH_3-concentration < 0.02 mg NH_3-N L^{-1} is assumed, for the Lammersen values (Lammersen 1997) a temperature of T = 20 °C is assumed, in BWK M7 (BWK 2007) no further influencing variables are considered.

A review of international impact-based guidelines for stormwater management (Matzinger et al., 2008) has shown that the following three approaches are most relevant for the Berlin situation:

- the UPM guideline from the UK (FWR 1998),
- the BWK-M7 guideline from Germany (BWK 2007) and
- the approach according to Lammersen (1997), which summarizes various results from ecotoxicological tests.

The three approaches provide detailed evaluation schemes for critical DO and NH_3 conditions, using duration-frequency-relationships. These relationships assume that pollution events of a specific duration may maximally occur at defined recurrence intervals. Apart from the dependency of critical concentrations on event duration and recurrence frequency, the influence of temperature, pH and concurrent NH_3-concentrations or DO-minima are considered by UPM and the Lammersen-approach. The relationships used by the three approaches for NH_3 and DO are similar (for DO see Figure 1). Nevertheless, their comparability is limited, as the approaches generalise various local situations.

For the evaluation of critical DO concentrations in the urban river Spree a combination of the Lammersen-approach with an analysis of meteorological and hydrological boundary conditions was applied. The considered boundary variables were rain event heights before critical DO depressions, water temperature (T) and conductivity as tracers for CSO impact in the river and T and DO before critical DO depressions to assess effect of background contamination. Thus, oxygen depletion related to CSO discharges could be distinguished from oxygen depletion related to background stress originating from organic matter and algae biomass from nutrient-rich upstream lakes (see Riechel et al., 2010).

2.2 Structure of the planning instrument

The planning instrument for CSO management that is currently developed within the project MIA-CSO will be based on the aforementioned approach for the identification of critical DO and NH_3 conditions in urban lowland rivers. The planning instrument will link two numerical models that have already been applied in several former studies in Berlin and a module for statistical analysis of the simulation results.

Simulation of flow and pollutant transport in sewers is done by the dynamic flow routing model InfoWorks CS of Wallingford Software Limited. The quality simulation is based on the accumulation and washoff of pollutants on the ground surface and advective pollutant transport within the conduits. The network has been built up in a skeletonised form, nevertheless accounting for the total available storage capacity. Storm water tanks and combined sewer overflows as well as actuators for real-time control have been considered in detail (Schroeder and Pawlowsky-Reusing 2006; Rouault et al. 2008). The resulting hydrographs of flow and pollution parameters (NH_4-N, TKN, TSS, COD and BOD_5) and constant values for temperature, conductivity, pH-value, ortho-phosphate, acid capacity and calcium are used as input to the simulation of the processes within the water body.

For the modeling of flow and quality processes in the receiving water the software package HYDRAX/QSIM (Schumacher, 2009) is used. HYDRAX is a one-dimensional flow model solving the Saint-Venant equations. The water quality model QSIM was developed by the German Federal Institute of Hydrology (Kirchesch and Schöl, 1999). It describes the biogeochemical processes in rivers. The model calculates the most important processes of the oxygen and nutrient budget, like the development of phyto- and zooplankton and processes at the river bottom. The model is suited to simulate processes in simple channels as well as in complex river networks and can cope with variable flow directions (e.g., in estuaries). To enable simulation of the highly dynamic processes resulting from CSO the calculation is carried out in 15-minutes time steps.

Input data to the models like meteorological data (rainfall, air temperature, global radiation, humidity, wind velocity, cloud cover) and hydrological data (flow and substance concentrations at the boundaries of the river body) is provided in a database.

The two models and a module for statistical analysis of the simulation results will be linked in series. A parallel coupling of the models will not be necessary for application in Berlin since no feedback between the models has to be taken into account (e.g. backwater or flooding, integrated real-time control). Furthermore, there is a segmented responsibility for the later use of the models. Sewer modelling will be carried out by the water and wastewater utility Berliner Wasserbetriebe. River water quality modeling will be in the responsibility of the Berlin Senate Department of Health, Environment and Consumer Protection, which is the Berlin water authority responsible for surface waters.

The planning instrument will be used for impact/recipient based scenario analysis of CSO management strategies and will support management and investment decisions in planning the Berlin combined sewer system. A schematic view of the structure of the planning instrument is given in Figure 2.

Within the project MIA-CSO a demonstration of the planning instrument will be carried out for an 11.6 km section of the River Spree (Berlin-Charlottenburg). The section is limited by locks and weirs, which gives clear boundary conditions regarding the hydraulic situation. The connected urban drainage area covers 85 % of the Berlin combined sewer system and consists of 55 km² of paved area. CSO enter the river section and its side channels via 65 outlets.

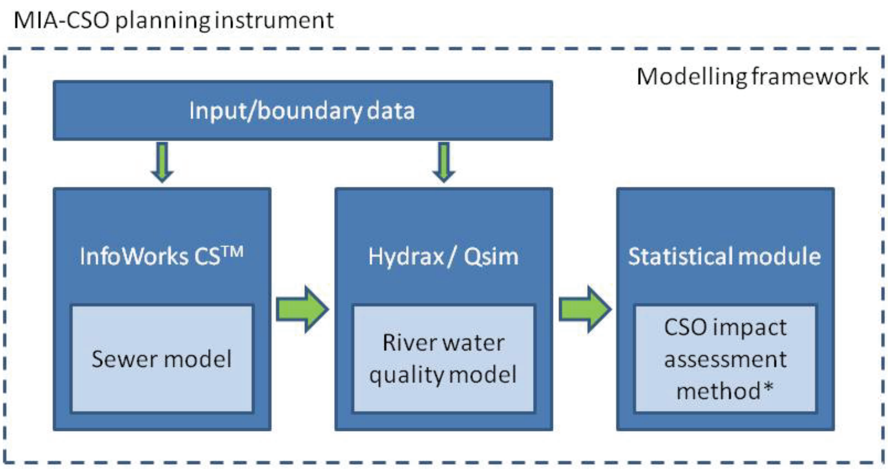

Figure 2: Structure of the planning instrument for impact-based CSO management. The CSO impact assessment method is based on duration-frequency-relationships for DO and NH_3 as described in chapter 2.1

2.3 Stakeholder involvement

After final development the planning instrument will be used for scenario analysis of integrated CSO management strategies in Berlin. Possible CSO control measures to be evaluated are in the field of

- Urban planning: green roofs, unsealing of impervious areas, local infiltration of rainwater
- Wastewater infrastructure (within combined sewer system): in-pipe storage, storage in stormwater tanks, constructed wetlands
- Wastewater operation: increase of flow/pumpage to WWTP, real-time control
- River management: umbrage through vegetation/trees, oxygen enrichment through injection.

Project partner	Research centre	Water & wastewater utility	Public water authority
Project management	Overall project management Communication Dissemination	Coordination with water and wastewater utility departments	-
Technical & scientific work	Review and analysis of available data on CSO impacts on River Spree Planning of integrated monitoring (CSO + river) Setup and operation of sewer monitoring CSO and river data management and analysis Description of river water quality processes Definition of CSO impact assessment method (cf. chapter 2.1) Adaptation, calibration and validation of river water quality model QSIM Development of module for statistical evaluation of simulation results Linking of sewer model, river model and module for statistical evaluation	Monitoring of CSO discharges CSO data analysis and interpretation Calibration and validation of sewer model Sewer simulations Definition of CSO impact assessment method (cf. chapter 2.1)	River monitoring (hydraulics and water quality) River data analysis and interpretation Definition of CSO impact assessment method (cf. chapter 2.1)
Demonstration	Simulation of scenarios for CSO management Interpretation of results from scenario analysis	Definition of scenarios for CSO management Evaluation of results from scenario analysis	Definition of scenarios for CSO management Evaluation of results from scenario analysis
Supervision	Control project progress and outcomes	Control project progress and outcomes Ensure usability of planning instrument	Control project progress and outcomes Ensure usability of planning instrument
Application	-	Application of sewer model Coordinated evaluation of measures	Application of river water quality model Coordinated evaluation of measures

Table 1: Project structure and responsibilities and tasks of the project partners

Those measures are usually planned and realised by the water and wastewater utility and/or the public water authority. To adapt the planning instrument to their respective needs and to guarantee an efficient transfer of the results to the end-users a specific project structure was established. Through direct participation in project management, technical and scientific work as well as demonstration, representatives of the end-users can actively influence the development but also provide technical input on local issues, technical information and data.

Furthermore, a supervisory committee with members from all project partners and the funding organisations has been established to control progress and outcomes of the project. An overview of project responsibilities and tasks is given in Table 1.

3 FIRST PROJECT RESULTS

3.1 System analysis

A review and analysis of available data from the combined sewer system and the River Spree reflecting CSO impacts was carried out. The focus was on (i) the identification of critical situations in the receiving water due to DO depletion and (ii) the relevance of CSO as pathway for organic trace pollutants into the Berlin river system.

Following the approach described by Riechel et al. (2010) it was found that the oxygen regime of the urban Spree is influenced by notable background stress, which can lead to fish-critical conditions in some parts of the urban Spree even if no CSO had preceded. However, very low concentrations of DO (< 2 mg O_2 L^{-1}) are only measured directly after CSO (cf. Figure 3) and occur at least every second year at the Spree estuary with the River Havel in Berlin (Sophienwerder). Summer rain events with more than 20 mm of precipitation do have adverse effects on DO levels in most cases. However, no significant correlation could be found between the duration or intensity of DO depletions and the precipitation height of the related rain event. Instead, the variable composition of CSO (e.g. due to varying surface washoff load) seem to be of prevalent matter.

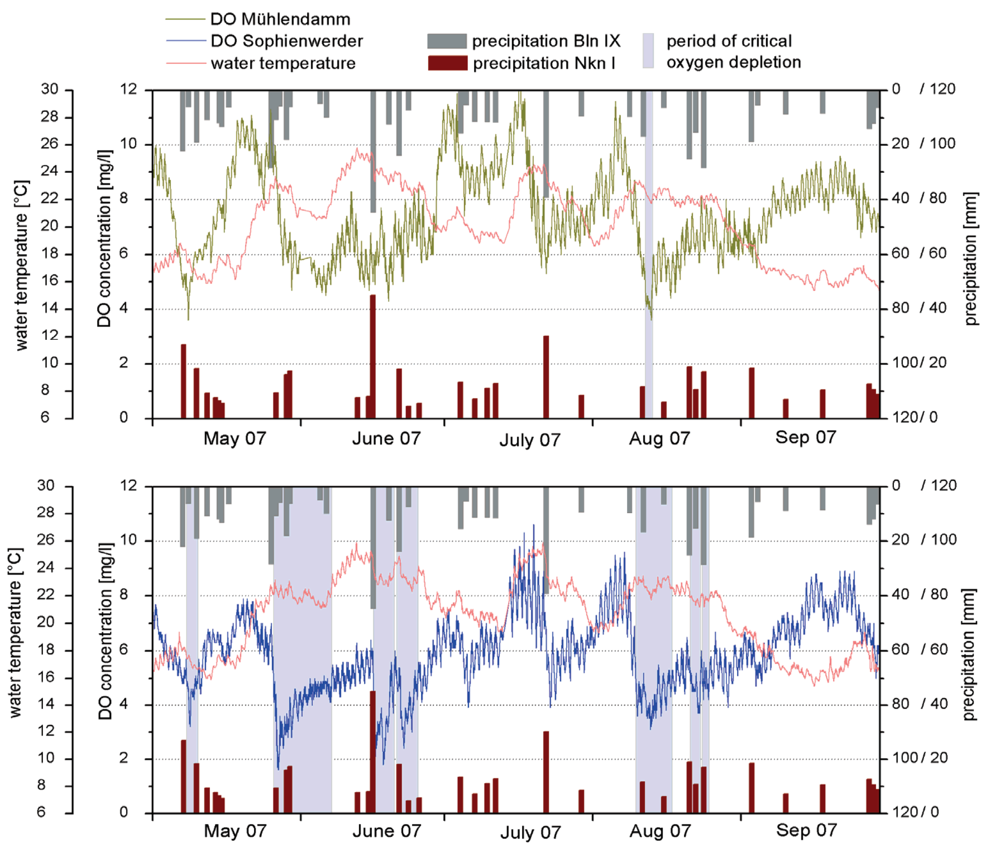

Figure 3: DO concentration and temperature in River Spree as well as precipitation height for the period May to September 2007. Periods of critical oxygen depletions are highlighted for gauge upstream of CSO inflows (on the top) and gauge downstream of CSO inflows (on the bottom)

The importance of CSO as pathway of organic trace substances into the Berlin surface waters versus wastewater treatment plant (WWTP) effluents was assessed by calculating mass balances based on emission data and rates of substance degradation in WWTP. The assessment indicated that annual loads are dominated by CSO for substances with removal in WWTP above ~90 %. Furthermore, it was found that substances with high removal rates in WWTP may also show concentration peaks in the river during CSO events. This could be verified based on eight years of rain data and monitoring data from the River Spree, collected between 2000 and 2007. Substances that are well removed in WWTP such as NTA (nitrilo triacetic acid) were found to occur in significantly increased concentration after CSO, while the concentration of substances that are poorly removable in WWTP such as EDTA (ethylenediamine tetraacetic acid) decreased in CSO influenced samples due to dilution effects (Matzinger et al., 2009).

3.2 Modelling

First simulations with the integrated model showed that the processes governing the oxygen cycle that are implemented in QSIM (decay of organic matter in the water column, photosynthesis, reaeration, decay of organic matter at the sediment and nitrification) have to be adapted to the specific situation of the lowland River Spree. Due to a lack of data the simulation results for ammonium could not be validated yet.

4 DISCUSSION

Open questions that have to be answered next are related to the current data situation and the adaptation of the river water quality model to the specific application.

Currently, continuous measurements in River Spree are only available for the standard parameters T, pH, conductivity and DO. Additional measurements of DOC and ammonium are planned to provide data for process description as well as model adaptation, calibration and validation. The full parameter set will be measured at the upper system boundaries (incl. one major CSO) and at a reference point at the end of the studied river section. Furthermore, measurements of T, pH, conductivity and DO will be carried out at another two reference points within the river system. The implementation of the monitoring program is detailed in Rouault et al. (2010).

If DO deficits and high NH_3 concentrations occur simultaneously an intensification of the respective effects can be expected. Therefore, Lammersen (1997) proposes correction factors to account for the influence of oxygen saturation on ammonia toxicity. Based on Milne et al. (1992) the UPM guideline proposes to increase DO thresholds by 1-2 mg L^{-1} depending on NH_3 concentrations. However, this interdependency makes the evaluation of measurement or simulation results rather complex. It has to be discussed how to account for these synergetic effects in the statistical analysis of the results.

As stated before, the river water quality model QSIM has to be adapted to the specific situation of the River Spree that is influenced by organic matter and algae biomass from upstream lakes. Under this background condition a sufficient accurate simulation of the target parameters DO and NH_3 has to be guaranteed to enable interpretation of CSO impacts. However, to avoid unnecessary computation time, to reduce data requirements and to simplify interpretation of simulation results model complexity will be reduced as far as possible and adapted to the specific application. Concerning the oxygen cycle the focus will be on sufficient description of decay of organic matter in the water column, photosynthesis, reaeration, decay of organic matter at the sediment and nitrification.

5 CONCLUSION

To gain better understanding of the impact of CSO on the chemical and ecological status of lowland rivers and to evaluate the effect of CSO control measures a standardised methodology and a planning instrument for impact-based CSO management is being developed in Berlin, Germany. The development is carried out in cooperation between partners from research, water and wastewater utility and public water authority.

The impact-based approach focuses on possible effects of CSO on the receiving surface water and its aquatic organisms. It aims at deriving locally adapted measures to minimise CSO impacts. The identification of critical impacts on the river is based on duration-frequency-dependent threshold concentrations for the target parameters NH_3 and DO as proposed by Lammersen (1997).

The planning instrument will be based on the aforementioned approach. It will link (a) the dynamic flow routing model InfoWorks CS used for simulation of flow and pollutant transport in sewers with (b) the software package HYDRAX/QSIM for simulation of flow and quality processes in the receiving river and (c) a module for statistical analysis of the simulation results.

In Berlin, the planning instrument will be used for impact/recipient based scenario analysis of CSO management strategies. Sewer modelling will be carried out by the water and wastewater utility. River water quality modeling will be in the responsibility of the water authority responsible for surface waters. To adapt the planning instrument to their respective needs and to guarantee an efficient transfer of the results to the end-users a specific project structure was established. Through direct participation in project management, technical and scientific work as well as demonstration, representatives of the end-users can actively influence the development but also provide technical input on local issues, technical information and data.

First project results show that the oxygen regime of the urban Spree is influenced by notable background stress originating from organic matter and algae biomass from nutrient-rich upstream lakes. By combining the Lammersen-approach with an analysis of meteorological and hydrological boundary conditions, oxygen depletion related to CSO discharges could be distinguished from oxygen depletion related to background stress. First simulations with the integrated model showed that the processes governing the oxygen cycle that are implemented in QSIM have to be adapted to the specific situation of the River Spree. Due to a lack of data the simulation results for ammonium could not be validated yet. Comprehensive measurements in the River Spree and in parallel at one major CSO are planned for the next project phase to gain data for process description and model adaptation, calibration and validation.

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