Strategic planning of blue-green infrastructure to reduce surface water pollution from combined sewer overflows

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Highlights

- The model chain allows an impact-based evaluation of stormwater management strategies.
- Surface water quality can be improved most significantly by disconnecting impervious areas.
- Roofs and courtyards offer the highest potential regarding impact and feasibility.

Introduction

Overflows of Berlin's combined sewer system after heavy rainfall events often result in low oxygen concentrations in the affected water bodies, leading to fish mortality (Riechel et al., 2016). To enhance the quality of Berlin's surface waters, a comprehensive modernisation programme of the combined sewer system is currently in progress. Based on numerical simulations, it is predicted that the goal of limiting the annual combined sewer overflow volume to 25 % of the annual stormwater runoff will be achieved by 2024. However, the objective of the Water Framework Directive (EU 2000) - a good ecological potential - is far from being achieved for the surface waters affected by combined sewer overflows. Therefore, additional measures will be necessary (Riechel et al., 2020). For this purpose, the MiSa project is evaluating the effects of impervious area disconnection, sewer network adaptation and river management measures on the number and volume of combined sewer overflows and their effects on oxygen conditions. The results are used to develop city-wide management strategies with local decision-makers to improve surface water quality.

Methodology

The MiSa project consists of four steps: deficit analysis, model setup and validation, establishing realistic management strategies with authorities and modelling of these management strategies.

Deficit analysis

To evaluate the dissolved oxygen (DO) conditions for fish, a combination of three indicators was defined: the time below critical DO concentration, the number of critical DO events, and the negative deviation from a reference state (e.g. DO concentration of a water body without CSO influence). Critical DO conditions for fish were defined as a concentration below 1.5 mg/L.

Model setup and validation

In the second step, the model-based assessment was established. This assessment is based on the results of a model chain that consists of a sewer network model of the Berliner Wasserbetriebe (Software: InfoWorks ICM) and a surface water quality model of the Berlin Senate (Software: GERRIS/HYDRAX/QSim) (Matzinger et al., 2013). The model chain has been updated and extended to include Berlin’s entire combined sewer system with 64.5 km^2 of impervious surface, 17 main pumping stations and 176 combined sewer outfalls. The overflow characteristics serve as input to the water quality model. Both models were calibrated individually and in combination for the year 2017. Calibration data included high-resolution monitoring data for the affected river sections in Berlin, data from nine rain gauges and flow data from the 17 main pumping stations.

Establishing realistic management strategies

In cooperation with the Senate Department for Urban Mobility, Transport, Climate Protection and the Environment (SenMVKU), the Berliner Wasserbetriebe (BWB), the Berliner Regenwasseragentur and two Berlin district authorities, management strategies for the reduction and disconnection of impervious surfaces in combined sewer systems, measures for the sewer network and stormwater management strategies were discussed and developed in workshops. These strategies must be feasible and aligned with other district objectives such as climate change adaptation, flood protection and biodiversity conservation. For three timeframes (10, 30 and > 30 years), the type of stormwater management measure (e.g. unsealing of parking areas, green roofs, etc.), the location (street or property) and the extent (e.g. all streets with high heat exposure, all flat roofs of public properties, etc.) were defined.

Modelling of management scenarios

To ensure realistic conclusions about the effectiveness of the measures, the scenarios were evaluated based on rainfall events that caused critical DO events. Fourteen rainfall events from 2011 to 2019 were selected and used to simulate the scenarios developed with the model chain. All scenarios were then evaluated using the three MiSa indicators and compared with the so-called base scenario, which represents the combined sewer system catchment areas, the combined sewer network and river management in their current state.

Results and discussion

Deficit analysis

Pollution is most significant in the central areas of the city. While the mean of critical events between 2000 and 2019 is only 0.06 per year in the river sections at the beginning of the city centre and the combined sewer system, it increases to 2.63 in the central main channel of the River Spree and up to 7.67 in some side canals in the city centre.

Model chain validation

The model chain was validated for the period of high precipitation from May to September 2017. The DO concentrations were successfully simulated throughout the time period, during dry weather and after combined sewer overflows (see Figure 1, right side). The left graph in Figure 1 shows a comparison between the number of critical DO concentration events based on measured values and simulated results. The analysis was carried out separately for three oxygen thresholds: 1.5 mg/L, 2.5 mg/L and 3.5 mg/L.

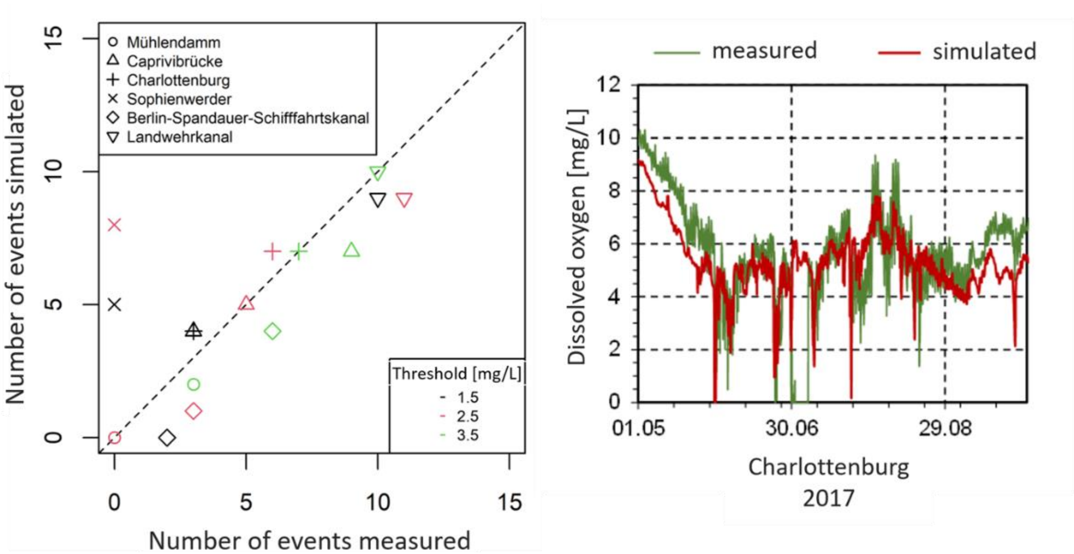

Figure 1. Left side: Comparison of the number of measured and simulated critical DO events at 6 monitoring sites; Right side: Comparison of measured and simulated DO concentration at the monitoring site Charlottenburg in summer 2017.

It illustrates the quality of the model chain achieved between May and September 2017 at six monitoring sites along the affected river sections. For five of the analysed monitoring sites, the number of simulated events corresponds well with the observations. Only for the monitoring site at the end of the combined sewer system (“Sophienwerder”) too many deficit events are simulated, most likely due to the discharge of cooling water from a power plant upstream of the site, which was not part of the surface water quality model at the time. The results indicate that the updated model chain simulates the DO concentration and the duration of the critical DO events satisfactorily, with the exception of the monitoring site “Sophienwerder”.

Management scenarios

As a result of the workshops, eight management scenarios were developed. Each scenario is a combination of impervious area decoupling and sewer network adaptation. One scenario combines measures for sewer network adaptation and surface water management through adapted weir control. The identified potential reductions of connected impervious area for the two districts are listed in Table 1 and range from 1.5 % for 10 years to 47.5 % for > 30 years. The disconnection of streets, properties or streets and properties is combined with a sewer network renovation of one or nine sewer catchments planned by BWB for the same period. A 1.5 % reduction of impervious surface only reduces the deficiency time of 199.25 h (all 14 events, base scenario) by 29 h at this exemplary monitoring site and does not reduce the number of events. In contrast, the 30-year scenarios show a major improvement in water quality with much lower deficiency times and number of events. A reduction of 47.5 %, combined with the renovation of nine sewer catchments, will prevent all 14 critical events at this monitoring site.

Table 1. Characteristics of management scenarios for timeframes 10 a, 30 a, > 30 a and example results: Location of measures, reduction of connected impervious area in percent, number of combined sewer (CS) catchments renovated, deficiency time in a central section of the river Spree in hours and corresponding number of critical DO events.

Timeframe	Location of measures	Reduction of connected impervious area [%]	Number of CS catchments renovated	Deficiency time in a central section of river Spree [h]	Number of critical DO events
10 a	Streets	1.5	1	170.25	14
	Properties	4	1	153.75	11
	Streets & properties	5.5	1	137.75	10
30 a	Streets	4.5	9	156.5	11
	Properties	22.5	9	35.75	6
	Streets & properties	27.5	9	21.5	3
> 30 a	Streets & properties	47.5	9	0	0

Figure 2 shows the duration of critical DO events in the Berlin surface waters for all 14 rainfall events in the form of georeferenced isolines and a comparison between the base scenario (left) and an example of a scenario for the timeframe of 30 years (right) with a reduction of the connected impervious area of 27.5 % and the renovation of nine catchments (highlighted in light blue). From a hydraulic point of view, these catchments are suitable for the creation of additional storage volume.

In the base scenario, the shortage times in the Spree vary between 0 and 212.25 h, while the deficiency times in the tributaries are even higher, ranging from 258 to 971.75 h. Compared to the base scenario, the period of critical DO concentrations in the shown scenario is much lower with < 25 hours in almost all river sections. Exceptions are parts of the “Landwehrkanal” in the city centre and the “Neuköllner Schifffahrtskanal” (see Nkn I). The latter is a special case as the DO concentrations in this river section can be very low even without CSO effects. In this case other factors influencing the surface water quality have to be considered. In contrast, the water quality of the “Landwehrkanal” can be improved by further disconnection measures, as indicated by the simulation results of the scenario for more than 30 years.

First model results show that a quick increase in flow can significantly improve the oxygen conditions downstream of combined sewer outfalls.

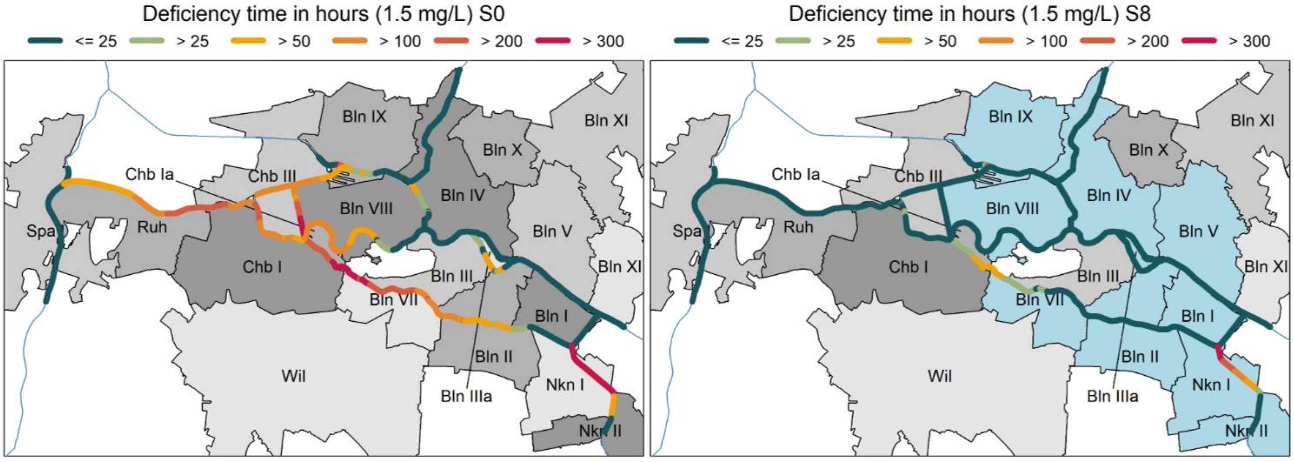

Figure 2. Left side: Base scenario (S0); the time of critical DO concentrations (Deficiency time) in hours for the 14 rainfall events with combined sewer overflows affecting rivers in Berlin; displayed in grey: combined sewer catchments; Right side: The time of critical DO concentrations in hours for the 14 rainfall events in the 30-year scenario with an impervious area reduction by 27.5 %; highlighted in light blue: combined sewer catchments renovated.

Conclusions and future work

The MiSa indicators can be used to evaluate the renovation of the combined sewer system on the basis of immissions. In addition, the model chain consisting of the sewer network model and the surface water quality model can provide a good representation of the impact of combined sewer overflows on the main watercourses in the urban area of Berlin in their current state. By linking the two models, urban drainage management can be integrated into different scenarios throughout the Berlin combined sewer system catchments and evaluated for their impact on Berlin's surface waters.

The workshop format and the close cooperation of all partner institutions allow for the first time a strategic planning of urban drainage management considering economic efficiency, feasibility, climate adaptation and flood protection measures.

While the simulations show a high need for adaptation of catchments and stormwater management, but also a high potential for CSO mitigation, the workshops also demonstrated a high motivation for implementation by the authorities involved.

In addition to further workshops with the relevant districts in the combined sewer system, more defined scenarios of the river management strategies are already planned. The simulation of the river management strategy has shown that there is further potential to improve water quality by adapting river management.

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