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Ecological evaluation criteria driving integrated urban water quality modelling and system optimisation

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Summary of key findings

During the last decades, ecological evaluation criteria have developed much faster than the normal rate of sewer rehabilitation (80 years) or of wwtp rehabilitation (20 years). As a consequence, water utilities had to be very creative in finding cost effective solutions for complying with the changing (types of) performance requirements. Integrated modelling has shown to be a very necessary tool enabling water utilities to succeed. This paper shows how the development of ecological evaluation criteria have driven the development of urban water system modelling, is illustrated for the case of the Dommel River in the area of Eindhoven (Netherlands).

Background and relevance

The Dommel is a relatively small and sensitive river flowing through the city of Eindhoven (Netherlands), receiving discharges from the 750,000 PE wastewater treatment plant (WWTP) of Eindhoven and over 200 combined sewer overflows (CSOs). In summer time, the WWTP effluent makes up to 50% of the dry weather flow in the Dommel River, and during small storm events up to 90% of the flow. Therefore, the river is strongly influenced by the discharges from the CSOs and the WWTP. Waterschap De Dommel (the utility responsible for the compliance to water quality standards) and the municipalities have been improving the wastewater system since the 1970s to improve the river quality to the desired level. During this period, evaluation criteria have continuously been adapted according to the state of the art in legislation and science and, during the last 2 decades, these criteria have influenced the choice of the models applied.

This paper shows how the development of evaluation criteria has driven model development, as well as decision making.

Results and discussion

Since the beginning of the 90s, the municipalities and the water board have been improving the performance of the wastewater system with a dedicated set of measures aimed at meeting the emission-based requirements for the CSOs and the WWTP. The sewer systems were equipped with storage tanks to reduce the annual CSO volumes and the treatment plant had to meet effluent quality standards expressed as average yearly concentrations. The required size of the storage tanks depended on the sensitivity of the receiving water body and, as such, this approach at least showed some ecological awareness. CSOs discharging into the upstream, more sensitive, reaches of the receiving waters had to be provided with storage equal to the overflow volume of a 2-year return storm. The modelling tools at that stage were a static model for the design of the WWTP and hydrodynamic models to size the CSO tanks.

Since 2000, the Dommel River has to meet strict requirements of the European Union Water Framework Directive (WFD), shown in table 1. Even though most of the measures based on the earlier emission-based requirements had been taken, the Dommel River did not yet meet these WFD requirements in 2010. In addition, the WFD requirements do not account for short term impacts of discharges via CSOs and WWTPs. As a consequence, that framework was not suitable for defining an appropriate set of measures, except for nutrients (eutrophication). The associated modelling efforts focused on nutrient removal at the WWTP in order to minimise investment costs for effluent polishing.

As the WFD standards are based on summer averages, they are not applicable for short during events resulting from CSO-loads and effluent discharge of WWTP's. Therefore, a new ecological framework was derived in 2012 from response curves for critical macro-invertebrate species typical for the Dommel River for NH4 and dissolved oxygen (DO). The ecological framework defines threshold values for concentrations that are not supposed to be passed for given durations and return periods. It is an approach comparable to the UPM procedure (FWR, 1998), see table 2 showing an example for dissolved oxygen for critical macro-invertebrates.

This ecological framework is used to search for sets of measures able to meet the WFD requirements by using an integrated model as described by Langeveld et al. (2013) and by Benedetti et al. (2013). This validated integrated model has been developed to calculate DO and NH4 levels in the receiving water. The integrated model consists of:

- a tanks-in-series hydraulic sewer model
- a newly developed empirical water quality model (Langeveld et al., 2014) to calculate the WWTP influent composition during dry and wet weather in function of the influent flow rate
- an ASM2d-based WWTP model combined with an improved model for the primary clarifier (Amerlinck et al. 2013)
- a tanks-in-series hydraulic river model
- a river water quality model to calculated DO and NH4, comprising oxygen budgets (BOD decay, reaeration, plant production and respiration, sediment respiration), nitrification and settling/resuspension of suspended particulates.

The integrated model and the impact based evaluation matrix allowed comparison of the cost-effectiveness of measures in sewer systems, WWTP and receiving waters, resulting in the development of impact-based real-time control and a new strategy employing river aeration, which before adopting the impact based approach, would not have been acknowledged as an effective measure.

In 2014, on-line pH sensors in the river showed the pH to be relatively low and typically below 7.5 in dry weather and below 7.0 in wet weather. At low pH, the ratio NH4/NH3 in water shifts towards NH4 that has no acute toxic effect, unlike NH3. The ecological framework has been adjusted to account also for NH3 rather than for NH4 only and, as a result, the integrated model had to be adjusted accordingly.

From the integrated assessment, a strong effect of pH on required measures and associated investments can be observed. This means that without accounting for pH might lead to a much too conservative design decisions resulting in severe overdesign of e.g. the river aeration and associated non-effective costs.

This emphasizes the need to move away from effluent concentrations in regulation and replace by this type of framework. Moreover, it illustrated the need and advantage to further develop the framework to make it as realistic as possible. Policy developers should make this change in their thinking. We now have the tools for them to come up with scientifically supported evaluation frameworks with the adagium 'More brains and bytes and bytes – less euros'

Conclusion

The development of the evaluation criteria over the last decades has clearly contributed to the adoption of appropriate models in order to better size and optimise the measures that needed to be taken to comply with the requirements. At the same time, the range of measures to be evaluated expanded drastically from CSO tanks to river aeration and real-time control. As such, modelling contributed to meeting the requirements as cost effectively as possible.

In particular, this paper illustrates that, besides sufficiently correct modelling of the subsystems of the urban water system, correct detailing of the assessment and regulatory framework is of paramount importance in application of models in decision making and design in urban water management.

Table 1. Required water quality for the Dommel River

Parameter	WFD requirements for the Dommel River (summer average)	
	Until 2014	2015-2021
P_{total} (mg/l)	≤ *0.14*	≤ *0.11*
N_{total} (mg/l)	≤ 4.0	≤ 2.3
DO saturation (%)	70 - 120	70 - 120

Table 2. threshold values for dissolved oxygen (mg DO/l) based on critical species]

		duration		
		1 - 5 h	**6 - 24 h**	**> 24 h**
Acceptable frequency (n/a)	**12**	< 5.5	< 6.0	< 7.0
	4	< 4.0	< 5.5	< 6.0
	1	< 3.0	< 4.5	< 5.5

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