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Model based estimation of pollutant loads from wet-weather discharges: something is uncertain in the state of Denmark

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Highlights

- Model are routinely used to estimate pollutant loads from wet weather discharges
- Although widely investigated by researchers, model uncertainty is often neglected in practice
- Uncertainties should be explicit addressed to avoid an incorrect interpretation of results

Introduction

Wet weather discharges from urban drainage systems (CSO - Combined Sewer Overflows and outlets from separate systems) can be important contributors to the overall pollutant loads from urban areas into natural surface waters. Given the logistical difficulties in continuously monitoring these discharges, dynamic simulation models have been employed since the 1970s to estimate the discharged pollutant loads. The uncertainty of these model outputs have been widely investigated by the research community during the last decades.

Following the requirement of the EU Water Framework Directive and related legislation, the Danish Environmental Protection Agency (DK-EPA) reports annual discharges of traditional macro pollutants (N, P, Organic matter - NPO) from point sources. There are currently almost 5,000 CSOs and about 14,000 separate outlets in a 43,000 km^2 country with 5.8 million inhabitants. Data for all these discharge points are provided by the 98 Danish municipalities and fed into a national database, which has been described as “a good or excellent knowledge base” based on a review of the information on wet-weather discharges in the EU Member States (Moreira et al., 2016). All the reported data are based on the results of model simulations, where calculated discharged volumes are simply multiplied by fixed pollutant concentrations.

To encourage the reduction of pollution from wet-weather discharges, the option of implementing a tax on NPO loads to supplement the taxation of emissions from WWTP is currently evaluated. The purpose is both to decrease the emissions from wet weather emissions in general and to avoid sub-optimization by WWTP operators to reduce inlet flows during peak flows, which in reality increases the direct emissions from the sewer systems via CSOs.

This work presents the outcomes of an analysis that was initiated by the DK-EPA to evaluate the uncertainty of the current model estimations of NPO loads from wet weather discharges. We first analysed the possible sources of uncertainty based on literature review, and then surveyed the modelling practices followed by the municipalities/water utilities leading to their reported emissions. The analysis showed many very unlikely reported results with uncertainties and biases that by far exceeded what should be possible. Based on the outcomes of this analysis, the resulting reactions from the public when realizing how uncertain the reported data were, and the follow-up action taken by the DK-EPA, we propose a roadmap to increase robustness of model results and favour a more widespread and confident inclusion of uncertainty analysis in common practice.

Methodology

Model for estimation of wet weather discharges

Until 2020, Danish municipalities could employ two different methods for estimating the annual pollutant loads from wet-weather discharges:

- Lookup tables, relating the discharge volumes to impervious catchment area, existing storage depth and the annual rainfall depth. Tables for each specific discharge point are based on statistics derived from long-term simulation using a conceptual hydrological model (SAMBA), which was a standard in the urban hydrology community in the 1990s;
- Results from distributed hydrodynamic models, where Mike Urban is the current de-facto standard in the country.

Uncertainty analysis

The various sources of uncertainty affecting the results of the two employed methodologies were assessed by using the framework outlined in Warmink et al. (2010), defining their location, level, and nature. International literature was surveyed in order to provide an estimate of the uncertainty affecting the identified sources of uncertainty.

Survey of common practice

Anonymous questionnaires were sent to three major water utilities employing distributed hydrodynamic models in their daily professional practice. The utilities were selected based on the feedback from DK-EPA on results robustness, and knowledge on their quality assurance procedures in model development and application. The questionnaire investigated the procedure for model building and maintenance (e.g. parameter estimation procedures, attribute data and input choices, model validation).

Results and discussion

Uncertainty analysis

The uncertainty analysis showed how the majority of the identified sources of uncertainty had a stochastic nature, i.e. their contribution to the output uncertainty can be quantified by assuming probability distributions. However, this is not accounted for in the official modelling guidelines, where standard values are commonly employed. As example, the standard (average) concentrations are estimated based on a limited dataset with measurements collected over 2 decades from a few selected Danish monitoring sites. Considering the natural variability of wet weather discharges, the uncertainty of this value is estimated to be around 30-50%. Nevertheless, this uncertainty is neglected in the annual reporting.

The survey of the international literature highlighted a research gap with respect to the cumulative uncertainty when looking at pollutant fluxes at the catchment and municipal level. Indeed, several studies quantified model uncertainty for single discharge points, or for single events. The effect of aggregation on the spatial scale (several outlets discharging to the same surface water body) or on the temporal scale (annual values) has seldom been investigated.

Common practices

The analysis of the data from the 98 municipalities highlighted that it was not possible to quantify the uncertainty of simulated annual pollutants loads at the national basis. One third of the municipalities still employed the lookup tables. However, these tables are based on simulations from 1980s and they were seldom updated to the specific characteristics of a catchment or to the changes in rainfall patterns that have occurred over the past decades. Example values from the official guidelines were often employed, neglecting the high location-variability of wet-weather discharges (exemplified in Figure 1, where results from hydrodynamic models are also included). Further, the then used integrated modelling software (SAMBA) is not available anymore, and there is a general tendency to only rely on hydrodynamic models instead of switching to currently available software (KOSIM, SIMBA, WEST, etc.). Therefore, the water utilities are not in the condition to update or create new look-up tables that reflected the conditions in their systems.

The response of the questionnaire highlighted that none of the utilities had their distributed hydrodynamic model calibrated according to methodologies proposed in the scientific literature. Model simulations are simply compared against measured data on a routinely basis, and model parameters are manually adjusted until results are deemed satisfactory.

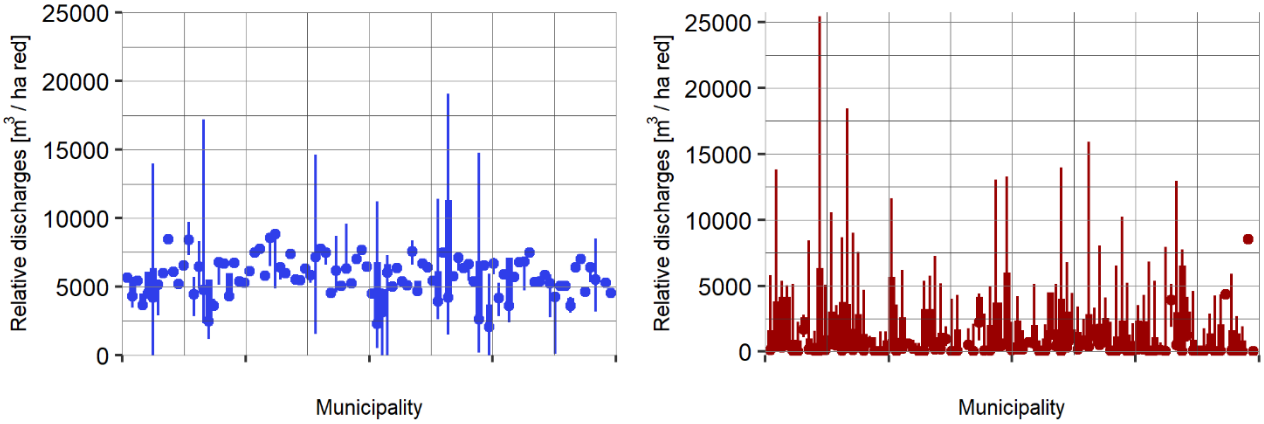

Figure 1. Reported relative discharges for separate systems (blue) and CSO (brown) for the 98 Danish municipalities.

Other subjective choices made by modellers included selection of rainfall input, discharge curves for CSO structures, description of dry weather flows and groundwater infiltration-inflow, etc. Furthermore, there were no requirements for model documentation.

Public outcry and follow-up

The analysis outcomes analysis reached the media and public opinion, stressing the difficulties in conveying the concept of "model uncertainty" to a broad public. While the scientific community acknowledges the intrinsic uncertainty of simulation models and recognizes uncertainty estimation methods as tools to increase the robustness of the simulation results, the media and general public perceives uncertainty as a weakness. The public debate focused on an increased use of measurements (neglecting the uncertainties of directly monitoring wet-weather discharges) and on reduction of uncertainty to below arbitrarily chosen thresholds.

The DK-EPA initiated a series of initiatives aiming at improving the data reliability starting from 2020-21. This included: (a) abandoning methods based on software no longer in use (look-up tables), (b) increased demands for documentation of model application, and (c) additional methodological options for estimating annual discharges (ranging from simple hydrological balances to the use of software sensors to quantify outflows from CSO structures). All these efforts focus on overall annual loads of NPO pollutants, although wet-weather discharges only represent 1-2% of the annual NPO loads discharged from the country. Micropollutants are still neglected from emission inventories, and no efforts are still made to link the increased monitoring and modelling efforts to ecosystem vulnerability, despite the increasing body of scientific literature suggesting that ensuring good ecological and chemical status need an integrated catchment-oriented approach, which is not limited to the evaluation of discharged volumes/loads.

Conclusions and future work

Despite several decades of research activities into identification and quantification of model uncertainty, these aspects are often neglected or underplayed in the everyday practice. Dynamic simulation models are routinely used for environmental reporting in Denmark, and perceived as "good or excellent data". However, model uncertainty is disregarded, affecting the reliability of data collected by the Danish Environmental Protection Agency. This example should be a wake-up call for researchers to facilitate a wider implementation of model uncertainty methodologies in practice. The focus should be on simple methodologies for uncertainty assessment, and to methods to explicitly visualize and account for the model uncertainty. Finally, specific care should be taken when communicating the model uncertainty to a non-specialist public in order to avoid misunderstanding and loss of confidence in the reliability of models.

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