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Probabilistic design and upgrade of wastewater treatment plants in the EU Water Framework Directive context

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SUMMARY

The introduction of the EU Water Framework Directive requires compliance with effluent quality standards and with receiving water quality standards. Therefore, the boundaries of the system to be managed expand from single structures (e.g. wastewater treatment plant) or sectors (e.g. agriculture) to all activities affecting the water environment in the river basin.

This increased complexity implies that the evaluation of the impact of measures on the water quality should be evaluated with instruments able to cope with such complexity, both from the methodological point of view – by developing and applying systems analysis investigations and modelling uncertainty assessment tools – and by making the developed methodology applicable in practice by means of adequate software tools.

Urban wastewater systems (UWWSs) – on which this dissertation focuses – are crucial components of river basins, since they usually contribute substantially to the pollution loads affecting the receiving water body. They also have more flexibility in their operation and management than other subsystems as agriculture.

One part of this dissertation tries to answer the question "where" to improve the UWWS by means of systems analysis. A case study is presented and tackled with the help of substance flow analysis (SFA) to identify the critical paths and of the evaluation of a suite of performance indicators. The case study was the Nete river basin in Belgium, being the basin with the largest data quantity available in Flanders. It consists of by 29 sewer catchments studied both separately and all together as a whole basin.

SFA allowed to identify the pressures on the receiving water through organic pollution and nutrients from households, treatment plants, industry and agriculture. Evidently, information gaps were detected especially regarding diffuse pollution and regarding the availability of reliable data on micropollutants like heavy metals. The indicators – evaluated only for wastewater collection and treatment systems – highlighted the critical structures in the basin. A considerable amount of infiltration water was estimated to enter the sewer system, causing problems of higher treatment costs and lower treatment efficiency.

The spatial scale of the study was found to be of paramount importance, since indicators evaluated for single catchments were in some cases showing extreme values, while the same indicators evaluated for the whole basin had values very well in reported ranges.

The other main part of this dissertations deals with the question "how" to improve the UWWS, by proposing a systematic methodology to design correction measures, illustrated by the example of WWTP design and upgrade. The evaluation of the options is divided in emission-based

(considering the quality of the plant effluent) and immission-based (judging on the basis of the receiving water quality).

The first step consists of a pre-selection of alternatives, in which the non-feasible options are discarded and the most promising ones are selected for further detailed analysis. The next step is the generation of influent time series to be fed to the WWTP models. This is done with a new phenomenological model of the draining catchment and sewer system. One year time series with data every 15 minutes are produced which realistically represent the influent dynamics with time scales varying from minutes (e.g. first flush effect) to months (e.g. seasonality in infiltration rate).

Ten different treatment process configurations were selected for the comparison. The modelling of the WWTPs is based on dimensioning using the ATV-131 guidelines and by using the ASM2d model to describe the dynamics of the activated sludge processes. Eleven options to upgrade a low loaded system were selected for evaluation, partly requiring real-time control (RTC) and partly the construction of additional treatment volume. All configurations were implemented in Tornado, the new back-end of the WEST software, which allows for high flexibility of use and short simulation time.

For the immission-based evaluation, the integration of the WWTP model with a river model – based on a real river modelled with a simplified version of RWQM1 – was made by means of the continuity-based interfacing method (CBIM) and the whole integrated model was implemented in Tornado.

It is deemed that modelling results should always be accompanied by information on the confidence of such predictions. Some probabilistic descriptors were developed and quantified for the options evaluation. The propagation of the uncertainty on model parameters was performed by means of Monte Carlo simulations making use of Typhoon, a software developed to distribute the large number of Monte Carlo simulations on a network of computers, which dramatically reduces the simulation time necessary to apply the proposed methodology.

The first example of emission-based evaluation shows the comparison of different activated sludge volumes for a low loaded system. The main result is that with a volume down to 60% of the one derived from the ATV-131 guideline, the plant is complying with emission limits on yearly average values. The comparison of the ten different process configurations allowed to conclude that given the assumed boundary conditions, alternating systems show the best treatment cost-efficiency. Concerning the upgrade options, RTC upgrades showed good potential for low-cost compliance with regulations, but with higher risk of limits exceedance then with the increase of treatment volumes, which allow for more stable process performance but at higher cost.

The immission-based evaluation of some plant upgrade options revealed that considering the system from a holistic point of view can lead to substantial savings. The option which consisted in just allowing more water to be treated in the plant – hence implying lower effluent quality but less untreated water to be directly discharged in the river – resulted in better environmental and economic performance than the one involving the extension of the treatment volume.

Finally, perspectives for future research are given, such as the extension of the design assessment methodology to include the whole wastewater system and other pollutants and the use of Bayesian networks to frame the performed uncertainty assessment in a wider context.