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Modeling and multi-objective optimal control of integrated wastewater collection and treatment systems in rural areas based on fuzzy decision-making

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Abstract

Historically, sewer networks and wastewater treatment plants are designed and operated separately. Integrated control of urban wastewater collection and treatment systems is in the focus of research since the 1990s. Despite numerous scientific publications and some reports of implementations in practice showing increased system performance thanks to integrated control, the majority of operators are still cautious when it comes to the implementation of complex control approaches. The main cause for the missing acceptance among operators thereby is the fear of losing the ultimate control decision, especially when it comes to compromise multiple conflicting objectives. At the same time, especially in the case of small rural wastewater collection and treatment systems, treatment capacities often remain unused due to the lack of staff able to optimally adapt the operation to the current situation.

Due to this situation, the present thesis investigates the implementation of decision-making in system-wide control of integrated wastewater collection and treatment systems with a focus on rural catchments. Model predictive control is chosen to systematically investigate dynamics in the control of integrated rural systems. Fuzzy decision-making is used to compromise multiple conflicting objectives in system-wide control of integrated systems with a focus on specific goals and constraints of rural systems. The wastewater treatment plant capacity is determined simulation-based according to the predicted loading. For this purpose a Lagrangian model for time-dependent wastewater treatment plant load prediction had to be developed. A case study situated in Luxembourg is used to test the developed approach according to local rainfall time series and corresponding pollution loads. The reference model for simulation-based evaluation of the developed approach is calibrated according to the results of system-wide measurement campaigns. A phenomenological-deterministic reference model is proposed to consider the local variability of runoff from rainfall. Simulation results are compared to reference scenarios based on separated control of the sewer network and the wastewater treatment plant.

The simulation results of system-wide fuzzy predictive control of integrated rural systems during rain events show conflicting objectives predominantly according to stable wastewater treatment plant loading and combined sewer overflow reduction. At the wastewater treatment plant conflicting objectives predominantly consist of the wastewater treatment plant loading, total solids secondary settlement tank effluent concentrations and the optimization of the aeration according to efficient combined wet weather flow treatment and increased nitrification for simultaneous aerobic sludge stabilization. The comparison to the performance of the reference scenarios reveals potentials to reduce combined sewer overflow volumes and loads and increased aeration efficiencies according to the balance of multiple objectives.

Additionally, the developed tool for fuzzy predictive system-wide control adds transparency by visualizing the decision-making according to the chosen objectives of the operator.