Recent advancements in predicting heat budgets in storm- and wastewater at network scale during dry and rain weather conditions

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Highlights

- Compartment-overarching modelling framework to describe the evolution of heat budgets along the flow path (from catchment runoff and household tap to WWTP inflow) at network scale.
- Distributed temperature observations in very high spatiotemporal resolution allow verification of model-based estimation of temperature and heat transfer dynamics at network scale.

Introduction

Stormwater temperatures and corresponding anomalies in wastewater fluxes can considerably affect the treatment plant performance (biological: nitrification; sludge settling: temperature layering). For instance, manifold examples show nitrification deficiencies i) due to generally lower temperatures in winter and spring periods, ii) due to heat recovery strategies in the network (Wanner *et al*. 2005), but iii) less obvious, due to cold stormwater events. Predicting temperature dynamics would enable WWTP operators to optimise load and treatment capacity management, e.g. adaptive dosing of process water from sludge treatment. To date, surprisingly little research has been devoted to modelling the evolution of temperature across the entire urban wastewater system.

1. Modelling concepts: Thermal-hydraulic models of sewer networks, or sewer sections, usually simulate for steady state and dry weather conditions; rain weather phenomena widely remain unconsidered. This is the case for TEMPEST, developed by Dürrenmatt and Wanner (2014). Although the TEMPEST model covers in-sewer temperature processes in detail, the model is however limited with regard to its spatial resolution: thermal-hydrological processes are described in single, unbranched sewer sections. Abdel-Aal *et al*. (2018) address the spatial discretisation constraint by feeding the output of a standard hydraulic sewer network model into a heat transfer model to allow evaluating the heat recovery potential at multiple locations. Most recent developments provide a fully integrated thermal-hydraulic modelling tool SWMM-HEAT *(Figueroa et al*. 2021), which allows distributed heat transfer modelling at a large spatial extend with existing EPA SWMM models at reasonable computational costs.

2. Model verification: Reliability of predictions from distributed thermal-hydraulic models is often ambiguous due to the lack of reference data in sufficient spatiotemporal resolution. Very few of the modelling studies on heat fluxes in sewers rely on *sufficient* observations (Sitzenfrei *et al*. 2017). However, technological advances in sensor technology increasingly help to close this gap. Although gaining quantitative information at network scale is still difficult, most recent improvements in data communication technology, also suitable for underground applications (Ebi *et al*. 2019), enable large-scale deployments of low-power sensors across drainage networks, providing system status information in high spatiotemporal resolution.

Previous studies provide valuable insights on steady state conditions and with a limited spatiotemporal differentiation. Building on these efforts, we aim at consistently describing heat budget dynamics in storm- and wastewater from the catchment surface to the WWTP inflow. Our models are verified by long-term observations at very high spatiotemporal resolution. In this abstract, i) we give a glimpse of the overarching modelling framework, ii) we reveal how thermal enrichment dynamics of surface runoff can be estimated from long-term observations, and iii) we present preliminary results obtained with the proposed modelling framework.

Methodology

Modelling framework: We propose a consistent, compartment overarching modelling framework that links thermal enrichment and hydrologic transport of stormwater surface runoff with thermal-hydraulic transport processes in underground drainage networks. The framework consists of three main components (see Fig. 1): 1. the WaterHub model (Hadengue *et al*. 2019), a stochastic generator for sub-hourly thermal-hydraulic consumption behaviour at household level; 2. MINUHET (Herb *et al.* 2009) to simulate the heat uptake in stormwater as it travels across surfaces; 3. SWMM-HEAT (Figueroa *et al*. 2021) that embraces distributed hydraulic flow and heat transport/transfer in urban drainage networks in one single tool. Key processes covered in this framework are: stochastic water-energy patterns originating from domestic consumers, heat loss in house connections, thermal enrichment of stormwater surface runoff, and heat transfer between various compartments including in-sewer atmosphere/sewage and pipe-soil/sewage.

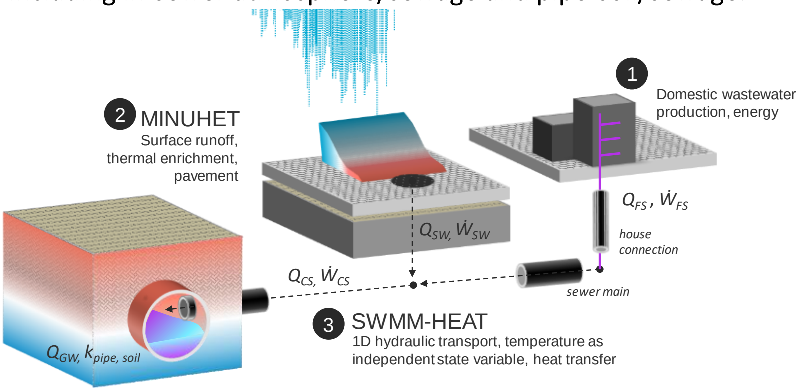

Figure 1 Proposed modelling framework to describe the evolution of heat and water fluxes in urban drainage networks.

The suggested approach requires a careful treatment of the information provided by numerous sources. Figure 2 shows a scheme of the dataflow adopted to inform the SWMM-HEAT tool: flow and temperature time series from runoff and wastewater produced by households are mixed using the alligation method, while groundwater infiltration patterns are provided in the SWMM-HEAT input file. Once the routing simulation starts, an internal module in SWMM-HEAT mixes the thermal-hydraulic flows accordingly.

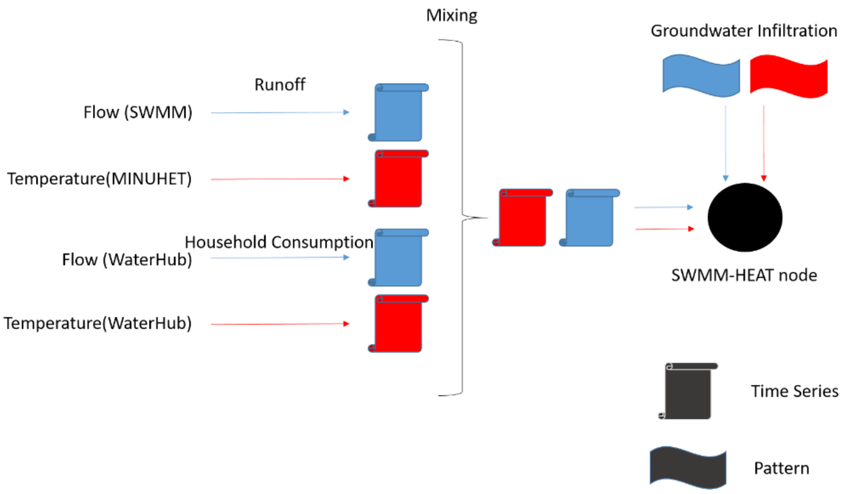

Figure 2 Time series and patters with flow (blue) and temperatures (red) from surface runoff, wastewater produced by households and groundwater infiltration are introduced at the nodes of the SWMM-HEAT model to perform routing simulations.

Distributed field data and case study description: We use data from the Urban Water Observatory (UWO), a long-term monitoring initiative providing consistent observations on rainfall/runoff processes in very high spatial and temporal resolution (Blumensaat *et al*. 2018). Beyond hydraulic variables, we measure i) in-sewer wastewater temperature and in-sewer atmosphere temperature using 24 dual-temperature sensors, ii) groundwater and soil temperature (12 sensors), and iii) ambient air temperature (4 locations). The sensor network is embedded in a real-world urban drainage system in Fehraltorf, Switzerland. An overview on the UWO sensor network and insight in data series is given at https://uwo-opendata.eawag.ch/.

Results and discussion

Indirect monitoring of thermal enrichment of stormwater runoff to inform the heat transfer model: Water temperature is continuously monitored in five different stormwater inlets since February 2019. Whereas we can observe consistent temperature increases for the summer period (representing thermal enrichment due to hot surfaces), we see clear temperature drops corresponding to rainfall in the colder season. Correlating the magnitude of these anomalies with land surface temperature measurements and own rainfall observations allows deriving parameter values for the heat transfer process at the surface.

Modelling the thermal-hydraulic impact of rain weather conditions in sewer networks: Numerical simulations have been conducted to quantify the thermal effect of surface runoff in a combine sewer network. Preliminary results (Fig. 4) indicate that hydraulic and thermal anomalies occur during precipitation events compared with "dry" periods. A comprehensive validation of the results is in progress and it will be included in the conference presentation.

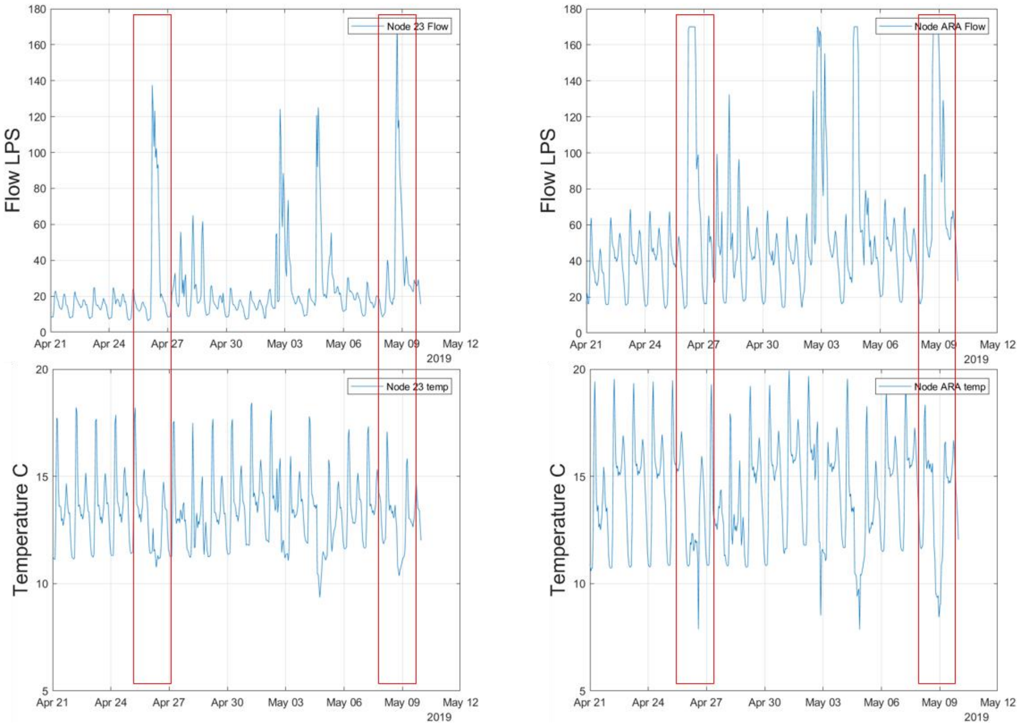

Figure 3 Preliminary results of water flow and temperature for the period of April-May 2019 at two distinct locations. Left: midstream (node 23). Right: wastewater treatment plant (node ARA). Red boxes show periods where precipitation events are registered.

Conclusions and future work

We conclude that, apart from understanding the dynamics of the observed temperatures, distributed sensing of hydraulic variables and temperature of corresponding fluxes contribute to more representative heat balancing models in the storm- and wastewater context. We show this by using spatially distributed long-term observations to inform a consistent process-based modelling framework. Numerical experiments using this overarching modelling framework reveal deficiencies in existing modelling concepts, namely the disregard of heat transfer in house connections and inability to model rain weather conditions. More details and thorough validation will be given in the full paper.

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