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Forecast and Real-Time-Control for the Sewer System of Warsaw, Poland

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Abstract

The Sewer Department of the city of Warsaw, Poland in collaboration with ITWH GmbH restructures and expands the sewer network. The objective of the initiative is to reduce combined sewer overflow (CSO) volume and limit the number of registered CSO events. A real-time-control system is established to facilitate centralised control of pumping stations and storage channels, thereby ensuring efficient utilisation of retention space. A digital hydraulic twin of the sewer network is developed. This tool allows real-time access to current conditions and predictions of hydraulic conditions up to two hours into the future. The creation of a fine-resolution precipitation forecast is facilitated by the incorporation of radar, rain gauge, and disdrometer data, which serves as an input for the hydraulic prediction feature. Real-time data of water level and flow measurements is directly used in the digital twin for an online calibration of the sewer network through the adjustment of water levels. The accuracy of the volume prediction is heavily dependent on the initial calibration and is repeatedly affected by changes in the sewer network, as manual readjustment is necessary.

Highlights

- Implementation of a digital twin for hydraulic state and prognosis
- Adaption of real-time online measurement
- Control strategy to reduce the number and the volume of CSO events

Introduction

The Sewer Department of the city of Warsaw, Poland, in collaboration with ITWH GmbH, is undertaking a project to restructure and expand the sewer pipe network. This report delineates the methodologies and strategies employed by the real-time-control and forecast system (see Figure 1) to reduce CSO volume and to limit the number of registered CSOs. The primary focus of this work is on the adaptation of water levels between the digital twin and the sensor values.

Methodology

Digital twin of hydraulic state

A hydraulic twin of the sewer network is implemented to have insights into the dynamics of the sewer. Radar-based rainfall runoff is utilized to generate the dynamic inflow into the sewer network, with a temporal resolution of 1 minute and a spatial resolution of 1 km. Approximately 100 water level

sensors provide measurements in real-time, which are employed for the online adaptation of the digital twin. At manholes that are equipped with water level measuring points in reality, a volume exchange is carried out in order to equalize the water level in the online hydraulic simulation with the measurement. A volume flow is defined with which the water level can be maintained. The addition or removal flow decreases over time in order to allow the hydraulic image to decay until the real value is updated after one minute. This exchange flow makes it easier to check compliance with volume balances than if the water level were kept static. The adjusted volume is distributed hydraulically in the system so that the water level and flow rate in the digital twin can also be read out at locations where there are no sensors in the network.
In addition to the water levels, dynamic control elements such as weir crest height, gate position and pumping capacity are also integrated into the simulation. All element values are updated once per second and synchronized with the digital twin every minute to get the most up-to-date status report.

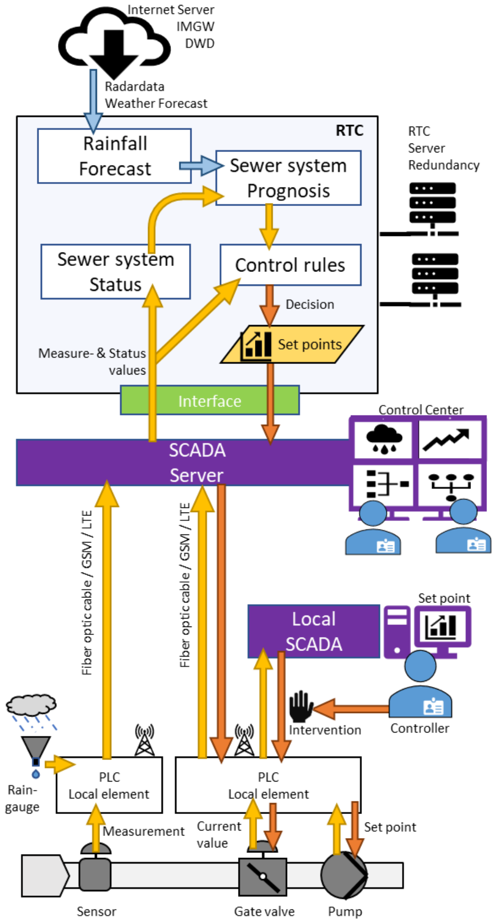

Figure 1. Schematic dataflow for each minuten in the RTC

Hydraulic Prognosis

Every 15 minutes a snapshot of the current hydraulic state is taken from the digital twin to serve as a starting point for a hydraulic prognosis simulation (ITWH, 2025). Radar forecast for precipitation with a lead time of two hours is used for the rainfall runoff volume generation. A prognosis simulation run for upcoming 120 minutes requires nine minutes for computation for all values in the sewer network. From the generated forecast, the expected inflows to pumping stations are indicated in expected time horizon and provide an extended knowledge base for runoff control.

Control Strategy

The hydraulic prognosis is used to optimize a global control strategy with a mixture of deterministic and Fuzzy based rules. The main objective is to prevent the flooding of structures and to reduce the discharge volume into the receiving watercourse. We consider dynamic boundary conditions in the capacity of pumping stations, transport structures and the current acceptance capacity of the sewage treatment plant. To comply with the capacity restriction, the controllable inflows are reduced upstream in a cascading manner. The information from measurements and hydraulic prognosis simulation are used together for this purpose. The control system publishes a control decision every minute, which is implemented by the local control system to control weirs, operate retention tanks and storage sewers, run dry weather- and overflow pumps.

Failure replacement strategies
All incoming data is validated online. If measured values from sensors fail, substitute values from the online adapted digital twin can be used to utilize states in the duct network for control purposes.
If precipitation data fails, there is a multi-level system for maintaining the precipitation forecast. In the regular case, radar data is adjusted with disdrometer and 25 rain gauges and used for the forecast. If the rain gauges fail, a static adjustment of the radar data is carried out. If radar data fails, a spatially interpolated map for the current precipitation is calculated based on the locations of the rain gauges and measured rain intensity. The result of a numerical weather forecast from the German Weather Service is used for the forecast as a substitute if neither radar data nor rain gauges provide any data.

Case study

The catchment area has a size of 77 km², 1.8 Mio inhabitants and a sewer network length of 4.48 km (MPWiK S.A., 2023). The combined sewer network is connected to the sewage treatment plant with an acceptance capacity of 14.2 m³/s. The sewer network is modelled with a coarsened subset of 10,000 transport elements. The Vistula River is the central receiving water. The sewer system contains controlled objects including: a siphon with a capacity up to 10.85 m³/s, four storage sewers (biggest one up to 54,000 m³, a retention tank (82,000 m³) and 6 controllable main pumping stations.
The hydraulic simulation and prognosis are based on the 1D hydrodynamic model itwh.HYSTEM-EXTRAN 8 while the control strategy is implemented with itwh.CONTROL software. Rainfall data is calculated with itwh.NVIS software based on a radar data of Poland Weather Service (IMGW), rain gauge and disdrometer data from the sewer department (MPWiK) and numerical Weather forecast from German Weather Service (DWD).

Results and discussion

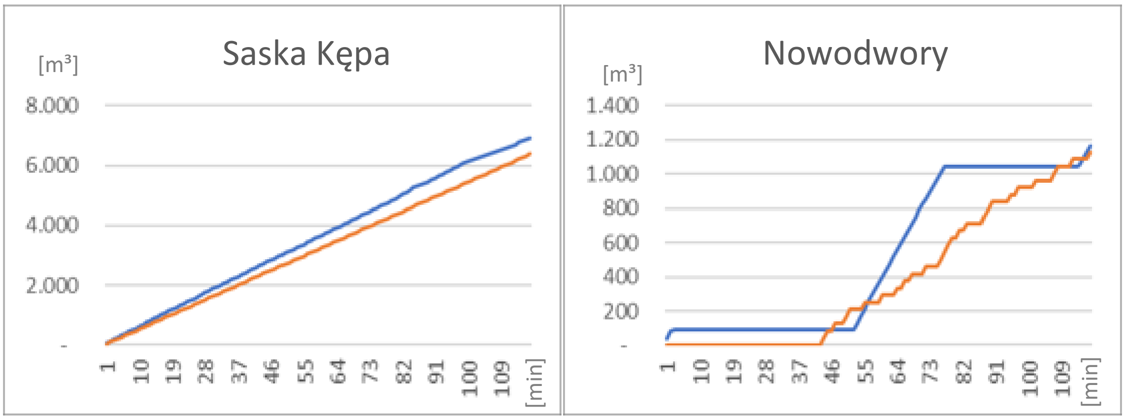

Figure 2. Comparison of pumped volume (blue=measured, orange=hydraulic prognosis) in m³ over 120 minutes for two different pumping stations.

Long time series simulations with rain events from 10 years show reduction of CSO volume of 44% when comparing the system from 2019 with the final installation state. The latter refers to the installation of the RTC system, which is accompanied by the remodeling of the canal system, in which larger storage spaces were created. In part, this involves collector pipes, which are activated by

movable weirs, and in part, completely new structures were created. In addition, the pump systems were upgraded and automated for coordinated control through a central SCADA system.
The prediction of pump activity is very accurate in terms of volume. **Figure 2** shows the accumulated flow through pumps during a hydraulic simulation of 120 minutes compared to the measured pumping rate. Deviation here is less than 10%. The variation is due to the difference between the simulation pumping rate and the real pumping rate. By adjusting the water level at the inlet to the pump, the volume is maintained in the best possible way. However, the expected switch-on and switch-off times are offset by a few minutes. We attribute this to the results of the online adaptation of the water levels. A very good accuracy (deviation <1%) of the water level at individual manholes is assumed via this adaptation (see **Figure 3**). There is also a direct influence on the discharge from this manhole. By using additional water to fill up or lower the water level to the measured value, a considerable volume is introduced into the simulation model. This causes suction chambers and tanks to fill faster or more slowly. This effect is more pronounced in dry weather, as the additional volumes are then large in relation to the dry weather flow.

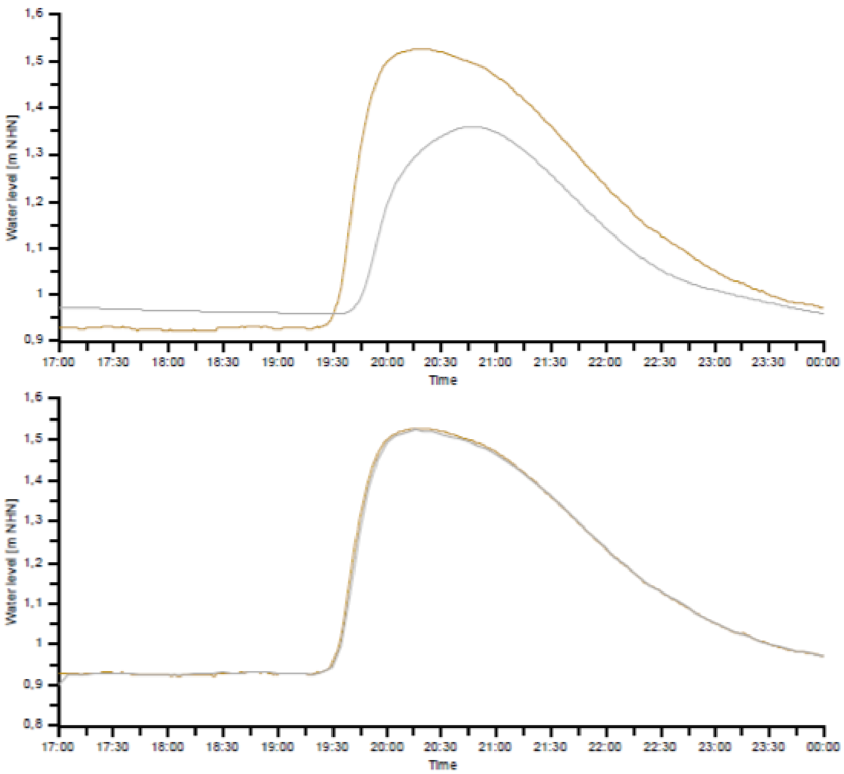

Figure 3. Water level in manhole. Yellow: Measured water level, Grey: Calculated water level
Top: Low compliance when adaptation of water level is deactivated
Bottom: Good fit when water level adaption is enabled

Conclusions and future work

The online adjustment of water levels makes an important contribution to the provision of simulated hydraulic values. A reliable quantification of flows at the same location is only possible with sufficient detailing of the geometry. This requires extensive calibration work. Established relationships between water level and flow can easily be altered by changes in the sewer network (e.g. siltation, sensor maintenance) and thus rendered invalid. Despite potential inaccuracies in flow rate sensor readings relative to water level measurements, direct utilisation of flow rate data for online adjustments remains a viable approach. However, this model-based mapping approach poses challenges related to volume conservation and the stability of the numerical solver. Consequently, the direct adjustment of volume flows in the digital twin remains a subject of ongoing development.

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