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Modelling and implementation of a modified floodgate in SWMM for simulation-based optimization of a sewer network

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Abstract

The discharge of combined sewer overflows (CSO) during rain events and the efficient operation of the sewer system can be a challenge for sewer network operators. Discharges into water bodies will probably have to be reduced even further in future due to new regulations. Long dry weather periods and deposits have a negative impact on the substance of sewer networks and shorten the lifetime of the infrastructure. Activating unused storage volume in the sewer can be an efficient and cost-effective alternative to building new storage volume. One possibility for predictive sewer maintenance can be the use of flushing waves from backed-up wastewater. Basically, sewer network control can utilize a lot of potential and help to overcome future challenges. This report from an application-oriented research project in the city of Jena shows the implementation and modelling of a modified floodgate in SWMM. The Results show the gained storage volume, the reduction of combined sewer discharge and flushing velocities for possible sewer flushing.

Highlights

- We used SWMM to model a modified floodgate inside a sewer network.
- Modified floodgates seem to reduce untreated sewage discharge into rivers.

Introduction

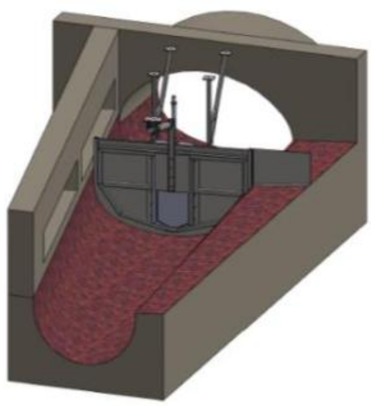
Extreme weather conditions with heavy rainfall can lead to uncontrolled discharge of combined sewage into water bodies. Even with the available storage capacity in the wastewater infrastructure and modern approaches to preventing combined sewage, discharge still occurs. This environmental damage must be avoided. Approaches to sewer network control can increase the utilization of the network. However, one aspect of extreme weather conditions in Germany are periods of drought. The wastewater infrastructure must then cope with the extreme of low flow in the sewer. This leads to deposits, which lead to odor and an increased risk of corrosion. While adapting to new guidelines and regulations and the resulting tightening of discharge conditions, it is necessary to exploit all potential of additional volume in the sewer and the use of preventive maintenance measures for a long-lasting wastewater infrastructure. In an application-related research project "InSchuKa4.0", modified mechanical floodgates should be installed to cope with both weather extremes and promote an efficient operation of the sewer network.

The approach for the entire research project has included several working steps, from the collection and evaluation of operational data from the WWTP to updating and validating the entire sewer network model. Static optimizations of all CSO´s were carried out, and a feasibility study was carried out on the positioning (maximum volume activation) of the modified floodgates. An important boundary condition is that the sewage treatment plant in the city of Jena is reaching its hydraulic capacity limit. Therefore, one target condition was the maximum activation of unused storage volume in the sewer, with the possibility of delaying the wastewater inflow to the WWTP and generating flushing waves to clean the sewer bed. This report focuses on the modelling and simulation of a modified floodgate.

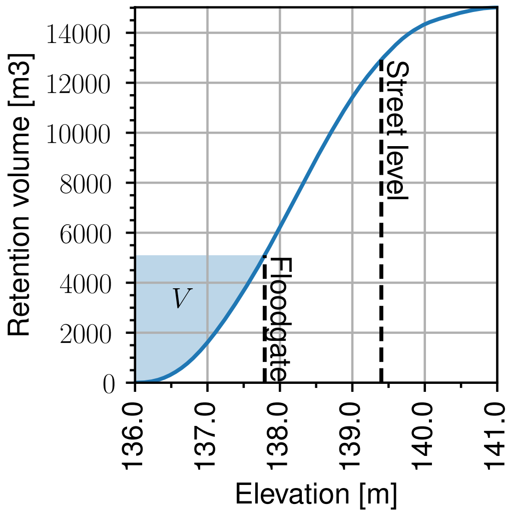
Methodology

The sewer turns into a facultative storm water tank via the floodgate

The installation site for the application is at the end of the sewer network of the city of Jena. The main sewer in the old town area has a length of approx. 6 kilometers and is operated as a combined sewer system. This is where the largest sewer dimensions and, in dry weather, the lowest flow velocities are found. The installation is carried out in a CSO, as this provides simplified access and low-cost installation conditions. Figure 1a shows the final construction plan, with special features of the structure and its geometry. The access to the building limits the maximum height of the floodgate to 1.8 meters and is therefore the limiting factor for the available/activatable volume. This gained volume serves primarily as a buffer volume to slow down runoff and prevent untreated runoff discharges into the river. The large CSO directly at the WWTP has the most dominant discharge in the whole sewer network. The WWTP is located approx. 1 kilometer away from the installation site of the floodgate. The sewer upstream of the floodgate is a DN 3600/2250 sewer, the backflow extends approx. 1.5 kilometers and is well below the local ground level. The calculation of the possible activatable volume is true to scale and can be seen in Figure 1b.



(a) Floodgate concept in the sewer by HST-Systemtechnik

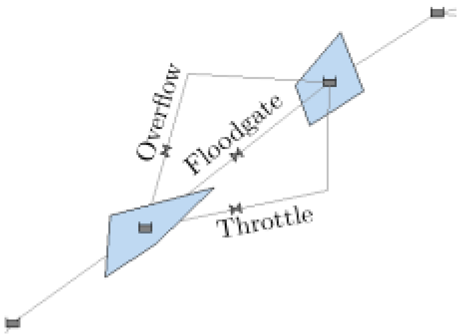


(b) Retention volume function

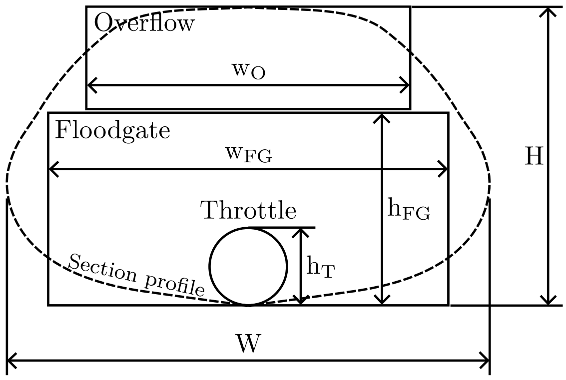
Figure 1 Estimated gained volume for the floodgate

Floodgate abstraction in SWMM

A floodgate with an additional throttle was simulated in SWMM. In order to do this, we used a combination of orifices and weirs. To preserve the slope, the sewer canal section was proportionally divided into two subsections at the location of potential installation. At the end of the first subsection and at the beginning of the second subsection, nodes of zero area and infinite height were added to abstract an interface that only has water height. Between these interfaces, we represented the opened floodgate, the throttle and the overflow of the closed gate, with respectively three orifice links, as depicted in Figure 2b. The floodgate orifice FG has as height of h_{FG}, the height before it overflows and a calculated width of w_{FG}, so that the floodgate area coincided with the area of the profile section from the bottom up to h_{FG}. The overflow orifice had its width w_o, calculated in the same way from the top. The orifices for the floodgate and the throttle opening are opened and closed through the "SETTING" parameter from SWMM (Rossman,2022). The floodgate was assumed to open and close instantly. Orifice parameters were left in their default values.



(a) SWMM Orifice and Node setup



(b) Orifice dimensions based on section profile

Figure 2 Floodgate mechanism abstraction in SWMM

This abstraction was validated by comparing the flow through an unmodified section to the flow through a modified section with the floodgate opened, since they should be exactly the same. The simulated flows were almost identical for a wide range of flows, so we considered that this abstraction was valid for the simulation of the mechanism.

Case study

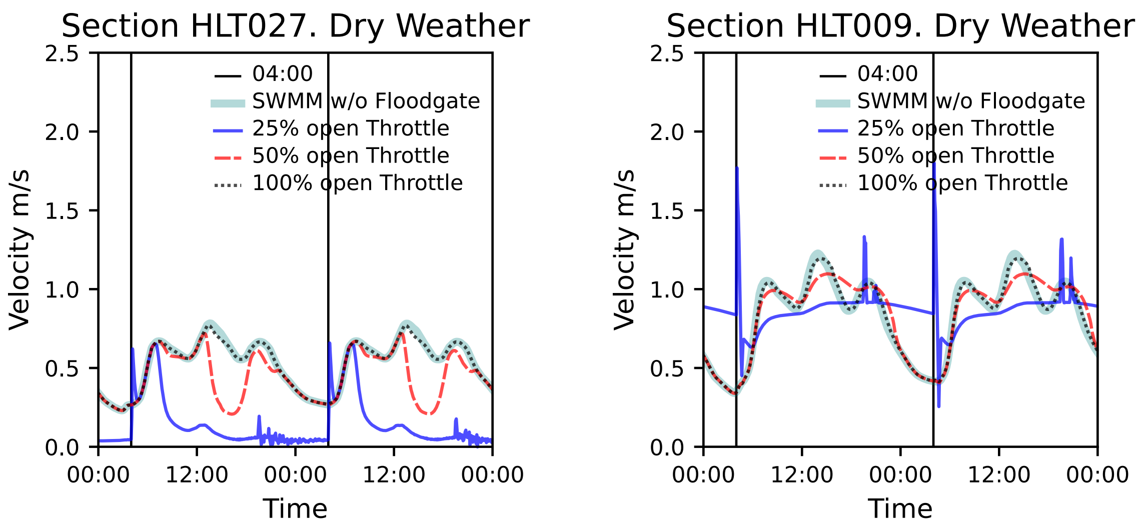
The city of Jena has around 110,000 inhabitants and an area of 90 km², with the river Saale running through the city. The sewer network has 10 CSO´s that discharge into the river when the network is overloaded. The available sewer network model dated back to 2015, so it had to be updated and transferred to SWMM. The results in Table 1 show the simulated reductions that would occur in the entire network. Even in dry weather or with the smallest amount of rain, discharge occurs. These small amounts of losses only occur in areas that have not been optimized and can be regarded as network anomalies. The results therefore include a direct comparison between the reductions without the use of the floodgate and with the intervention of the floodgate. The rainfall events originate from real weather data that happened in the years 2022 and 2023. We chose two distributions of intensities for three- and seven-days rainfall to simulate the effects of sudden and prolonged rainfall. The simulation results in Table 1 only show a throttle opening position that corresponds to a fixed maximum opening of 0.6 meters.

Scenario	Duration [days]	Intensity [mm/day]	Discharge [1000 m³]		Reduction %
			w/o Floodgate	w/ Floodgate	
0	7	0.00	5.4	4.8	11%
1	7	0.72	5.8	5.2	10%
2	7	1.47	28.3	25.9	8%
3	7	2.14	22.1	16.4	26%
4	7	2.90	350.0	272.3	22%
5	7	3.79	165.5	159.0	4%
6	7	4.29	146.8	137.5	6%
7	7	5.21	240.1	284.4	-18%
8	3	0.00	3.0	2.4	20%
9	3	1.68	20.1	8.0	60%
10	3	3.34	3.6	3.0	17%

11	3	5.00	79.0	39.3	50%
12	3	6.97	274.1	253.2	8%
13	3	8.35	255.2	252.3	1%
14	3	10.78	506.2	494.5	2%
15	3	15.00	504.6	581.3	-15%

Table 1 Simulated untreated discharges to the Saale

With the adjustable throttle countless position openings with different management concepts can be realized. There are several conditions for the floodgate, so when the maximum height of the gate is reached, the gate should open to protect the mechanics. This creates a flushing effect when the retained volume is released at high velocities. This flushing wave had to be triggered at night (4:00 am) so that it arrived at the sewage treatment plant before the first daytime peak. The velocity profiles downstream and upstream of the floodgate for three different throttling settings are shown in Figure 3a and 3b. A maximum throttle configuration allows the highest flushing potential but causes the greatest sedimentation risk upstream of the flushing gate. The high velocities and flushing potential are observed far downstream of the floodgate, as seen in Figure 3b. The right concept must be found between slowing down flow to the treatment plant and flushing the sewer bed. In all cases except in high intensity rainfall events, the unused retention volume contributes to the reduction of untreated discharge. The non-linearity of the results is due to the temporal and special distribution of the events, as well as to the geometry of the network.



(a) Velocity reduction 760m upstream of floodgate

(b) Flushing 400m downstream of floodgate

Figure 3 Sedimentation risk upstream of floodgate and flushing effect downstream of it.

Conclusions and future work

The use of a modified floodgate in a sewer can be an efficient and affordable solution for utilizing additional volume in the sewer, compared to the high construction costs of a submersible weir. The floodgate achieves a significant reduction in combined discharge from medium but frequent rain intensities. Equalizing inflows to the WWTP and releasing flushing waves to clean the sewer bed offer valuable advantages for the operation of a WWTP or a sewer network. Suitable control or management concepts must be in place, as otherwise negative effects can also occur. The technology described has been installed and we expect our simulation studies to be confirmed by real operating data.

References

Rossman, L. A. (2022). *Storm Water Management Model User's Manual Version 5.2.* Washington, DC, EPA/600/R-22/030: U.S. Environmental Protection Agency.