BALANCING INFLOW VOLUMES AND LOADS TO THE SEWAGE TREATMENT PLANT THROUGH DYNAMIC SEWER NETWORK MANAGEMENT

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Sewer networks and sewage treatment plants must be adapted to challenges such as stricter legal requirements and increasing environmental demands. Climate-related extreme events such as heavy rainfall and periods of drought place particular demands on structural adaptations and the management of these infrastructure facilities. While heavy rainfall events lead to hydraulic overloads, backwater including flooding and mixed water discharges, periods of drought cause deposits, odour problems and corrosive processes in the sewer network. In many cities, this stress situation leads to an unstable inflow situation in sewage treatment plants, increased energy requirements, fluctuations in cleaning performance and difficulties in complying with limit values [1]. Against this background, the InSchuKa4.0 research project investigated how intelligent and dynamic control of the sewer network can contribute to adaptation to extreme weather events, reduce mixed water discharges and increase the operational reliability of existing systems. It was found that this innovative sewer network management can also be used to specifically relieve sewage treatment plants and, depending on the design, avoid the need for capacity expansion, e.g. through the construction of new treatment facilities. The combination of modern sensor technology, hydrodynamic simulation and innovative control based on the principle of case-based reasoning (CBR) enables adaptive network management. This involved specifically combining the empirical knowledge of operating personnel with real-time data and weather forecasts, a method that is particularly suitable for locations with little data documentation. In practice, this means that unused storage volume in the sewer is used in a targeted manner, the flow behaviour of the wastewater in the sewer is controlled situationally by intelligently networked flushing gates, and additional inflow volumes to the sewage treatment plant can thus be smoothed out – with positive effects on the hydraulic utilisation, operational safety and energy consumption of the entire sewer network and sewage treatment plant system. Using the city of Jena as an example, the InSchuKa4.0 project demonstrated that additional storage volume of around 8,000 m³ can be made available in the existing sewer system and that mixed water discharges can be reduced by up to 50% if control and technology are optimally coordinated. It is particularly noteworthy that all this was made possible by minimally invasive technical retrofits consisting of sensor technology, machine technology and AI-based digitalisation in existing structures.

Load situation at municipal sewage treatment plants. In urban combined sewer systems, climate-related frequent heavy rainfall events lead to sudden overloads, where the existing retention volume in the sewer network is insufficient or underutilised. As a result, large quantities of untreated combined sewage must be discharged directly into water bodies because sewage treatment plants cannot accommodate these additional wastewater volumes due to existing volume limitations. At the same time, prolonged dry periods promote the formation of deposits on the sewer floor, leading to odour problems, sulphide formation and an increased risk of corrosion. These two extremes – overflow during heavy rainfall and sediment growth during dry periods – are occurring more frequently and in closer succession during the summer months, placing a considerable strain not only on the sewer network but also, depending on the inflow situation, on the operation of sewage treatment plants. The resulting fluctuations in inflow volumes impair continuous biological treatment, increase energy consumption due to the need for adjustments and, in the worst case, lead to inadequate treatment performance, which jeopardises compliance with legal requirements [2]. Most existing control concepts for sewers and sewage treatment plants are based on rigid operating strategies that are not suitable for the changes in load described above.

One possible solution would be to expand the sewer infrastructure with increased storage capacity, but this is not financially feasible in many municipalities [3]. The solutions developed in the InSchuKa4.0 research project[1] offer a cost-effective and efficient alternative with data-based, dynamic sewer network control.

Intelligent sewer network control to relieve sewage treatment plants. The InSchuKa4.0 project pursues an integrated approach that expands classic control concepts with intelligent data processing and case-based decision logic. At its heart is a control system that works according to the principle of case-based reasoning (CBR) – an artificial intelligence method in which past operating situations are stored as cases, compared with new, comparable situations and thus made available for current decisions. This systematically links the operational staff's experience and knowledge with current measurement data. Each management case is stored as a so-called "case" in a knowledge database and compared with real-time data from sensors, operational management and weather forecasts. Through this comparison, the system automatically identifies the control strategies that have been successful in comparable situations in the past, and the operating personnel can draw on these suggestions. It is particularly important that the decision-making processes remain transparent and traceable – an essential aspect for operations in a municipal environment [4].

This method was put into practice in the sewer network of the city of Jena. In a detailed simulation study, weak points such as hydraulic bottlenecks and areas with potential hydraulic storage volume were first identified, taking into account necessary flushing processes and unused potential in the network. It was found that, particularly during moderate rainfall events, additional storage volumes can be utilised by specifically activating this retention potential, which results in a more even inflow to the sewage treatment plant and prevents adverse effects on the treatment process. On this basis, two existing structures in the main collector were equipped with controllable dam and flushing gates and these were connected to the new CBR control system. This allowed both optimal use of existing storage volume and targeted flushing of the sewer beds during dry weather phases. This concept of innovative retrofitting in existing structures did not require any major structural work, but was implemented using modular technical components and individually adapted installation technology (see Fig. 1).

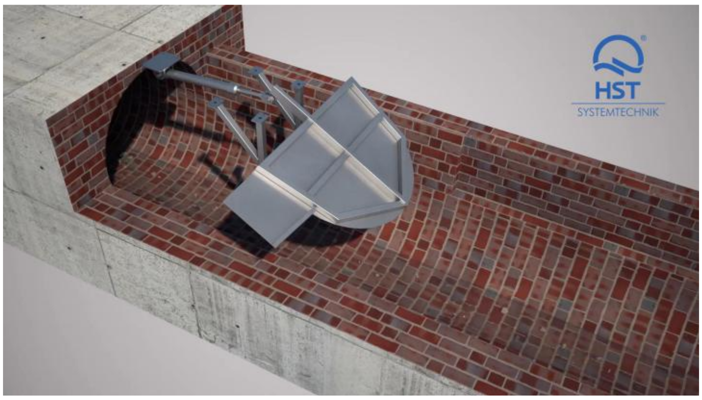

Fig. 1. Concept of the retrofittable storage flap in the Jena pilot area for activating storage space volume and flushing. Source: HST Systemtechnik

The control system was linked to the existing SCADA system of the sewer and sewage treatment plant as well as to the weather data service NiRA.web, whose 48-hour forecasts were integrated into the decision-making process of the CBR system. This enabled the system not only to react to current measurement data, but also to act proactively by analysing precipitation forecasts.

A central element of the control approach is the continuous expansion of the CBR case database. In the course of the project, 13 typical application scenarios were defined, representing different

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weather conditions, inflow situations and sewer conditions. These scenarios were linked to real operating data and serve as a reference for real-time control. The results showed that the application of this intelligent sewer network management system led to significant improvements: the number of mixed water discharges was reduced by up to 50%, while at the same time the effort required for manual interventions such as opening and closing throttling devices or manually triggering flushing processes by operating personnel was significantly reduced [5]. Table 1 provides an overview of the effects in different scenarios and shows that measurable benefits were achieved in both rainy and dry weather phases.

Table 1: Simulated combined sewer overflows (throttle opening 100%), total combined sewer overflows from the simulated sewer network, with throttle function fully open

Scenario	**Duration [days]**	**Rain Intensity [mm/d]**	**Combined Sewer Discharges [1000 m³]**		**Reduction [%]**
			Without Flush Protection	**With Flush Protection**	
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	232.3	9 %
14	3	10.78	506.2	494.5	2 %
15	3	15.00	504.6	581.3	–15 %

In addition, it was found that a more uniform inflow situation to the sewage treatment plant could be achieved, which led to more stable process control of the sewage treatment plant, especially in the biological stages. This reduced the specific energy consumption per cubic metre of wastewater. There are also advantages from an ecological point of view: reduced discharge volumes from the sewer mean less pollution in water bodies, which in turn contributes to improving the condition of water bodies and complying with water law requirements. The approach shows that the intelligent use of modern process technology with predictive control and artificial intelligence in existing sewer infrastructures improves flow behaviour in the sewer and results in effective relief for sewage treatment plants – a pragmatic approach that can already be implemented today with less investment than a classic structural expansion and can be transferred to other municipalities [4].

Conclusion. The results of the project show that sewer operation adapted to extreme weather conditions and the additional relief of sewage treatment plants do not necessarily require the construction of further expensive storage facilities or costly conversions in the sewer network, but can already be achieved with modern machinery and intelligent, dynamic control. The use of the CBR principle opens up new possibilities for systematically utilising empirical knowledge, linking it to real-time data and weather forecasts, and responding proactively to complex operating situations. The pilot application in Jena has shown that innovative technology can significantly reduce mixed water discharges, which not only offers ecological advantages but also contributes to more stable, energy-efficient and safer operation of the sewage treatment plant. It is particularly noteworthy that the approach developed remains adaptable in both technical and organisational terms, thus representing a transferable solution for many municipalities facing similar challenges. At a time of growing demands, dwindling resources and worsening climatic conditions, this form of intelligent sewer network management makes a practical, economical and sustainable contribution to sustainable water management.

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STRATEGY FOR APPLYING BESS AND CAES ENERGY STORAGE SYSTEMS IN SBR WASTEWATER TREATMENT PROCESSES

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Sequencing Batch Reactor (SBR) technology is widely used in wastewater treatment plants (WWTPs) and is characterised by a cyclic aeration mode. These cycles cause fluctuations in electricity demand: during aeration, the power load rises sharply and then drops during the non-aeration phases like denitrifcation, sedimentation and clear water outlet. Aerobic biological treatment processes, based on activated sludge principles like Continuous Flow and SBR systems, are responsible for up to 70% of energy consumption. Of the total electricity demand at wastewater treatment plants [1]. Consequently, improving energy efficiency and flexibility of such facilities has a direct impact on efficiency and thus for sustainability of their operation. Against the backdrop of better utilization of renewable energies during periods of reduced sun activity (solar modules)