Current state and development of the real-time control of the Berlin sewage system

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Abstract Since the 1970s, we have known about real-time control of urban drainage systems. However, global real-time control strategies still show a lack of implementation for large drainage systems of high complexity. In Berlin, Germany, a city of 3.5 million inhabitants covering an area of around 900 km², the demand for enhanced protection of the environment and growing economic pressure have led to an increasing application of control assets and concepts within the sewage system. In the framework of the project “Integrated Sewage Management”, the possibilities of a global and integrated control strategy for the Berlin system are examined. The paper is focused on the historical concept and design of the sewerage and the further improvement towards an environment-oriented system that builds the basis for today’s considerations. The operational method and functionality of local regulators that have already been implemented are described. Furthermore, the model-based methodology for the analysis of the system and the development of global control concepts, as well as the results of system analysis, are stated. On the basis of model simulations, it is shown that a global coordination of pump stations can lead to a reduction of sewer overflows, and consequently to an enhanced water protection.

Keywords Drainage system; inline storage; real-time control; sewerage

Introduction Within urban development areas, domestic and trade wastewater, as well as extensive quantities of rainwater dependent on the percentage of impermeability, accrue. The central task of urban drainage is to collect and treat this wastewater, ensuring safety for man and infrastructure, as well as maximum operational reliability. The objective is the prevention of adverse effects on the natural water cycle, and thus the protection of the environment. Special attention is paid to the design and construction of combined sewer systems where combined sewer overflows (CSOs) and discharges from storm water retention tanks present a potential risk of water pollution.

In the past, drainage problems within the combined sewerage have been solved exclusively by static and constructional concepts. Since the middle of the 1970s (at first in the USA, later on in Europe, too), real-time control has been applied to manage systematically existing drainage assets and thus to utilize the maximum of the system’s capacities. The development of the integrated control of the sewer network and wastewater treatment plant has been furthered in the past decade. The integration of the receiving waters and their processes has also been taken into account. Due to the diffidence of planners and operators of urban drainage systems, an operational application of the researched control methods, especially on large and complex systems, is still rare.

This paper will give an overview on the state and the current and future development of real-time control of the Berlin sewage system. The main focus is a state description of the Berlin combined sewer system enclosing the local regulators already implemented. The history, the development towards an environment-oriented system, and the functioning of
the system are described. Special attention is turned to the objectives and the operating methods of local control structures that have been integrated within past years. Furthermore, the analysis of global control concepts carried out within the framework of the project “Integrated Sewage Management” is illustrated.

**Real-time control of urban drainage systems**

The primary function of a combined sewerage is to collect sewage and convey it to the treatment plant. Flooding within the drainage area shall be avoided and discharges over combined sewer overflows into the receiving water shall be kept down to a minimum. As the majority of load situations usually depart from the design load, the combined sewerage will rarely optimally fulfil its function. The non-uniform, spatio-temporary distribution of rainfall can lead to local overload of the system. At the same time elsewhere within the sewerage, transport and storage capacities may be under-utilized.

The objective of real-time control (rtc) is to influence, and hence to even up, the highly unsteady processes within the sewage system so that the above-mentioned adverse effects only occur after full utilization of collection and storage capacities. Moreover, negative effects shall occur preferably where damage is slight (Schilling, 1996).

With regard to rtc systems, there are three groups of elements that play an important role.

1. The constructional assets, such as collectors, branchings, retention tanks, CSOs or throttles where flow processes take place.
2. The actuators such as sluice gates, weirs, valves or pumps, which influence the flow processes.
3. The sensors, controllers and data transmission systems, which provide the necessary information to control the actuators.

Only if elements from each of the above-mentioned groups are present, can one speak of real-time control (ATV, 1985). Many regulators use process measurements that are conducted directly at the actuator site. Here, we speak of local control. Simple examples are based on the functioning of counterweights or floats. Global real-time control is applied where all regulators are monitored and operated in a co-ordinated manner with respect to process measurements throughout the entire system. Such a superior control concept can lead to a further improvement of the drainage system (Pfister et al., 1999). On the other hand, the development of a global control concept involves a high planning effort.

A further step in the control of sewage systems is the integrated control of sewerage and wastewater treatment plant. The integration of the receiving waters and their processes has also been partially taken into account (Grüning, 2002; Meirlaen, 2002). A review of the current state of the art of real-time control of urban wastewater systems is given by Schütze et al. (2002).

**The Berlin sewage system**

**General water management situation in Berlin**

In Berlin, Germany, the pumping of drinking water has historically been developed almost exclusively within the city boundaries. Berlin is therefore one of the few European metropolises where drinking water is almost completely supplied by groundwater located within the municipal area, and which, at the same time, has to manage its wastewater disposal within that same municipal area. The inevitable high degree of usage conflict that occurs between urban development on the one hand and lasting water pollution control and groundwater protection on the other makes particular demands. The close spatial
interlock between drinking water supply, wastewater disposal, and water use conceals a high potential conflict.

3.5 million inhabitants and an area of around 900 km² are connected to the sewage system. The total length of collectors is around 9,000 km. Three-quarters of the area of Berlin is drained via the separate system, whereas in the inner city, a quarter of the total area drains into the combined system. The wastewater is pumped by 149 pump stations and over 1,000 km of pressurized pipelines to six wastewater treatment plants for mechanical and biological treatment. On average, a total of approximately 635,000 cubic metres of wastewater are delivered and cleaned per day.

Current state of the combined sewer system

After 13 years of concept discussion, the ground-breaking ceremony for the construction of the Berlin sewerage was held on 14th August, 1873. The implementation of the construction works took place largely in the years 1873 to 1893, and realized the concept of master builder, James Hobrecht and pathologist, Rudolf Virchow. The basic idea of Hobrecht was not to build one single network for the entire city, which was very flat and large at that time (60 km²). He designed the so-called ‘radial system’, twelve individual drainage systems that were arranged radially to the watercourses and separated from each other by the natural watersheds (Bärbeth, 2003). The sewers were designed as a combined system. They conveyed the waste and storm water towards a topographic low point near the river. Here, pump stations were built to deliver the water through pressure pipes to sewage farms outside the city border.

Today, Berlin is drained by both a separate and a combined sewer system. In the inner city, an area of 167 km² is still drained by a combined sewerage. Most of the constructions and the main structure of this sub system are still based on the design concept of Hobrecht.

With an official directive in the year 1998, the federal state of Berlin called for a noticeable reduction of discharges (volumes and pollution loads) from the combined sewer system. Concerning the volumes, the discharge rates of CSOs and storm water tanks shall fall below 25% of the average annual rainfall runoff volume. Concerning the pollution loads of COD, BOD₅, and TSS, the discharge rates shall fall below 20% of the average annual load of the rainfall runoff. To meet these legislative requirements, the Berliner Wasserbetriebe (the local agency for water and wastewater services) carry out a rehabilitation programme. Until 2020, the construction of additional storage assets and the activation of available inline storage capacities will ensure compliance with the legislation. The implementation of the rehabilitation programme already includes the integration of local regulators into the drainage system. These control objectives will be described in the following paragraphs.

Current state of real-time control of the Berlin sewage system

As described above, the objective of rtc is the uniform and maximum utilization of collection and storage capacities within the entire drainage system. To a certain extent, that is possible by local rtc. This section will give a review of local control objectives that are operated within the Berlin system.

Inherently, as a result of Hobrecht’s decentralized concept for the combined sewerage and due to the low topographic gradients, all outflow from the networks, and consequently the in-pipe storage capacities, are controlled by pump stations. These pump stations deliver the wastewater to the treatment plants and act simultaneously as variable throttles in case of rainfall events. When exceeding the maximum pump capacities, the combined water is dammed up within the sewer network until a critical level is reached and there is discharge.
over the combined sewer overflows. Due to big-sized conduits and very low sewer gradients in some of the subcatchments, high storage space can be activated. Depending on the size of the networks, between 1,200 m$^3$ and 12,500 m$^3$ of storage space can be utilized. These figures correspond to a minimum specific in-line storage volume of 3 m$^3$/ha $A_{red}$ and a maximum of 65 m$^3$/ha $A_{red}$. The total in-line storage volume accumulates to a dimension of 125,000 m$^3$ corresponding to an average specific volume of 15 m$^3$/ha $A_{red}$. In addition, 25,750 m$^3$ of storage space are available in the form of storm water tanks and sewers with storage capacity and overflow.

Figure 1 gives an overview of available storage capacities before and after realization of the rehabilitation programme.

Further activation of in-pipe storage is realized by local actuators within the sewer networks. Since 1996, a movable weir is operated within the main collector of the catchment Berlin IX. The sewer is 3.07 m wide and 2.30 m high. The weir is activated in case of a storm water event and backs up approximately 3,000 m$^3$ of combined water. A position sensor within the hydraulic cylinders of the weir, as well as upstream and downstream level meters, record the necessary process data. The control strategy limits the flow towards the pump station to the design flow (twice the dry weather peak flow) by activating the weir. If the critical upstream water level is reached, the weir is lowered to hold this ordinate. In case of an exceedance of the critical water level, the sewer cross section is completely deblocked to avoid flooding. After the end of the rain event, the flow towards the pump station is limited again to the design flow until the collectors have been emptied.

Another alternative to store combined water is the modification of sewer overflow conduits. Two projects have been realized in Berlin. Originally, the conduits only conveyed discharges from combined sewer overflows to the receiving water. Now, they are operated as sewers with storage capacity and overflow. Due to wide and flat subcatchments, those overflow conduits may reach great lengths and provide high storage capacities. In the centre of Berlin (District of Tiergarten), there is one construction where the overflow crest is realized as a movable sluice board. This local actuator is used to control the water level within the overflow sewer. The dynamic operation allows the activation of an additional storage space of 11,000 m$^3$.

Another reconstruction of an overflow sewer in the District of Friedrichshain led to an increase of storage by 12,000 m$^3$. Here, a pump is used to control the emptying of the overflow sewer and the return of combined water towards the main pump station.

By storing combined water within the conduits, the number of critical hydraulic situations at the pump stations and at the main CSOs can be reduced. A reduction of discharges into the receiving waters can be observed especially for medium rainfall events. In Berlin,
the afore mentioned measures decisively contribute to compliance with the emission targets set by the water authority. Further local control objects are planned and will be realized in the course of future rehabilitation works.

**Development of global real-time control concepts**

The ambitions to enforce measures of global real-time control at the Berlin system are bundled in the project “Integrated Sewage Management” (ISM) that is realized at the KompetenzZentrum Wasser Berlin (Berlin Centre of Competence for Water) by the project partners, Veolia Water and Berliner Wasserbetriebe.

The ISM project aims to develop strategies for the integrated management, as well as the initialization of decision support tools for the planning and operation of the Berlin sewage system. Eventually, the implementation of local controls and an integrated global control of the system is sought. By integrating the subcatchment model into the operational decision-making process, an optimized utilization of storage- and treatment-capacities of the overall system shall be achieved. Thereby, a reduction of the impact on watercourses will be effected. Furthermore, the economic aspect of a real-time control of storage and control assets with a view to energy operational and maintenance costs will be studied.

The project is scheduled in four main phases. Each of these phases consists of one or more specific studies. Firstly, a ‘state of the art’ study of the Berlin sewage system was carried out and terminated with the buildup of a comprehensive report about the system. Structures, assets, and processes have been documented in detail, including its interfaces, to obtain a reliable set of data and information to revert to during all phases of the study. In parallel, and by taking into account this set of data, a rating of the system has been carried out according to the German ATV-workgroup 1.2.4 ‘Real time control of sewer systems’ (ATV, 1995). Due to the low average sewer gradient, the complex network structure, with a high number of control, discharge and storage assets, and its large spatial dimensions, the Berlin system is highly rated. It is classified as predestined for real-time control.

Phase II of the project embraced a comparison of different models used for the simulation of sewerage and wastewater treatment processes. The aim was to gain experience and to acquire an overview on the different model approaches and to assess the performance and transferability of the models. For these purposes, comparative calculations have been carried out for two catchments in Berlin-Köpenick (Germany) and Grand Couronne (France) and evaluated on the basis of measurements. For the modelling of the sewers, pump stations, and pressure mains, the dynamic flow routing model InfoWorks CS™ of Wallingford Software Limited was chosen. The modular program SIMBA® of ifak Magdeburg that is based on the Activated Sludge Model No. 1 (ASM1) is used to model the wastewater treatment plants.

To set up the sewer model, available data concerning the geometric design of the sewage system and the specifics of the terrain is adopted from either the GIS database of the Berliner Wasserbetriebe or from former hydrodynamic calculations. All catchments with a share of combined sewers are simulated deterministically. However, only the main sewers with an important contribution to the structure of the system are taken into account. Hence, the model consists of low detailed networks that allow simulating the main hydraulic and pollutant processes within the sewerage with an adequate accuracy.

Subsequently, a phase of model calibration and validation is carried out. At the catchment areas, a continuous recording of data is carried out at the pump stations and actuators, such as sluice gates and mobile weirs. These sets of data are used to calibrate
volume, flow and water levels at first. At specific catchments, additional measurement campaigns are realized to complete the data for calibration and to examine the hydraulic processes, as well as pollutant processes, in detail. **Figure 2** shows a set of measured flow data during an intense rain event and, in comparison, the corresponding set of simulated data after model calibration.

On the basis of the models, the functioning and the control potential of the sewage system are studied and evaluated. Eventually, the aim is to develop strategies for the integrated management and decision support tools for the planning and the operation of the Berlin sewage system. During Phase III of the project, the studies focused on the subcatchment of the wastewater treatment plant, Ruhleben (1.6 million inhabitants connected). During Phase IV until the end of 2005, the entire Berlin system will be examined.

**Results from simulations of global control scenarios**

As described above, any drop of Berlin wastewater is delivered by pumps. Hence, local pump stations control the in-pipe storage capacities of the single drainage networks. For that reason, it seems to be logical that a coordination, a global control of the individual pump stations, can lead to a uniform utilization of storage capacities. That, in turn, will help to reduce discharges over sewer overflows.

The control algorithm that was tested compares the utilization ratio of the sewers and retention tanks within each individual subcatchment with the average utilization ratio of the entire system. Depending on the observed deviation, the pumpage of the individual station is modified. **Table 1** shows a comparison of the control strategy with the currently applied local pump regime. For a simulation over five months of measured rainfall, a reduction of CSO activities can be observed. The total CSO volume is reduced by 14.1%. The total CSO load is reduced by 10.4%.

**Summary**

Real-time control of urban drainage systems allows activating capacities of storm water storage and wastewater treatment that were unutilized before. The historically grown structure of the Berlin combined sewerage, along with its afore-mentioned properties, allows *per se* a systematic management of the subsystems. In the course of rehabilitation works, the implementation of local regulators already opened additional storage reserves. Additionally, the potential of global control concepts for sewerage, pump stations, and treatment plants is studied within the framework of the project “Integrated Sewage Management” to increase the systems efficiency. In particular, a coordination of the currently

![Flow 12.08.02 - 13.08.02](Figure 2) Measured and simulated flow within a main collector during rain
locally controlled pump stations promises a reduction of sewer overflows, and hence an enhanced protection of the environment.

In the course of further studies, the integrated simulation of the entire sewage system, including the processes at the treatment plant, will lead to a balance of the total emissions into the receiving water. This is necessary to assess and analyse the total impact on the water body in detail and to further the improvement of the Berlin sewage system towards an environment-oriented system.

### References


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**Table 1 Effect of local and global pump station control on CSO activity**

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<th>Current</th>
<th>Global control</th>
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