Integrated control of the wastewater system: potential and barriers

● Applying integrated control to a sewer system and wastewater treatment plant often leads to additional benefits for both systems when compared to controlling them independently. However, barriers such as a lack of incentive for utilities to put this type of control in place mean that in practice integrated control of wastewater systems is rarely seen. **ANE LOFT MOLLERUP, MORTEN GRUM, DIRK MUSCHALLA, EDWIN VAN VELZEN, PETER VANROLLEGHEM, PETER STEEN MIKKELSEN** and **GÜRKAN SIN** outline the benefits of integrated control of wastewater systems.

While most sewer systems and wastewater treatment plants (WWTPs) have some level of control (e.g. manual control, on / off control of pumps, timers, cascade controls, etc.), there is a continuous interest in moving towards more advanced control systems. The efficiency of the existing system can in this way be improved by minimizing the overflows from the system and maximizing the amount of treated wastewater, without overloading the WWTPs. Research incites practice to move from distributed control systems towards more centralised control using modern model-based and rule-based methods to ensure an optimal coordination of the system actuators.

As part of the IWA smart network cluster, a workshop on integrated control of sewer systems and WWTPs was held at the 2012 IWA World Water Congress & Exhibition in Busan, South Korea. The workshop brought together experts in sewer system and WWTP operation and control, both practitioners from utilities and researchers from academia. Bringing people together across disciplines allowed for an exchange of experiences and for a discussion on the potential of better integration of sewer system and WWTP operation through integrated control. This article sums up the presentations and high-level discussion that took place during the workshop.

Why plan and control in an integrated way?

Sewer systems and WWTPs are directly connected, but often also indirectly connected through the sharing of receiving waters. Therefore, when changes are made to either of the systems, this usually impacts on both. Without integrated planning one risks suboptimising one system at the expense of another. This merely moves the problem from one place to another in the system and does not actually solve the issue. The same applies if control is used to optimise the operation of the individual systems, instead of the whole wastewater system. If instead an integrated approach is used, the potential to be gained from implementing control often increases.

However, there is more than one way of designing an integrated control system. Every control system has to be designed for the specific wastewater system at hand and, among other things, that means making decisions regarding what online information should be used in real-time. Level and flow measurements are commonly used in the controls, but two additional types of information that are gaining increasing interest are precipitation forecasts and water quality measurements. The benefits and the disadvantages of including these sources of information are discussed below.

DMI's Viring radar in Denmark. Based on, for example, radar images a forecast of the precipitation can be made and used in the control of the wastewater system.

The potential of including forecast in control

Precipitation forecasts provide information about location, intensity and temporal variation of the incoming rain. These forecasts can be used to anticipate specific flows within the drainage network as well as overflows. By combining this knowledge with information about the current state of the system, control actions can be identified that will minimize the overall negative effects (Vezzaro and Grum, 2012). For example, forecasts of the flow to the treatment plant can serve as a signal to switch to wet weather mode with higher capacity, thus increasing the plant's throughput and reducing the overflow.

A forecast can be based on either radar images or well-positioned rain gauges. The potential of using forecasts is undeniably large, but not all control points are sensitive to forecast. Through the use of simulations one can find out whether it makes a difference to have the control action be determined by forecasts, by comparing the control actions with and without the forecasting method activated. Whether and to what extent weather forecasts should be used is one of the important decisions to be made when a real-time control system is being developed for a particular urban wastewater system.

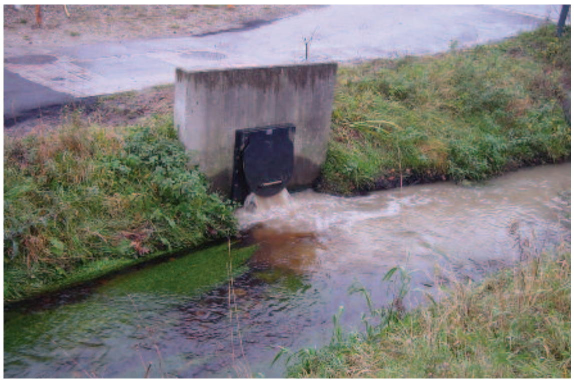
Extending the prediction horizon with weather models

Weather models present two main advantages in the context of integrated control of wastewater systems. First, their forecast horizon is comparable to typical emptying times of urban drainage systems and the time required to shift water around in the network. Second, forecasting dry weather periods allows for a reduction in energy consumption and carbon footprint by temporarily reducing pump heights and by sending water through the treatment plant during off-peak hours when power costs and carbon footprints are lower. To really exploit the former, weather forecasts need to contain information about where the rain will fall within the catchment. To exploit their full potential, information about the associated uncertainty is needed. In some situations the forecasts may be so uncertain that they do not contribute to the control decisions. Current developments in numerical weather modelling are tackling several issues, e.g. studying spatial resolution, the ability to forecast convective rains, and ensemble modelling to describe uncertainty.

Including water quality measurements in the control

So far, most of the implemented RTC systems have only used information about the hydraulics of the system. Just recently, new RTC concepts have been installed that use water quality information for pollution-based objectives (e.g. Hoppe et al., 2011).

Including water quality sensors allows the extension of control objectives to include water pollution metrics. A possible new objective for separate sewer systems is, for example, the diversion of less polluted stormwater to the nearby receiving water and more polluted water to a stormwater basin. In combined sewer systems, the location and time of



In many cases, implementing control can reduce the numbers of combined sewer overflows.

Table 1: Examples of different types of advanced control systems that have been implemented around the world

	Key figures	Control objectives	Number of control points	Control techniques	Forecast	Results	Biggest obstacles towards implementation
Netherlands *van Nooijen et al. (2011) Proceedings 12ICUD, Porto Alegre, Brazil. 10-15 Sep. 2011*	A = 80 ha PE = 11,500 PE Rain = 800 mm/year Volume = 4239m^3 or 5.3mm Number of CSOs = 14 Capacity of WWTP = 714m^3/h	Use full capacity of the WWTP Minimize CSOs	11	*Control Next.* Real time optimisation with constraints: equal filling of the catchments while meeting the load of the WWTP	No forecast	Minimum 10% CSO reduction and during rainfall 900m^3/h to the WWTP	A small system needs fast communication from central control to local controls and vice versa Adjusting local control software for safe central control
France	A = 190,000 ha PE = 13 million PE Rain = 650mm/year Volume = 900,000m^3 or 0.5mm Number of CSOs = 260 Capacity of WWTP = 115,000m^3/h in dry weather, 252,000m^3/h in wet weather	Minimize CSOs Distribution of CSOs over the water course Attenuate dry weather flow to WWTP Flood control	60	*CSoft.* Global predictive control with constraints (MPC approach)	Six-hour forecast during wet weather	30% less storage needed (equivalent to \$800 million investment reduction) 100% reduction of six-month CSO event	Extended and complex system Too small capacity available during wet weather Lack of sufficient, reliable online monitoring data Management of unavailability of data
Germany	A = 8000 ha PE = 100,000 PE Rain = 700mm/year Number of CSOs = 2 Capacity of WWTP = 4100m^3/h	Minimizing CSO frequency and volume Attenuate dry weather flow to WWTP Use full capacity of WWTP	3	*itwh CONTROL.* Fuzzy logic using water level and flow in the sewer system and quality parameters at the WWTP	No forecast	6000m^3 additionally activated volume CSO frequencies reduced by 23% CSO volume reduced by 25%	Fast and robust communication for global control
Canada *Fradet et al. (2010). Water Science & Technology. 63, 331-338*	A = 50,000 ha PE = 500,000 PE Rain = 1200mm/year Storage volume = 130,000m^3 or 0.3mm Number of CSOs = 50 Capacity of WWTP = 51,000m^3/h primary, 28,000m^3/h secondary	Minimize CSOs Achieve primary and secondary contact water quality	50	*CSoft.* Global predictive control with constraints (MPC approach)	Two-hour forecast included at sites where the controls were very sensitive towards using forecasting	35% less storage needed (equivalent to \$90 million investment reduction) 77% CSO volume reduction, 43% CSO event reduction	Training and system acceptance by operators

combined sewer overflows could be controlled in such a way that overflows of heavily polluted wastewater into sensitive receiving waters are avoided and the most polluted wastewater is directed to the WWTP.

The use of water quality sensors for RTC is still limited for two reasons. First, the implementation of water quality sensors in harsh environments is a challenging task, and second the dynamics of the quality parameters are needed at high frequency and with adequate accuracy. Some pilot studies have proven that long-term operation of water quality sensors is possible (Gamerith et al. 2011). Nevertheless, clever installation and considerable maintenance effort is needed.

Cases with different types of advanced control implemented

There are not many well-documented examples of utilities that have implemented integrated control. However, there are some and much can be learned from their experiences, starting from the generation of an idea to its implementation. The systems presented here all have in common that the objectives of the controls are related to the hydraulics of the system. Key information about each of the cases can be found in Table 1.

Based on the information in Table 1 as well as the discussions of the workshop, two key messages should be emphasized. First of all, full-scale implementations have shown that integrated control of the wastewater system can lead to very nice results in terms of, e.g., reduced CSO and investments. The second message is that the obstacles to implementation of integrated control are different for each utility, i.e. they depend on both the system and organisational setup.

Large retention basin in Copenhagen. Using control to coordinate the filling and the emptying of basins, the wastewater utility hopes to minimize the number of CSOs and the bypass from the WWTPs.

Conclusion

For years there has been talk of the great potential of control of the sewer system and in integrating the operation of the sewer system with the operation of WWTPs through integrated control (Schütze et al., 2004). Full-scale implementations have in the meantime confirmed this potential over the last decade (Fradet et al., 2010, Dirckx et al., 2011). That said, in practice there are still relatively few utilities that have implemented integrated control. Even though control can often prove a cost-effective solution to achieving better operation of the wastewater system, more traditional solutions are still often chosen. It is important to understand why.

In many cases this can be explained by the lack of incentive for utilities to implement control. If the legislation does not include demands on the efficiency of investments, utilities have no incentive to adopt control.

Lynetten wastewater treatment plant in Copenhagen, Denmark. When the hydraulic capacity of a WWTP is exceeded, bypass gates are opened. Integrated control minimizes the need for bypass.

As the barriers to successfully transfer a concept of controlling the system to practice can seem too big to overcome, more traditional, but costly solutions are often chosen. Especially for a utility with no prior experience with real-time control of the wastewater system, the barriers can seem overwhelming. Barriers commonly mentioned are the need for organisational changes and training of operators as well as integration of the different IT-systems to supervise and control the system by the operators. To overcome these barriers encouragement and promoting the sharing of experiences of implementing control are required.

Another barrier is that most of the publications on control still come from academia, where typically only proofs of principle are provided, which cannot be extrapolated easily and safely to practice. As a result novel approaches take a long time to mature into something the utilities trust enough to invest in.

Finally, there is no systematic way of evaluating different types of control systems, from simple on/off control to rule-based control to more advanced modern control. This makes it difficult for urban drainage planners to evaluate different control techniques for the specific aims and constraints of their system. There is a need for a methodological approach to help generate, evaluate and benchmark alternative control strategies, which will enable informed decision making about how to operate and control one's system. ●

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