ONLINE SIMULATION AND OPTIMISATION OF AN INTEGRATED SYSTEM - WASTEWATER TREATMENT PLANT AND SEWER SYSTEM

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ABSTRACT

Operation and building costs of wastewater treatment plants (WWTP) and sewer systems can be reduced by using an intelligent way of operation. At the WWTP there are several cost-intensive points in the treatment process that can be optimised, primarily aeration rates and pump rates. In a sewer system the size, position and operation of the stormwater tanks can be optimised. Finding out the most cost-effective operating method in consideration of all requirements on ensuring stable operation and compliance with regulations is hardly possible only by manual operation.

In this paper a forward-looking solution to optimise the operation of a wastewater treatment plant and a sewer system of 150.000 habitants based on a real time simulation model is introduced. With the help of a new optimisation tool of the WWTP in conjunction with real time control (RTC) of the whole sewer system it will be possible to smooth incoming flow rates and to operate the sewer system and wastewater treatment plant in the best way concerning costs and water pollution control.

KEYWORDS

Optimisation; real time control; online simulation; wastewater treatment plant, sewer system

INTRODUCTION

Higher environment quality standards lead to higher threshold values concerning the effluent of WWTPs and the discharges of combined sewer systems. For this the permanent increase in efficiency of existing WWTPs and sewer system is required. With conventional technics this normally results in higher building and operational costs.

This can only be avoided by using better technologies. Real time control (RTC) is one possibility, that can lead to reduced building and operational costs and better environmental and operational conditions.

By using RTC the system operation considers the actual situation in the system. Actual values, e.g. flow or nitrogen parameters, are measured to use them for online simulation and optimisation. To use the present values is especially important concerning the effectiveness of systems with high dynamics of boundary conditions. The urban drainage system is such a dynamic system and therefore particularly suitable for RTC.

RTC of an integrated system, sewer system and sewage plant, is carried out from the Wastewater Association Obere Iller (AOI) in co-operation with the consultant engineers for sewer systems, sewage plants and control (iaks GmbH) and Paul Schaad Ingenieure in the South of Germany. Objectives are the reduction of investment and operational cost and an acceptable level of water pollution control. The project is supported by the German Federal Ministry of Education, Science Research and Technology.

For the WWTP an optimisation tool based on a real time simulation model of the WWTP and a computerized databank has been developed. The optimisation system always finds the best way to reduce the operational cost of by taking into account the dynamics of the incoming wastewater, the full capacity of the WWTP and the legal threshold values. The sewer system as well is operated with the help of an online optimisation tool based on an online simulation tool. In the case of rain the tools calculate the best effluent values of the stormwater tanks in order to fill all tanks consistent and to discharge as less wastewater as possible. The final aim of the project is to control both parts, the sewage system and the treatment plant, together to enable an optimum function of the entire system.

THE SYSTEM OF THE WASTEWATER ASSOCIATION OBERE ILLER

Description of the Wastewater Treatment Plant

The sewage plant situated in the South of Germany purifies the wastewater of 150.000 person equivalents.

The speciality of this WWTP are two aeration-tanks, each of them with a volume of 4000 m3 having the form of a nearly rectangular tank with the lengths of 150 m, a width of 4 m and a depths of 6 m, winding up to a spiral. This form presents an almost perfect plug flow reactor with the advantage of better biodegradation kinetics. Thus less volume is needed compared with the more common rectangular tank. The spiral construction leads to an inherent stability so that the wall thickness could be reduced to 40 centimetres. Altogether the construction costs were very low. The water flows inwards and the flow of internal recirculation has to be guided from the centre outwards, which is a shorter way to pump.

Because of the plug flow the reactor is sensitive to flow peaks but also very capable of being controlled. Divided into 5 elements, each equipped with a separate aeration unit, variable zones for different biological processes can be installed. By switching on and off the separate aeration units zones for nitrification and denitrification can be created as needed. By moving the position, where the internal recirculation is introduced a zone for phosphorus removal can be added.

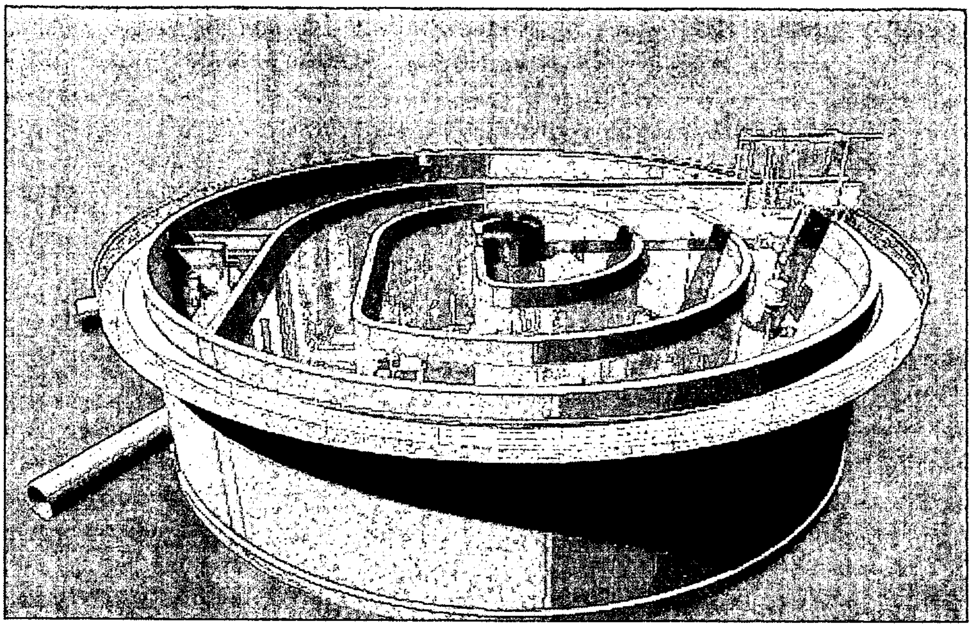

Figure 1 Special plug flow reactor on the WWTP of the Wastewater Association Obere Iller

Description of the sewer system

The system, mainly a combined sewer system, consists of 150 km sewer owned by the AOI, 300 km sewer owned by the communities, 33 stormwater storage tanks and 10 pumping stations. This system drains off the wastewater and the rainwater of an area of 56 km². A scheme of the system is presented in figure 2.

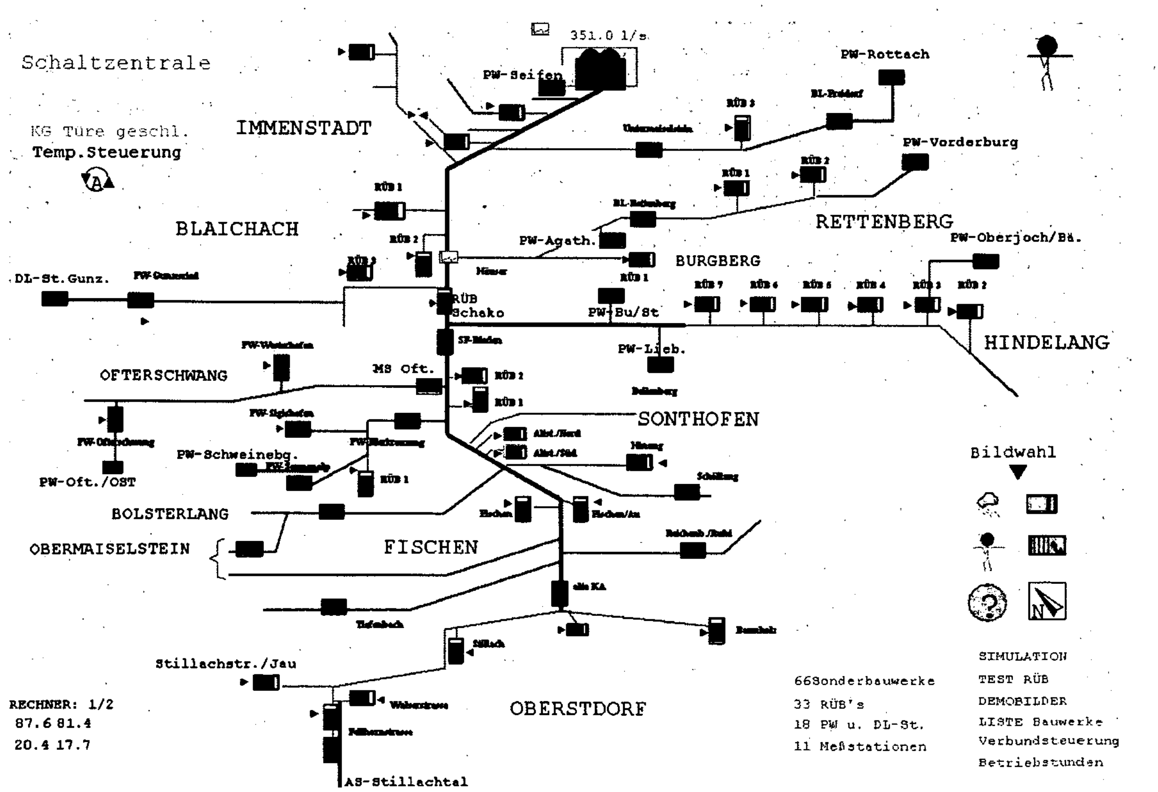

Figure 2 Sewer system with stormwater tanks, main sewers and the treatment plant

REAL TIME CONTROL OF THE SEWAGE PLANT

The system

In the frame of the described project the sewage plant is provided with RTC. There are control units, e.g. aeration units or pumps, and measurement units, e.g. for the water level, the flow and the concentration, which were managed by the control system.

The load of a WWTP depends on a variable wastewater quantity and composition. An operating method without consideration of the dynamic load leads to temporary capacity overload or derating. To use the total capacity of a WWTP becomes more and more important considering the aspects mentioned above. Aeration and pumping rates have to be adapted to the dynamics of the wastewater composition and energy cost.

Furthermore there are a lot of conditions to be fulfilled to ensure a stable operation i.e. a fixed dry-solid content in the aeration tank on the one hand and to keep effluent standards on the other hand. Considering all these requirements it is no longer possible to find out the most cost-effective operation by manual control only. An overall optimisation of the operating method of a WWTP will be necessary.

The online simulation model

The simulation model is based on the Activated Sludge Model No. 2d, ASM2d (Henze et. al., 1999). There are 100 input signals describing flow rate and composition of the incoming wastewater as well as parameters of the current operation on the WWTP like excess sludge rate. These signals are coming from online measurement on the WWTP. The simulation keeps starting new runs based on the latest values every 15 minutes. That way 1000 output signals are created, representing the actual state of the WWTP. The finally achieved state is the basis for the calculations of the optimisation tool. Furthermore the simulation offers parameters in real time that can not be determined by measurement, e.g. the sludge age or the degree of degradation of each tank. The model updates itself by comparing the fixed dry-solid content of the aeration tank in the simulation with measured values.

The first version of the online-simulation-model was launched one year ago. During this time the simulation-results were in good conformance with measured values. Nevertheless it is still necessary to evaluate manually the simulation results and to update various settings in the simulation model for example growth of biomass, to adapt the model to reality.

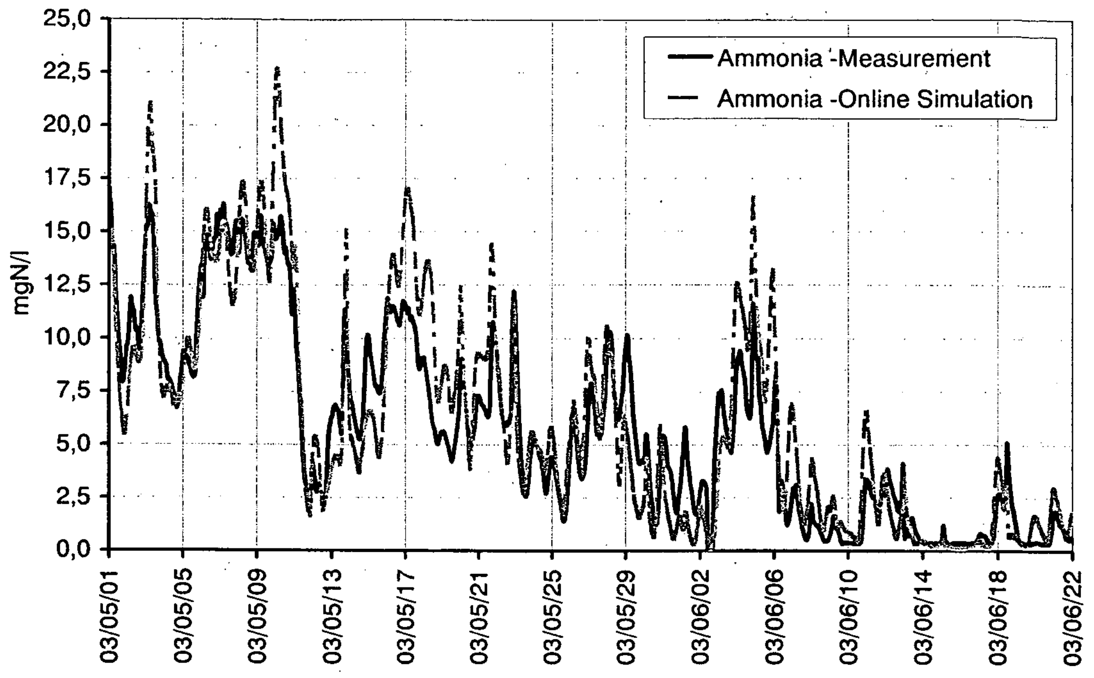

Figure 3 Results from the Online simulation compared with measured values of one month (ammonium nitrogen concentration in the effluent, 2 h time interval)

The optimisation tool

The optimisation tool is based on the online simulation model. With the latest state of the WWTP created by the online simulation the optimisation tool calculates the most cost-effective way of operation in an iterative procedure. The objectives of the optimisation are incorporated in a cost function. These objectives are

1.) Selected "optimiseable" variables, for example pumping rates
2.) Conditions that have to be fulfilled, first of all effluent standards

Every control object of the cost function has a special weight depending on its importance and effects. The minimum of the cost function has to be determined. This is done by changing selected "optimiseable" variables within an admissible range.

If necessary further control objects can be added, e.g. to limit the deviation from the desired concentration of total suspended solids in the aeration tank. Also further changeable variables like the ones in Figure 4 can be added as requested.
To calculate and propose the optimised values the quantity and composition of the influent has to be forecasted for one day. This is done by taking into account the forecast of the flow rate from the sewer system simulation and by using typical time variations in the course of a day for the most important wastewater ingredients.

Control objects with special weights in the cost function:		Selected variables to be changed in the optimisation process to find the optimum of the cost function:
Exceeding thresholds values	**Optimisation tool**	Rate of air introduced into each of the five elements of the aeration tanks
		Flow of internal recirculation
		Flow of return sludge

Figure 4 Changed "optimiseable" variables and control objects of the optimisation process

Example for a sewage treatment plant optimisation

The optimisation tool has been examined offline using real data input from the WWTP. In a first step the influence of all weighting factors shown in Figure 4 has been tested. It could be seen, that these weighting factors are all very sensitive and allow to adjust the optimisation tool precisely. The following figure exemplarily shows results from test runs with influent data from different days. For each day the curve of the reached maximal effluent value is shown by different costs for exceeding the effluent standard of 13 mg/l. It can be seen, how these costs control the optimisation results.

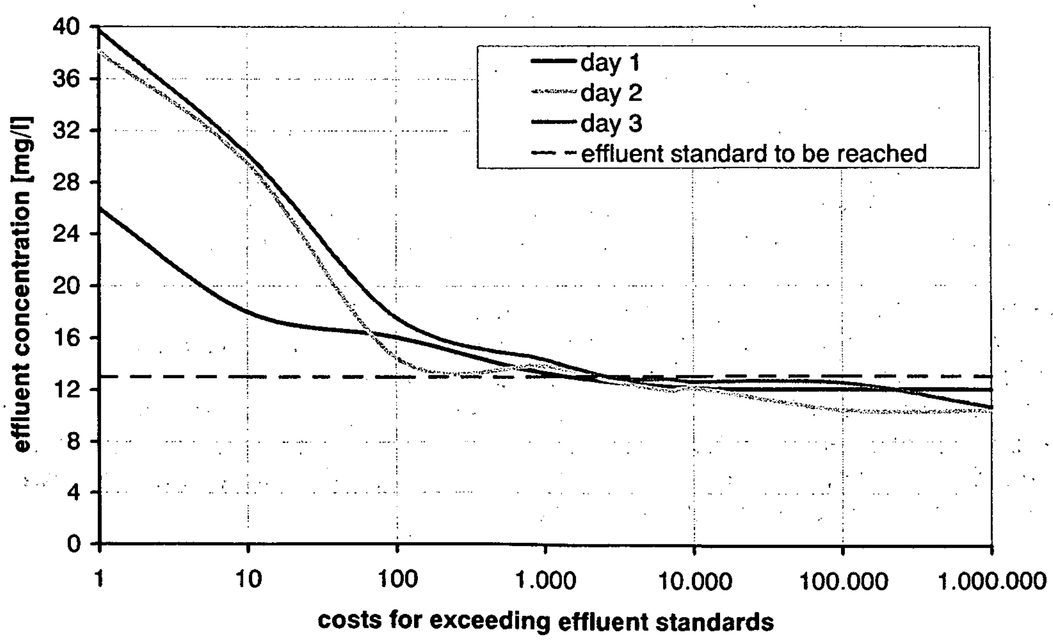

Figure 5 Maximal effluent ammonium nitrogen concentration by different costs for exceeding the effluent standard

In a second step of the offline test stage, the costs that can be saved with the optimisation were tried to evaluate. A precise statement cannot be given until the optimisation has been operating in real time over a longer period. First results can be given concerning the aeration rate, that has to be introduced into the aeration tanks. The optimised air rate is up to 20 percent lower compared to the operation without optimisation.

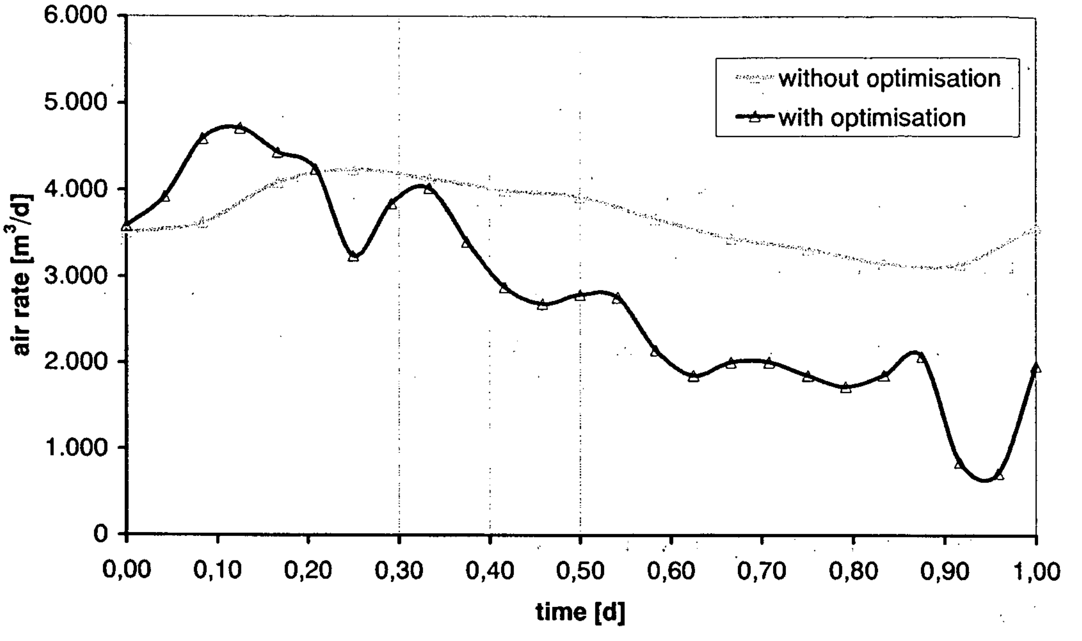

Figure 6 Air rate to be introduced into the aeration tanks with and without optimisation, test run with input data from one day in November 2003

Databank

A special computerized databank provides a basis for all mentioned applications. All data from online measurements on the WWTP are first accumulated at the process control system of the plant and then transferred to the databank. The databank stores and handles all values and provides the simulation model with all necessary inputs in real time. Furthermore the databank offers special functions:

- Data validation
- The real time calculation of parameters, that can not be measured, particularly specific components of the influent that are necessary for the ASM 2d
- Preparation of replacement values in order to provide the simulation model with data in case of failure of a measuring instrument

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All simulation results are also stored in the databank, which at last connects the online simulation with the optimisation tool. The results of the optimisation are also stored in the databank and transmitted into the operation process of the WWTP.

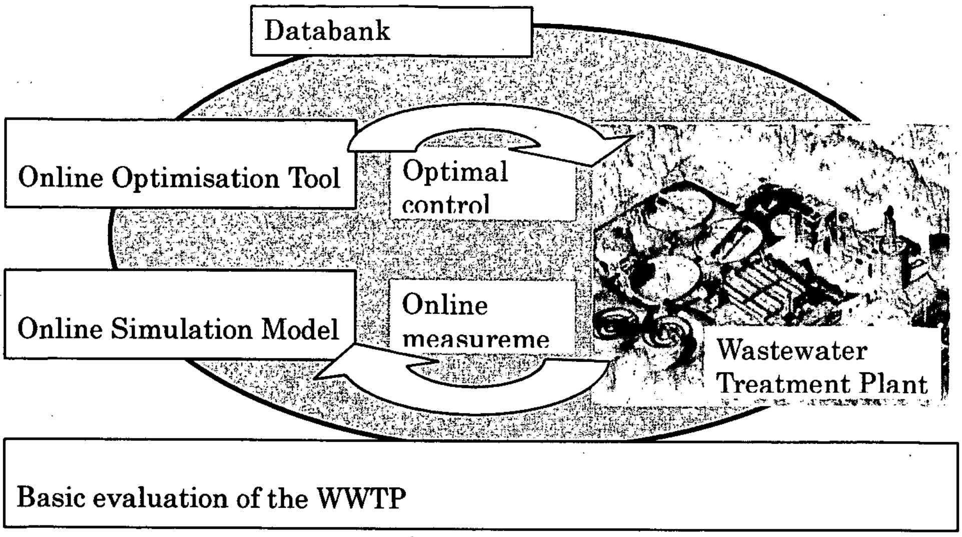

Figure 7 Cooperation of all tools of the real time control of the sewage treatment plant

REAL TIME CONTROL OF THE SEWER SYSTEM

The system

In the sewer system regulating gate valves and measurement stations for the water level and the flow are installed. All values, e.g. the opening degree of the slides, the flow and water level, are managed at the process control system. All important gate valves can be moved by it from the control room.

Online optimisation

During rainfall a simulation software calculates the hydraulic processes at the surface and in the sewer synchronously to the operation of the sewer system. Based on the rainfall data from the rain gauges a surface and sewer system simulation determines the future values of the influent into the stormwater tanks every five minutes. The simulation is faster than real time, that means that the states were forecasted.

The forecasted values as well as the measured values are basic data for the optimisation software. The optimisation tool calculates the set points for the gate valves with the objective to find the best settings for the actual state of the system. With the help of the process control system these calculated states were transmitted to the local regulation units. The simulation and optimisation system is presented in figure 8.

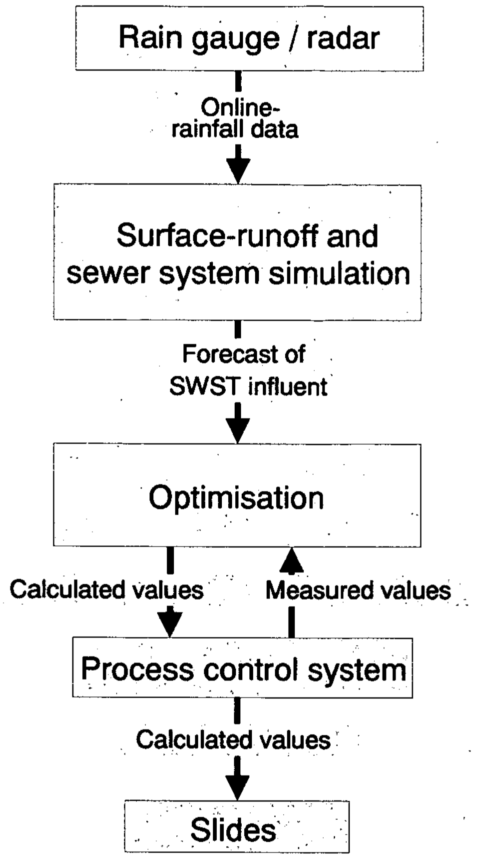

Figure 8 Optimisation of the sewer system

The systems are based on RTC. A RTC strategy has the following advantages:

- High degree of effectiveness due to individual treatment of every single rainfall
- Flexibility concerning the changes of control objectives
- Flexibility concerning the integration of further system parts
- Good transferability to other systems
- Consideration of failure (e.g. of a single gate valve)

The objectives of the optimisation are incorporated in a cost function. Every element of this function has a special weight depending on its importance and effects. For the optimisation the minimum of this cost function has to be determined. Control objectives are:

- Minimising the discharge volume in the receiving water
- Prevention of flooding
- Prevention of abrupt and continuously variations of the set points
- Uniform filling degree of all stormwater tanks

Example for a sewer system optimisation

To get an impression of the effects of the RTC in the sewer system a result of a simulation with and without RTC is presented in figure 9.

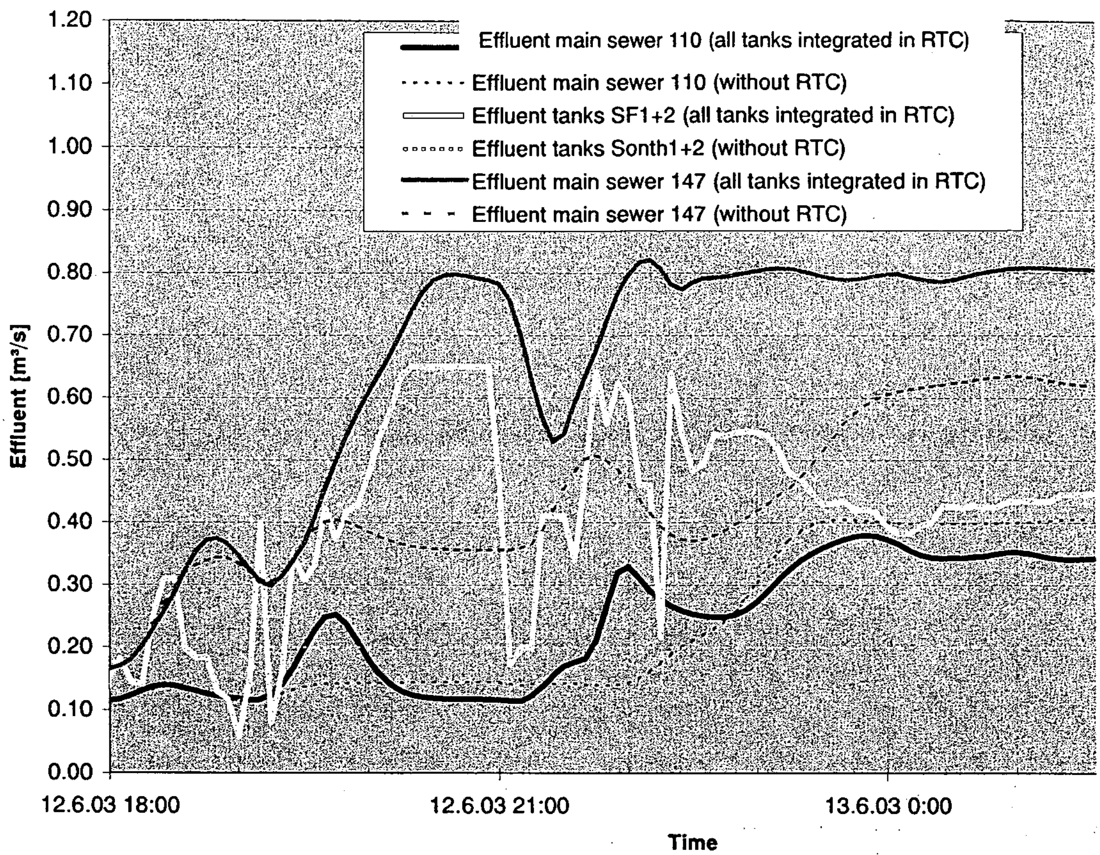

Figure 9 Effluent at different places of the sewer system with and without RTC

In figure 9 the effluents of three different places in the sewer system are shown. The two curves on the bottom show the effluent in the main sewer before the discharge of the effluent of the two stormwater tanks Sonth1 and Sonth2. The curve on the top shows the effluent after the discharge of the tanks. In all cases the thick lines are the result of the simulation with Real Time Control. The dashed lines are the result of the simulation without RTC. With RTC the effluent to the WWTP at main sewer 147 (including the effluent from main sewer 110 and the tanks Sonth 1 and Sonth 2) is higher than without RTC. This leads to a higher impact of the WWTP, that is capable to deal with this effluent in a acceptable way, and to a reduction of the discharge of the tanks into the receiving water. In this case the reduction of all tanks upside the point main sewer 147 is about half of the total discharge. With integration of RTC 3470 m³ were discharged in the receiving water, without RTC 6887 m³. Of course this result is only valid for this specific rain. In other cases the reduction can be lower.

REAL TIME CONTROL OF THE ENTIRE SYSTEM

The optimisation system for the entire system, the sewer system and the sewage plant, is presented in figure 10. Concerning the control objectives of this entire system you have to be aware that some control objectives of the pure sewer system or treatment plant control are contradictory. For example, the consequence of the control objective minimising the discharge volume consists in an increased flow to the treatment plant. But it could be possible, that the treatment plant has no capacity at this moment. In this case it is necessary to prioritise the objectives. The duty of the optimisation tool is to balance out all the objectives regarding to an optimum operation of the sewer system.

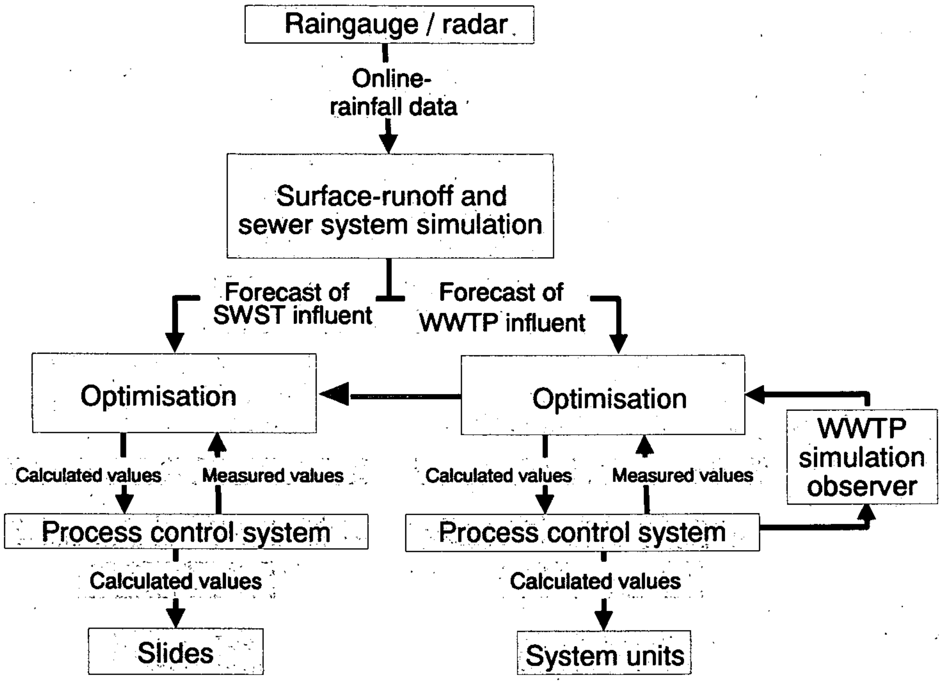

Figure 10 Scheme of the entire optimisation system

One aspect concerning the RTC of the entire system, sewage treatment plant and sewer system, is the hydraulic capacity of the sewage treatment plant. The hydraulic capacity depends on the hydraulic capacity of the secondary settlement tank, that is depending on the characteristics of the sludge. The maximum acceptable flow into the sewage treatment plant is calculated with an equation containing the sludge volume value. The actual value from the sewage treatment plant is available in the databank. This value is used to calculate the maximum flow into the WWTP. This maximum value is considered in the sewer system optimisation.

Another aspect concerning the RTC of the entire system is the calculation of the proposed flow into the WWTP in the case of rain. This forecast enables a good adjustment of the pumps and aeration units with view to low emission values despite of the disadvantages of rainfall, e.g. a hydraulic peak. The data exchange is carried out with the help of the database. The forecast is calculated with the simulation tool of the sewer system. The results were transmitted to the database. The optimisation tool of the sewage treatment plant access this values from the database and uses them for the next optimisation process of the WWTP.

STATE OF THE PROJECT UND PERSPECTIVES

The hard- and software components for the simulation and optimisation of the real time control system of the sewer system are already implemented. Some areas are already included in the controlled system. The other areas were tested offline and included in the online-system step by step. The hardware for the sewage plant optimisation is implemented. The software is tested offline at the moment. Then it will be integrated in the system. After both parts, the real time control system of the sewer system and that of the sewage plant, are working well, they were linked with each other.
Financial investigations would show the reduction of the operational and building costs effected by the online optimisation.

As the optimisation tool is a rather open system nearly all system elements and aspects can be integrated by adding to the cost function. The variation of the weight of the different elements of the cost function enables the consideration of the different aspects more or less.

The online optimisation tools allow the best and most cost effective operation. For the design and planning offline optimisation tools are used. Therewith e.g. it is possible to define the available capacity of an existing WWTP or sewer system and to detect those variables which can be optimised.

ACKNOWLEDGEMENT

The realisation of the projects is enabled by support of the German Federal Ministry of Education, Science Research and Technology. With this financial help it was possible to examine and develop the control strategy and to put the theories into practise, in spite of the financial risk of the development and realisation of a new technology putting into practise the first time. Moreover such a project can not be handled well without the help and engagement of all participants, the operators, i.e. the team of the Wastewater Association Obere Iller, and the members of the planning and management teams.

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