# COMPUTER SIMULATION AS A TOOL FOR LIMITING THE IMPACT OF WASTEWATER SYSTEM ON ENVIRONMENT

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**Abstract:** The paper presents potential benefits that may result from application of the integrated control of wastewater systems. Such control is applied to the whole wastewater system including the sewage network with all its components, the wastewater treatment plant, and the receiving water body, and it considers all important interactions and processes that occur in the system. Integrated real time control of such systems allows for their optimization with an ultimate goal to reduce the adverse effects of wastewater discharges to the environment. Such systems are based on computer simulations and on-line monitoring, and they may become a feasible alternative to conventional approach where the subsystems are controlled only locally in separation from the others. The areas of potential applications of integrated control in wastewater systems are illustrated with the examples of such systems developed in last several years.

**Keywords:** wastewater system; integrated control; computer simulation; pollution reduction.

## INTRODUCTION

The urban wastewater system with all its technical components including sewers, combined sewer overflows (CSOs), retention tanks, pumping stations, and wastewater treatment plants (WWTP) is a very complex system. The way the system is organized and operated directly affects the quality of receiving water body, where the storm water and wastewater are discharged to. Unfortunately, such systems usually are left without any integrated active control. In most situations controlled is only the operation of WWTP while other components of the system are left without any control or they are controlled only locally with passive methods that require minimum outside intervention. Moreover, all the components are often considered in isolation from each other, e.g. operation of the WWTP does not affect the operational decisions made for the sewage system, and the variations in quality of receiving water body does not affect directly the operation of the WWTP.

For the last several years more holistic approach to control of wastewater system has been evolving. A number of research projects concentrate on development of tools that would allow for integrated control of the whole wastewater system, with all its components, processes, and interactions. The focus is especially on new tools for real time control of wastewater systems. The results already presented in literature show that such control systems based on dynamic computer simulations supplied with on-line information about the state of the systems are far more effective in protecting natural waters than the conventional control approach. It must be mentioned here that whilst it is reasonable and technically feasible no integrally controlled urban wastewater system yet exists in practice (*Butler et al., 2005*).

## THE CONCEPT OF INTEGRATED CONTROL

The urban wastewater system should be perceived as a single complex system composing of a number of subsystems that dynamically interact with each other as it is shown in Fig. 1. The receiving water body always must be considered an important and coherent part of such system. The efficiency of wastewater system should always be evaluated on the basis of minimization of pollution load supplied to the environment with an ultimate goal to limit the deterioration of biological and physical-chemical quality of the receiving water body. For this purpose an integrated control of urban wastewater system based on computer simulation can be used. In such systems controlled are all important components (subsystems) and the interactions among them respecting vital processes that occur within the system.

The notion of "integration" needs to be defined and explained. *Shützе et al. (1999)* identifies two features that characterize integrated control systems:

- *integration of objectives*, where control objectives within one subsystem are based on criteria measured in other subsystems
- *integration of information*, where control decision that is taken in one subsystem may be based on information about the state of other subsystems.

Integrated control may be carried on as "on-line" or "off-line" procedures. Off-line control utilizes pre-defined algorithms and simulation tools that determine the reaction to different states of the system. Such control is relatively simpler, clear in its decision making process, and in some situations may prove very effective. On-line control is significantly more complicated. It requires more detailed dynamic characteristic of the system increasing the demand for on-line data and therefore the expansion of the on-line monitoring system. It also uses more computational power, what sometimes may require the simplification of the system's description. All that may impair practical applicability of on-line control in some specific situations (*Butler et al., 2005*).

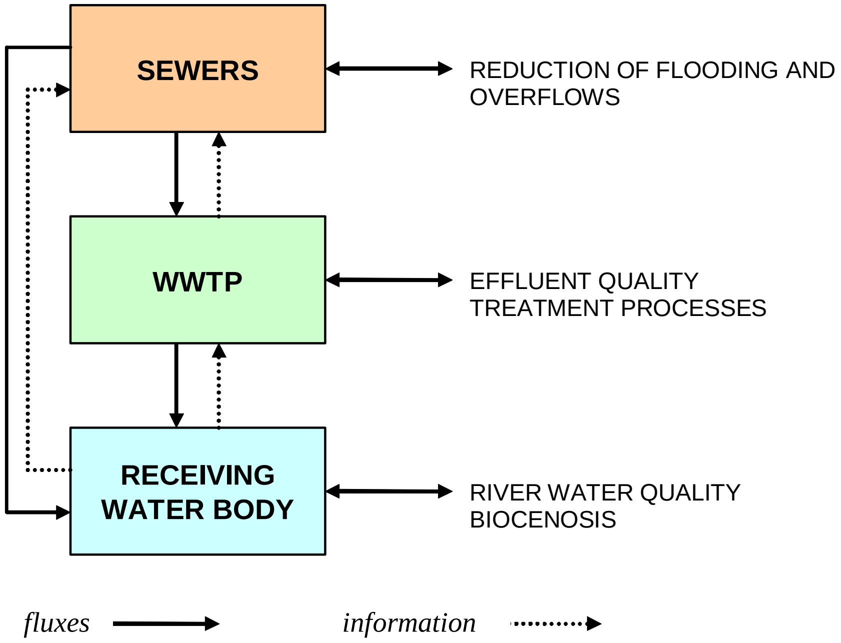

**Figure 1.** Structure of interaction within urban wastewater system (after *Shütze et al., 2003*).

## MODELING THE INTEGRATED WASTEWATER SYSTEMS

There are different attitudes that can be used for integrated modeling: the sequential or the simultaneous approach. In sequential approach the models are run one after the other, and the information "flows" in one direction only: from the model that has finished the calculations top the model that is about to start the calculations. In simultaneous approach all the models are run at the same time and the information from a model can be used "upstream" for feedback control. In both situations some information are supplied from outside the model (sensors, data entry, operator's intervention, etc.). Simultaneous simulation requires more data and more computational power, but it allows for real-time control (RTC) of the system. The used approach directly determines the software implementation of the integrated model.

For sequential simulation often separate models are used for modeling of the sewage system, the WWTP, and the receiving water body (river). If simultaneous simulation is needed, a coordinating program is necessary to integrate the mathematical models of each of the subsystems into a single coherent model of the whole system. This may create a number of problems. Firstly, the component models must communicate with each other using the same state variables and parameters. For example, some sewers models (Mousetrap, Hydroworks) and river models (ISIS, MIKE11) characterize organic matter on basis of BOD, while most of WWTP models use COD for this purpose. The exact relationship between the two is not constant and not easy to determine and this makes a model integration complicated (*Meirlaen, 2002*). Secondly, the models must consider all important processes that may affect operation of other subsystems (models). This means that system's boundaries should be possible broad, what may require supply of large amount of date to the model. At the same time the models should be kept relatively simple and clear, and the simulations can not be too time-consuming. These contradictory requirements make that models often must be reduced and/or surrogate mechanistic models must be used for integrated wastewater system modeling.

**Table 1**. Some software packages used for integrated modeling of wastewater systems (after *Rauch et al., 2002*)

| Name of simulator | SYNOPSIS | ICS | SIMBA | WEST |
|---|---|---|---|---|
| Developer | Imperial College, London, UK | DHI, Hørsholm, DK,<br>WRc, Swindon, UK | Ifak, Barleben, G. | Ghent University, B.<br>Hemmis n.v., Kortrijk, B. |
| Two-directional interaction between submodels | No | Yes | Yes | Yes |
| Truly synchronized simulation | Only sewer system and WWTP | Yes | Yes | Yes |
| Simulation of control options possible | Only sewer system and WWTP | Under development | Yes | Yes |
| Simulation of long time series feasible | Yes | Under development | Under development | Yes |
| Open simulation environment | No | No | Yes | Yes |
| Integrated use at a real case study reported | Semi-hypothetical | Yes | Yes | Semi-hypothetical |

In order to avoid or at least to minimize the above mentioned problems sometimes specialized simulation platforms (e.g. SIMBA based on MATLAB/SIMULINK) are used to define a complete model of the whole wastewater treatment system. Such software platforms allow for definition of a complete model of the whole wastewater system with maintaining consistency in using the same state variables and parameters throughout the whole model. There are a number of examples of integrated control and simulation tools developed in different research centers for various purposes. Some of them are briefly presented further in this paper.

## CONTROL STRATEGIES

Appropriate control strategies are essential for good performance of a wastewater system. On-line control may be applied either only to a specific part of the wastewater system (sewers, CSOs, tanks, treatment plants) or it can be applied to the whole system in form of an integrated control. The control can be carried on as volume-based, pollution-based, and immission-based procedure.

- *Volume-based control* attempts to minimize the volume of polluted water (wastewater, storm water) entering the receiving water body by appropriate storage and/or treatment.
- *Pollution-based control* attempts to minimize the total amount of pollutants discharged to the water body by storing it and diluting.
- *Immission-based control* tries to optimize the receiving water body directly through a system of sensors located in water body that control the operation of pumps, weirs, and treatment plants.

Among the possible control strategy options the immission-based control seems the most adequate for the integrated RTC systems as it takes resulting river water quality directly into account. When performing simultaneous simulations of the three subsystems (sewers, WWTP, river) the current and predicted state of the river directly determines the control actions in sewer subsystem and/or at WWTP. Volume-based and pollution-based control options are more suitable for sequential simulations and off-line control system.

Control strategies usually use algorithms with a set of if-then rules that describe the behaviour of the complete system. Thus it is essential to find an optimized set of rules for a given system and for given conditions. As the on-line control can be used under different weather conditions, different strategies and rules must be used for wet and dry weather situations (*Vanrolleghem et al., 2005*). According to *Butler et al.(2005)* optimization of the control system is usually performed in two stages. Firstly, the framework of rules has to be set up that specify which control device is to be operated in dependence of which sensor. Secondly, numerical values must be assigned to the parameters in theses rules. Quantification of the parameters can be performed by trial-and-error procedure or by classical optimization methods where an objective function must be represented by an integrated model of the system. The both described stages are essential for development of a well-performing control algorithm.

The possible control actions for each subsystem depend on subsystem characteristics. For the sewer subsystem usually they are limited to use flow regulators i.e. gates, slide valves, weirs, and pumps. This allows attaining the desired flow rates in specific sewers. Specifically, the control system makes decisions based on information from water level sensors, flow meters up- and downstream, residence times and stored volumes of water in tanks, and forecasted rainfall and flow rates (*Meirlaen, 2002*). The possible control actions for the receiving water body are very narrow too. It is practically limited to the control of in-river flow upstream of wastewater discharge and to the control of discharges from WWTPs and CSOs. In some situations artificial re-aeration of water may be considered as an option. The most control options are available for the WWTP as this is the most technologically advanced and controllable part of the wastewater system. The possible control actions at the WWTP are typical and well known and they are only schematically presented in Fig. 2.

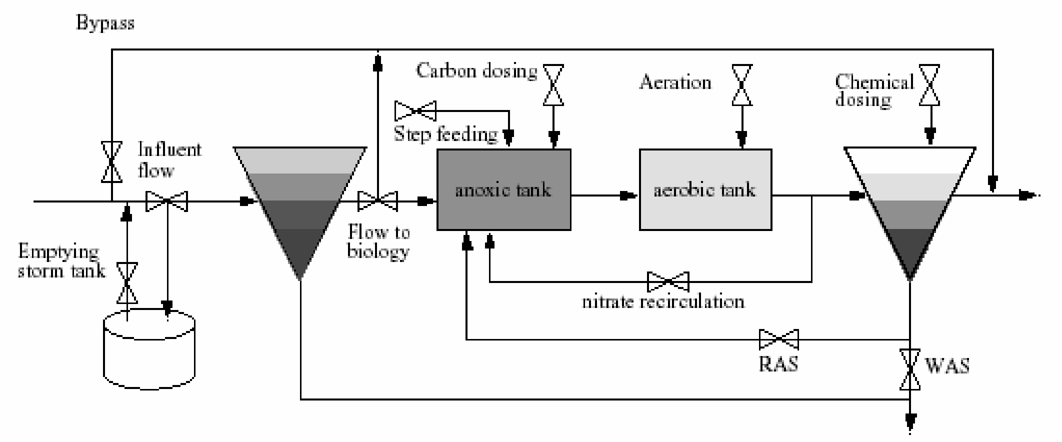

**Figure 2.** Typical control actions performed at the WWTP ((*Meirlaen, 2002*).

## EXAMPLES

There are a number of examples of integrated simulation tools that have been developed in the last several years to study different control strategies. Three of them are briefly presented in this paper to illustrate how simulation of integrated wastewater system may help in reducing the adverse effects of wastewater discharge. Other examples can be easily found in the literature.

### Odenthal wastewater system

An integrated model was set up by *Erbe and Risholt (2000)* with use of SIMBA software to optimize the performance of the wastewater system. The system includes sewers, water retention tanks, CSO, two-stage activated sludge WWTP, and river Dhuenn as a receiving water body. Qualitative transformations of pollutants in sewers and at the WWTP are described with ASM1-like models. The river was modeled with RWQM1 model. General scheme of the model is presented in Fig. 3.

Simulations performed with the model of the Odenthal wastewater system with different RTC strategies helped to find the most effective way of operation of the system. It appeared that it is most effective to increase the combined wastewater load to the WWTP based on the continuously estimated nitrification capacity in combination with controlling the operation of the largest combined-water retention tank in the sewer system (*Schütze et al, 2003*).

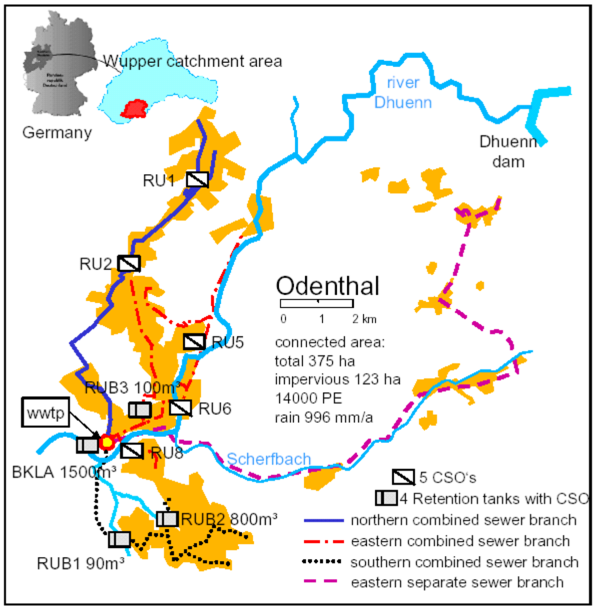

**Figure 3.** Scheme of the Odenthal wastewater system (*Shütze et al., 2003*).

Model-based predictive control at Hildesheim WWTP

The main objective of the project presented by *Seggelke and Rosenvinkel (2000)* was to use on-line model-based control to optimize the use of the Hildesheim WWTP capacity during storm events. This was done by increasing wet weather flow to the plant above the design value (double peak dry weather flow) and installing a monitoring system based on adaptive prediction. This allowed for setting an optimal control strategy for a specific event and maximization of inflow to the plant. The model of the wastewater system was based on ASM2d model for the WWTP and KOSIM model for the sewers. The scheme of the system is presented in Fig. 4.

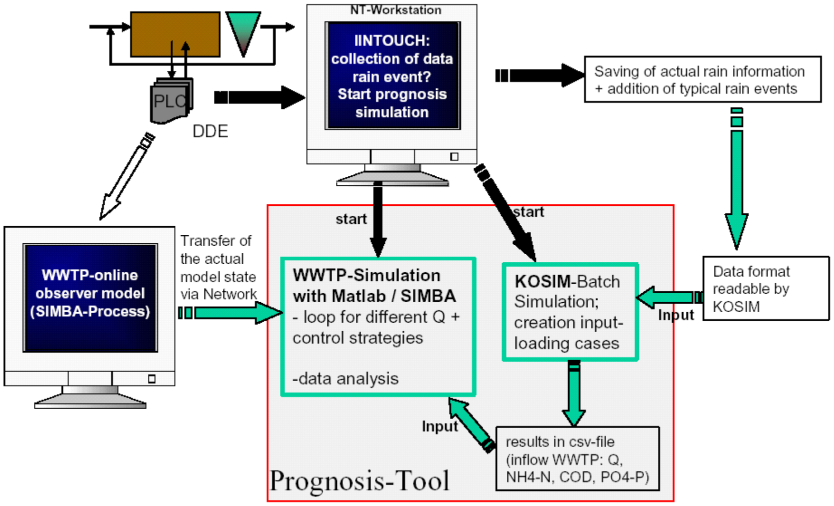

**Figure 4.** System of on-line prediction applied for the Hildesheim WWTP (*Shütze et al., 2003*).

The input data to the control system are form KOSIM sewer model and from observer model (state of biological processes). In the output there is continuously predicted effluent quality from the WWTP for various loading scenarios. This allows to determine maximum allowable inflow to the plant and to choose optimal control strategy.

SYNOPSIS

An integrated simulation tool for control of wastewater systems has been presented by *Schütze et al.* in 1999 . The software called SYNOPSIS allows simulation of long-term water quantity and quality processes in the sewers, the WWTP, and the river, including the interactions between these subsystems, and the analysis and optimization of real-time control strategies. Sewer subsystem is modeled with KOSIM package with no biochemical transformations, WWTP model was based on calibrated and validated simplified ASM1, and river water quantity and quality was modeled with DUFLOW shell program (*Butler et al., 2005*). The model was complemented with control and optimization modules. The general structure of the model is shown in Fig. 5.

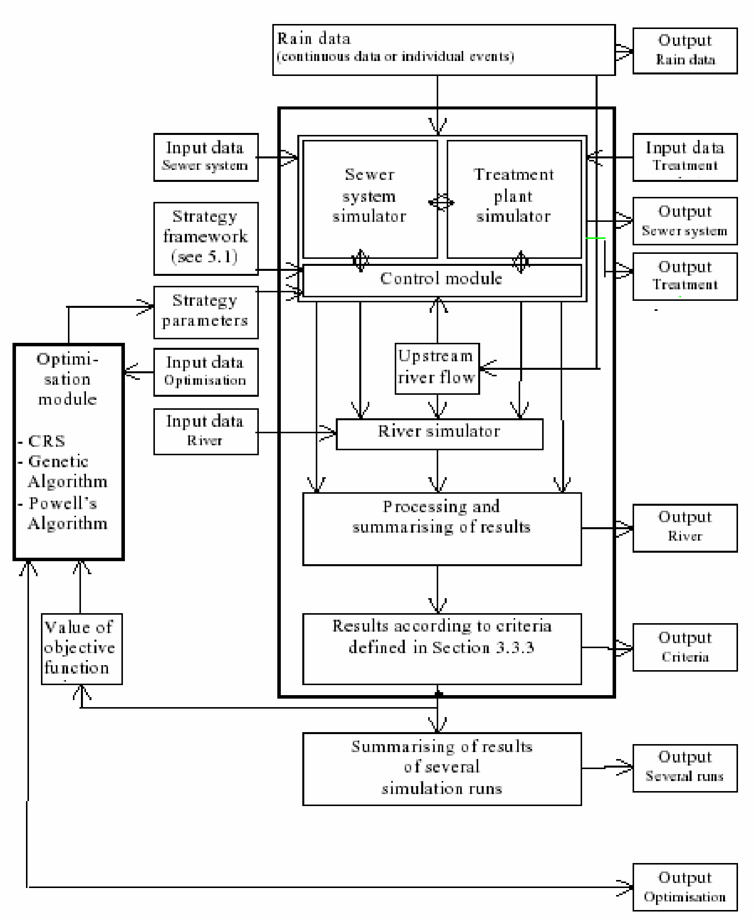

**Figure 5.** Structure of SYNOPSIS integrated simulation tool (*Butler et al., 2005*).

The program was used by authors to test and compare different control strategies for a semi-hypothetical case studies including (i) a sewer system adapted from a literature example; (ii) a real WWTP (Norwich, UK), and (iii) a hypothetical river. The results showed that application of integrated RTC control leads to significant improvement (over 80% under DO criterion) in the wastewater system performance as compared to local RTC system. More detail description of the study is presented in reference literature (*Butler et al., 2005*).

## CONCLUSIONS

Usually the components of a wastewater system have been considered almost in isolation from each other as it regards their control and operation. In recent years more attention is paid to interactions that occur among these components and gradually a more holistic approach is used for the control of such systems. The integrated control tools that have been developed at different research centers and effectively tested on real-life or semi-hypothetical examples can already be used for optimization of operation of the existing systems and as a planning tool during design of new systems. Various operational scenarios can be simulated and tested against various performance criteria without disruption of operation of the actual system. The set of those criteria when possible should be constructed on the basis of immission of pollution in the receiving water body and water quality states. As the presented examples show the application of integrated RTC in wastewater systems creates the possibility for optimized operation of such systems and ultimately for limiting the adverse effects of wastewater discharge to the environment even with no major capital investment in wastewater infrastructure. The use of the integrated RTC systems is technically and technologically feasible and usually the only barriers to their application are those of mental, formal, and financial nature.

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