Integrating catchment planning and management

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Work at the Swedich city of Helsingborg is bringing closer to everyday reality the prospect of integrated modelling of sewers systems, treatment plants and receiving waters.

Introduction

In most parts of the world, there is fragmented planning and management of the sewer system, the wastewater treatment plant and the receiving waters. Until today there has been a lack of methodology and technology available for the integrated planning and management and finally there is simply a lack of regulatory framework for "Integrated Thinking".

In the City of Helsingborg, Sweden, there has for a long time been a vision for a holistic approach for a joint management of the city's sewer system and the wastewater treatment plant, aiming at a better utilisation of the existing assets. The City of Helsingborg is about to overcome the obstacles, which have long kept them from realising their ambition. The city has now for two years been engaged as a pilot partner in a Technology Validation Project (TVP) "Integrated Wastewater", carried out and EU-sponsored under the Innovation Programme (1997-99). The 3.7 MECU project led by Danish Hydraulic Institute (DK), joins partners from six EU member states.

The aim of the project is to develop and validate through pilot projects implementations a generic integrated modelling tool for a complete urban wastewater system, covering all relevant processes on urban catchment, sewer network, wastewater treatment plant and recipient.

The Helsingborg implementation includes hydrology of the urban catchment, hydrodynamic and water quality aspects in the sewer network and the treatment processes at the WWTP. The project is focused on the interaction between the sewer system and the wastewater treatment plant, because the efficiency of the treatment processes in the plant is highly dependent on the hydraulic loads coming from the sewer network. The simulation tool "Integrated Catchment Simulator"–(ICS) will make it possible to

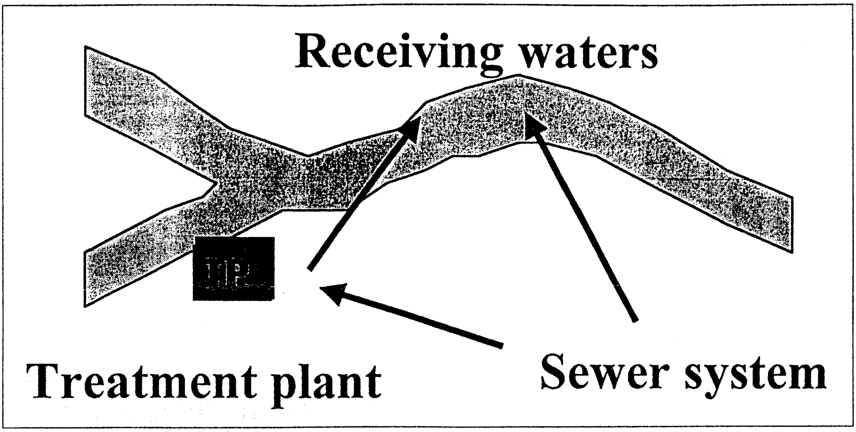

Figure 1-A, The sequential ICS mode

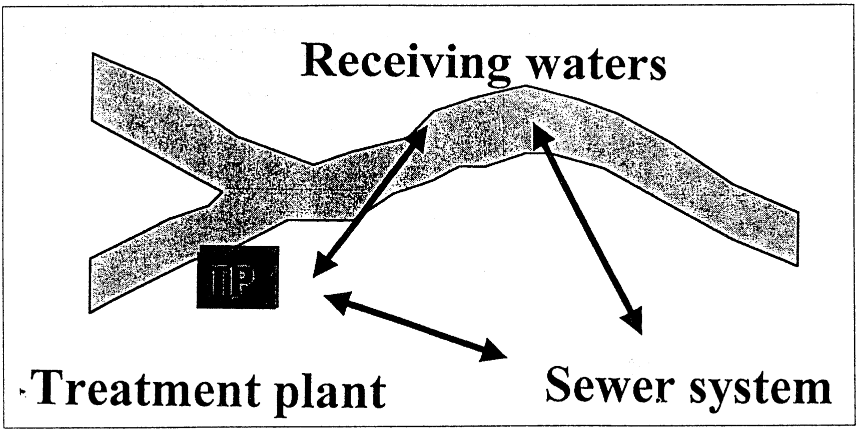

Figure 1-B, The parallel ICS mode

simulate seamlessly the processes in the sewer system and the WWTP, still using the special models for the sewer network and the WWTP, respectively. The models included in ICS will run either in sequence or simultaneously, depending on the type of interaction between the sewer and the WWTP, which has been modelled. The models included in ICS for the integrated analyses are based on MOUSE (Danish Hydraulic Institute, DK) for the sewer system and STOAT (WRc, UK) for the wastewater treatment plant. Prior to integration under ICS, both models were subject to calibration and verification, based on a comprehensive monitoring programme.

The Helsingborg project is carried out as a joint effort between the Muni-

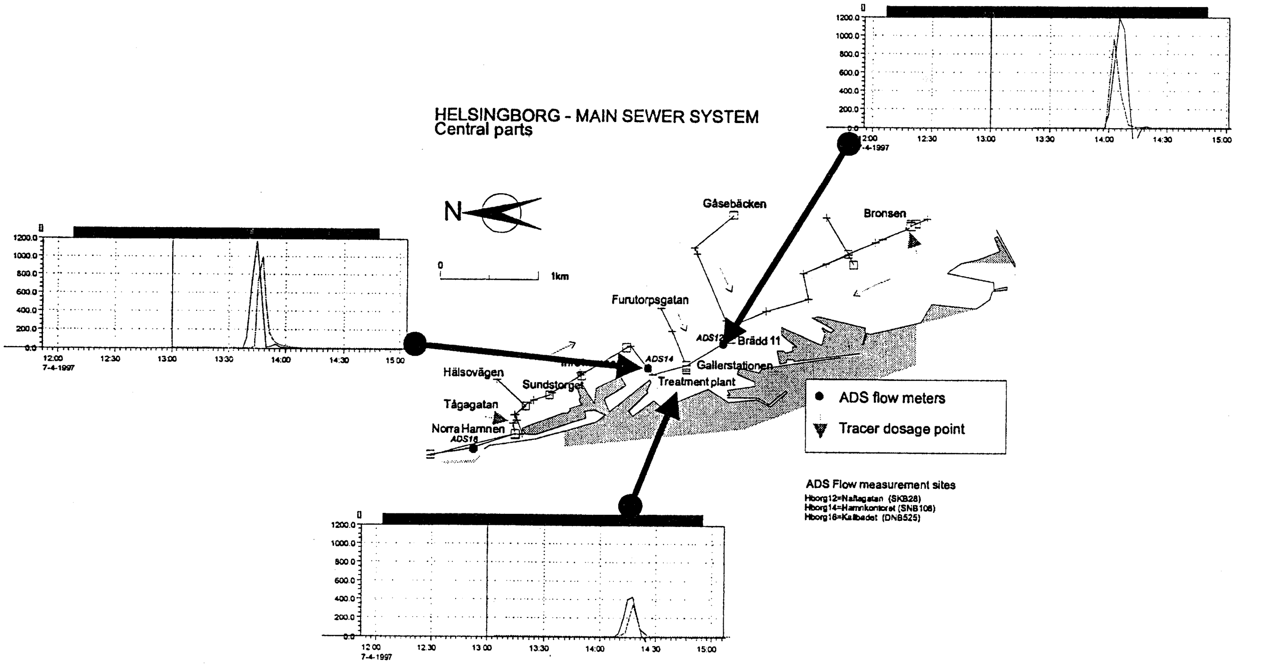

Figure 2 Tracer study. Analysed pulse response (µg/l) compared to MouseTRAP simulation results.

cipality of Helsingborg and its' consultant DHI Sweden, with the participation of, WRc and Danish Hydraulic Institute.

Description of the Helsingborg catchment

The municipality of Helsingborg is located on the South West Coast of Sweden. The sewer system is partly combined, with 330 ha of impervious area connected to the sewers, mainly in the central part of the city. The total catchment area connected to the WWTP Öresundsverket is approximately 50 km^2 and it receives wastewater from about 205 000 PE. The rehabilitation and upgrade measures carried out within the sewer system during the period 1994-99 aim to reduce the yearly combined sewer overflow (CSO) volume from approx. 300 000 m^3 down to 140 000 m^3. The dominant parts of the CSOs are located within the main wastewater interceptor sewer along the coastline.

The WWTP Öresundsverket is designed to a high degree of nutrient removal. Actually, it was the first in Sweden designed and built for biological nitrogen removal. Enhanced biological phosphorus removal has been used in two of the four treatment trains for several years. The effluent quality is further improved by filtration, which is applied as a final treatment stage.

The storage volume of 8000 m3 located at the plant inlet is used for peak flow equalisation. An additional volume of the same magnitude within the sewer system can also be utilised as storage by future implementation of real-time control (RTC) measures.

The Tool: ICS

The technological basis of the project is the "Integrated Catchment Simulator" (ICS), a deterministic simulation system developed by DHI and WRc within the TVP project.

ICS makes the simulations of the interactions between the sewer system, the WWTP and the receiving waters easy to handle and understand. Furthermore, through simultaneous simulations of the three urban sub-systems, ICS extends the capabilities of the modelling analyses available today, making it possible to simulate the back-water feed-back, as well as the RTC applications extending over the whole system. ICS is specifically developed for the integrated modelling application with models built with MOUSE (sewer system), STOAT (WWTP) and MIKE11 (receiving waters). However, the design allows the integration of models based on other similar modelling systems.

The ICS tool is an integration shell for the computational models, which provides an intuitive graphical working environment and automates the communication procedures between the individual models. In the first instance ICS has three empty sockets: one for MOUSE, one for MIKE 11 and one for STOAT. Depending on the type of analysis, MOUSE, MIKE 11 and

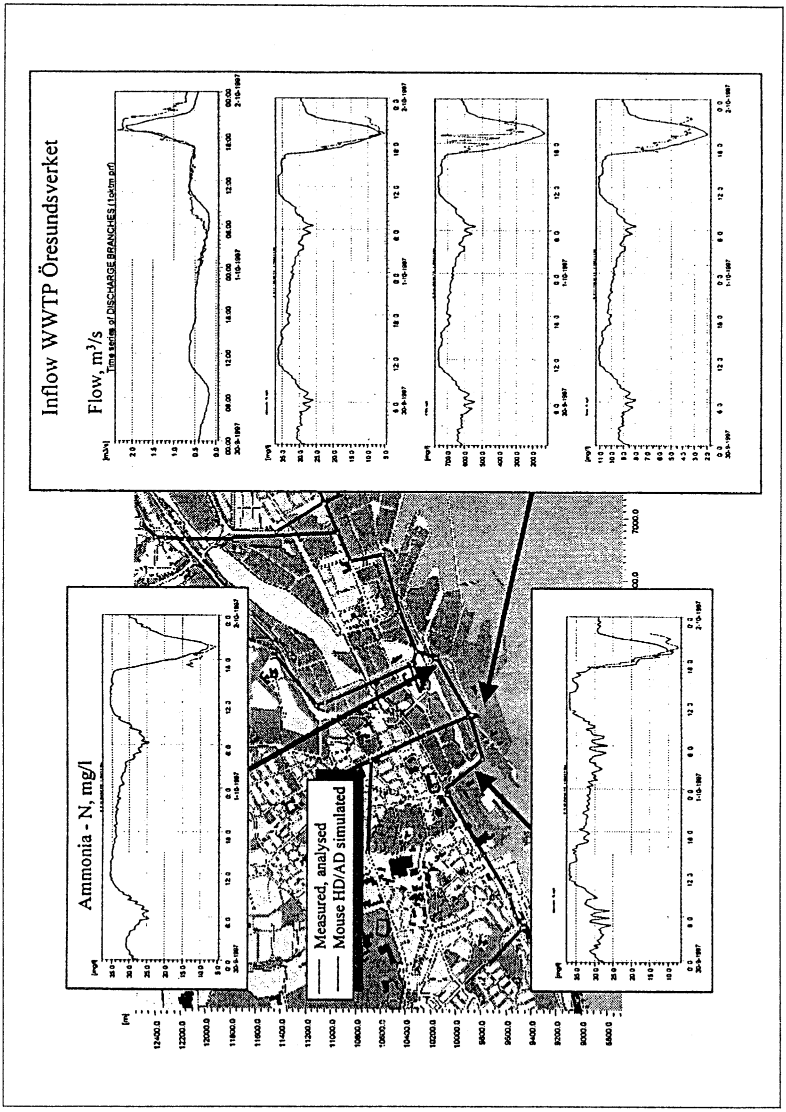

Figure 3 Wet wather sampling. Examples of measured flow and wastewater analyses compared to priliminary MOUSE HD/AD simulation results

STOAT models can be "plugged" into the sockets for the appropriate analyses. For the application in the City of Helsingborg, only the MOUSE and STOAT sockets have been used, since no serious WWTP effluent and CSO-related water quality problems exist within the watercourses in the city.

ICS can run two operational modes. The basic properties and the resulting limitations/advantages of the two modes are:

Sequential simulation:

- The models run in a sequence, i.e. one after the other, following the natural, upstream-to-downstream direction - e.g. first the sewers system, second the WTTP and third the river model.
- Data exchange on the points of interaction is through the result and boundary files
- No "feed-back" is possible between the models. This limits the application of this operational mode to the hydraulically well-bounded sub-systems, with RTC applied only within each model.

Simultaneous (parallel) simulation:

- The models runs simultaneously and exchange data during the simulation. The models included in the simultaneous simulation set-up are controlled by a specially developed control program.
- The data exchange between the models takes place at the "time step level", using special data exchange techniques between the concurrent applications.
- Simultaneous simulation provides the possibility for simulating a back-water inflow into the sewer and the simulation of global Real Time Control across the models, e.g. control of an overflow weir at the inlet to the WWTP as a function of the level of the sludge blanket at the WWTP.

In figure No. 1 the data flow can be seen both for the sequential and the parallel simulation of the urban water cycle. The sequential ICS simulation is especially suited for standard work on the impact on the receiving waters, e.g. according to the UMP procedure in the UK. The parallel ICS simulation is interesting when two of the systems interact in both directions, like a sewer system influenced by back-water from a river or when hydraulic operation of a sewer network is controlled by the operational variables from WWTP.

Methodology

In a broad sense, the goal of the Helsingborg project is to reduce the total pollutant emissions from WWTP and from CSOs by improving the treatment efficiency and reducing the CSO volumes, respectively. This will be achieved through optimising the flow and quality variations of the influent. In order to achieve the programmed goals, the following tasks have been identified:

1. Optimise the WWTP operation by levelling-out the daily flow and concentrations arriving into the WWTP - both based on RTC
2. Ensure that the RTC does not generate sediment deposits in the sewers with negative effects
3. Reduce the flooding and the CSO loading during rain events.

The project is divided into four phases, each constituting an important milestone in the project. The four milestones are:

- Baseline modelling analyses of

sewer system and WWTP – "off-line"
- Introduction of RTC and long term simulations, including RTC based on WQ
- Comparison to traditional approaches
- Establish On-line RTC installation - including forecast

Milestone no. 1 - Baseline modelling of sewer system and WWTP - off-line

At present, a MOUSE TRAP model and a STOAT model have been built and validated.

The STOAT model of the WWTP Öresundsverket includes the complete treatment process. However, the modelling is concentrated on the impact of the flow and quality variations of the influent on the nutrient removal processes, since this is the area where improved joint operation of the system sewer-WWTP may give the most significant results.

For the sewer model, tracer measurements have been carried out and these are used to validate the capability of the MOUSE TRAP to transport conservative dissolved pollutants in the Helsingborg sewer system. The results from the tracer measurement are presented in figure No. 2.

Further, simulations of Ammonia, Phosphorous and COD have been carried out for the sewer system. The input to these simulations consists of the diurnal variation of the dry weather flow concentration together with the industrial loads. The results can be seen in figure No. 3. The most simple simulation is the one for Ammonia, which is considered as a quasi-conservative pollutant, not influenced by the presence of sediment in the sewers. This has resulted in very good results. The results obtained by the simulation of Phosphorous are also good, but the simulated concentrations are always below the measurement, hence there may be scope for improvements. The simulation of COD is not satisfactory yet. This may be due to the fact that at present the total COD is simulated with the same transport mechanism as dissolved pollutants and sediments may contribute as particulate COD in the total COD load. Hence, the water quality model has to be extended in the near future.

Milestone no. 2 - Introduction of RTC and long term simulations, possibly including RTC based on Water Quality parameters

One of the goals of the project is to investigate the applicability of RTC strategies in the sewer network, with purpose of reducing the flooding risk and the CSO volume. Initially, the work has been focused on the formulation of the RTC objectives and the corresponding control strategies. The control objectives are presented in the list below:

- Use the available storage volumes at the treatment plant and in the sewers as much as possible
- Compensate for the increased risk urban flooding by movable weirs
- Maximise the volume of waste-water fully treated at the treatment plant for
- Use the in-line storage partially for flow equalisation
- In increased load situations, divert the excess flow to the incomplete treatment (via treatment plant storage overflow), rather than to CSOs.
- Additional in-line storage volume is used to avoid CSO
- Utilise the pumped CSOs for evacuation of excess flow as far as possible
- At higher (emergency) levels in the sewer system, CSO volumes are discharged over fixed weirs and by lowering the movable weirs.

At present, the RTC strategies are developed and they show the potential for reducing the CSO in the order of 40% for selected rain events. Further evaluation with respect to flooding risk is required. In the future, the RTC strategies may be extended to be based on measurements of water quality parameters in the sewers and at the WWTP. Such RTC based on the WQ parameters may improve the overall performance of the systems, in terms of reduced overall pollution emissions. Simulations with an RTC application including the control point (sensor) at WWTP and the operational point (flow regulator) in the sewer system will require an ICS run in a simultaneous mode.

In figure No. 4 the most important components of the planned RTC system are shown. In figure No. 5 results of a simulation with one of the proposed RTC strategies is shown. The reduction in CSO for the simulated rain event is about 40%.

The final hydraulic evaluation of the selected control strategy will be achieved by means of the statistical analysis of the key operational parameters, obtained by long-term simulations of the system performance over a continuous historical period.

The results of an RTC study like this cannot be approved without considering the sediment deposition, which may be significantly altered by the active use of in-line storage in the sewer network. The MOUSE sediment transport model is used to prove that the proposed RTC strategies will not create a flow pattern, which gives increased sediment deposition at critical locations in the sewer system. Sediment deposits may reduce the hydraulic capacity of sewer systems and in turn, this may cause flooding and increase the volume and the frequency of the combined sewer overflows. Based on the results from the sediment transport model, critical sites in the sewer system have been identified. These simulations point out locations where sediment deposits already exist, but may not have significant influence on the flow and the CSOs. This could e.g. be the case for a pipe with a negative slope (slope in the opposite direction of the flow),

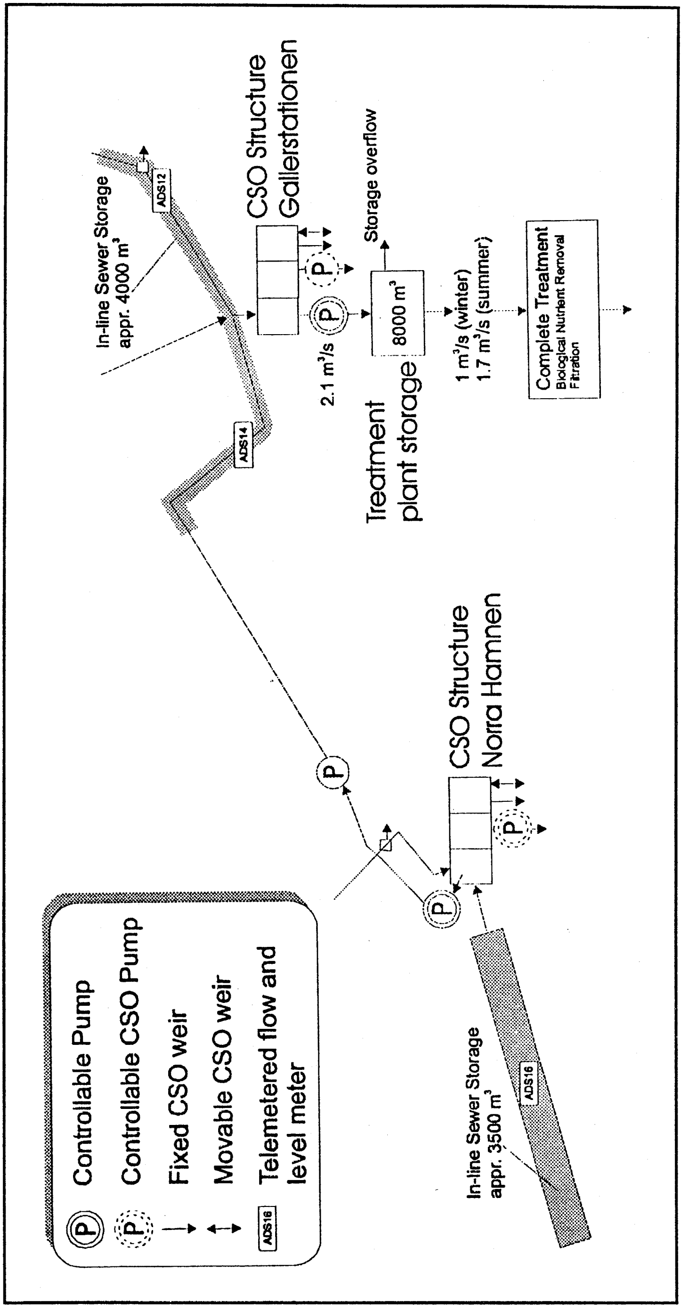

Figure 4 RTC components in Helsingborg sewer system

where local sediment deposits may develop, but these may reach a steady state where they do not influence the flow and the CSO. In order to evaluate the effect of eventual new local sediment deposits the morphological modelling is carried out.

Milestone no. 3 - Comparison to traditional approaches

When the milestone No. 2 has been reached, it will be appropriate to stop and evaluate what has been gained by the use of ICS and at what cost, compared to traditional analyses approaches. It will also be an appropriate time to elaborate in generalised terms on the performance of a combined system constituted by the sewer system and the WWTP.

This is expected to reinforce the concept of "Integrated Thinking" for urban wastewater, providing a significant input to the understanding of the joint operation of the sewers and WWTP.

Milestone no. 4 - Establish On-line RTC installation including forecast

The ultimate goal of the Helsingborg project is to couple the integrated model for the sewer system and WWTP with an existing on-line supervisory and control system. This will be brought about if the previous simulation studies identify the potential for an improved system operation within the existing structural framework.

Then, the sewer and WWTP sensors will feed the models within ICS with real-time information on the actual conditions in various parts of the system, thus allowing continuous harmonisation of the model representation of the system with reality. Such real-time assimilation of the measurement data and the ICS' ability to simulate the wastewater system performance significantly faster than real-time will make accurate near-future forecasts of the conditions in the system possible.

These predictions, generated automatically by the on-line ICS system in a continuous loop, will extend the amount of information on the wastewater system both in space and in time. This additional information will improve the operators' reaction time and the quality of their control decisions in real-time, which will contribute to the achievement of a programmed system performance – a high WWTP effluent quality and a minimised amount of combined sewer overflow.

Future perspectives

The Integrated Catchment Simulator used by engineers in Helsingborg facilitates a quantum leap in modelling studies of urban wastewater systems. These systems traditionally include several very different technical domains presently embodied into difficult, self-standing engineering disciplines. The integrated approach, as demonstrated in Helsingborg, breaks through these, actually artificial barriers. It opens new perspectives for understanding of the

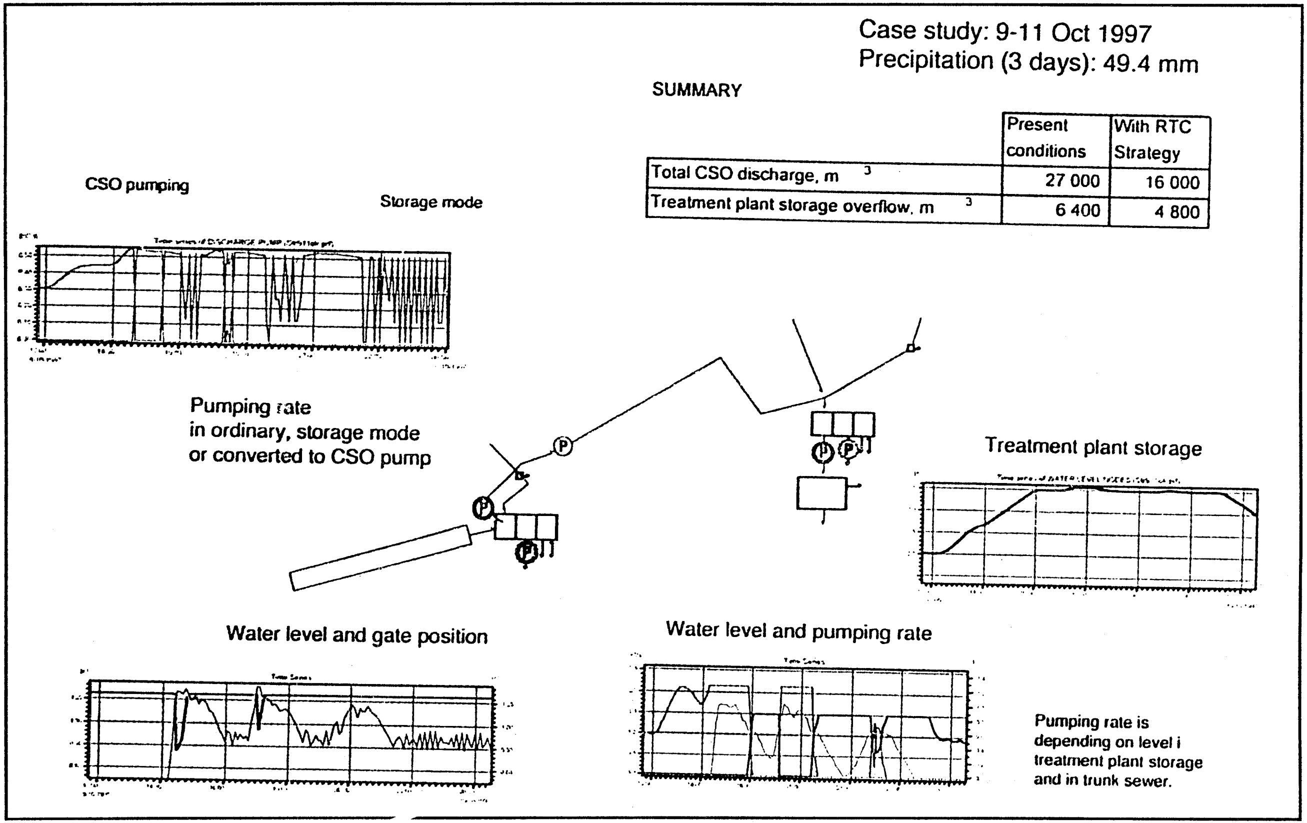

Figure 5 Example of a RTC simulation. Reduction in CSO was 40% for this event

often obscure and complex interactions between the sub-systems, for the benefit of the environment and cost-effectiveness of capital investments, maintenance and daily system operation.

In future, continued development of the integrated simulation system will provide the engineers with a tool capable of simulating any configuration of an urban aquatic system easily and cost-efficiently. This will make it possible that a very accurate planning and consenting process for urban wastewater systems is carried-out on a routine basis, thus introducing a full transparency into the decision process, before the heavy investments are undertaken. This may have an important impact on a successful fight against urban pollution facing the cities worldwide.

Also, a vision of a routine application of the integrated models as a part of the decision loop in a real-time supervision and control improves the chances that the urban wastewater system of the future will better harmonise with the public demands for a cleaner environment.

Engineers from Helsingborg and their partners from the "Integrated Wastewater" are proud of their pioneering contribution to cleaner waters.

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