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GENERAL ASSESSMENT OF POTENTIAL CSO REDUCTION BY MEANS OF REAL TIME CONTROL

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ABSTRACT

A number of case studies have been carried out in which the potential reduction of combined sewer overflows (CSO) by means of real time control (RTC) is assessed for existing sewer systems. It is an inherent problem of case studies that results cannot necessarily be generalized. In this paper results of a systematic investigation of hypothetical combined sewer systems are presented. The systems were characterized in terms of their topological structure, size, type and arrangement of storage and transport elements.

The RTC optimization model LOCUS was applied to simulate the performance of local control and of optimum control strategies. The results are expressed as "CSO reduction achieved by optimum control, compared to the locally controlled system".

General conclusions are drawn with respect to possible CSO reduction for a system with given topology, storage and transport characteristics. Finally, these are compared to some case studies reported in the literature in order to verify and show the general applicability of the findings.

KEYWORDS

Combined sewer overflows; combined sewer systems; controllers; hypothetical sewer systems; local/global control; LOCUS; optimization; real time control.

INTRODUCTION

In the last years many numerical and applied investigations have been carried out with the purpose of characterizing the effect of real time control (RTC) of combined sewer systems (CSS). Most often the intentions have been to estimate how much can be gained from RTC in terms of reduced combined sewer overflow (CSO). The problem with such investigations is that the results cannot necessarily be generalized, since they focus on a specific sewer system.

If it were possible to know in advance which system parameters are important in achieving maximum benefit of optimal control in CSS, it would be easier to determine what types of system would definitely benefit from RTC. Likewise, implementation of RTC in other types of system could be rejected immediately.

In this paper, a systematic investigation of hypothetical CSS with different characteristics will be presented, in order to get an idea of the potential of optimum RTC for different systems.

PROBLEM DEFINITION AND OBJECTIVES

The basic problem of most existing sewer systems is that they are operating statically or under local control and therefore only perform optimally for the design event (rare heavy storms, occurring not more than e.g. once in five years). A consequence of this kind of operation may be observed when overflow or flooding occurs in systems that are only partly at capacity during a storm. A solution to this problem is to implement optimum RTC in the system.

RTC in the most simple form (local control with fixed setpoints at regulators) is already established in many systems. This simple form of RTC operates far from optimally. A better RTC performance is reached by a global control of the entire system, i.e. by optimal variation of setpoints.

The main objectives of this study were to investigate the difference between locally and optimally controlled sewer systems and to quantify the potential in a given CSS if the mode of operation is upgraded from local control to optimal global control. The investigation was carried out by comparing the CSO-volume due to local control with the CSO-volume due to optimal control, using different setups of hypothetical CSS (system parameters in a CSS with typical capacity were changed). Thereby it could be concluded which types of CSS will benefit from upgrading to optimal control, and which system parameters are important.

REAL TIME OPERATION OF SEWER SYSTEMS

Some necessary technical terms are merely named in this paper. The following components are essential in a RTC system:

- control elements (e.g. sensors, regulators, controllers and communication systems)
- control levels (e.g. local control, regional control, global control and optimal global control)
- mode of operation (e.g. manual mode, supervisory mode and automatic mode)
- control strategies (e.g. rule based scenarios and mathematical optimization)

For a more comprehensive introduction the reader is referred to IAWPRC (1989) and Jørgensen (1994). However, it is important to summarize the control levels investigated in this study. On the one hand, local control is the <u>simple</u> type of control, where moveable regulators are operated such that predetermined water levels or flows are maintained, irrespective of the current state of the flow process in the sewer system. On the other hand, global optimal control is the <u>advanced</u> level of control. In a globally controlled system, setpoints of regulators (i.e. desired flow, desired water level) are conformably modified such that better performance is reached (i.e. less CSO). Consequently, a system under global control makes better use of its capacity than one under local control. Optimum control is the best possible global control, yielding the most favourable performance.

It should be noted, though, that static control (i.e. no moving regulators, only gravitational flow) usually yields an even lower performance level than local control. Static control is not discussed in this paper.

For optimal control the control strategies are found by mathematical optimization. The two levels of control are illustrated in Figs 1 and 2.

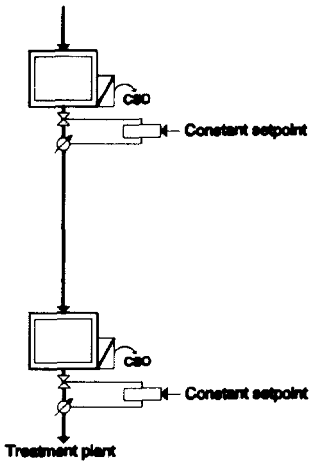

Figure 1. Local control.

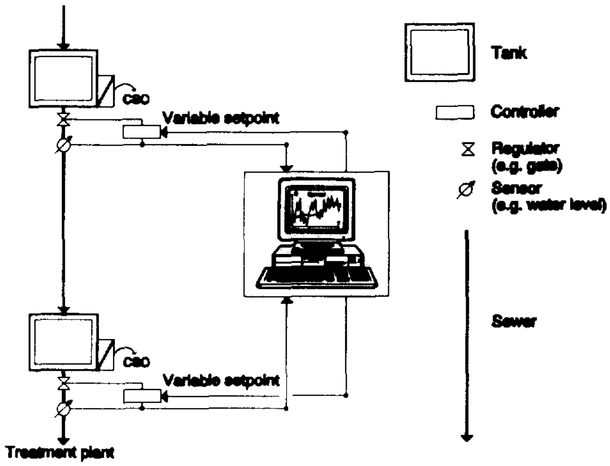

Figure 2. Global optimal control.

RTC POTENTIAL IN THE LITERATURE

In a number of case studies the potential for reduction of CSO is assessed. Almeida (1993) reports simulation experiments for the CSS of Fehraltorf in Switzerland, a small-town system with six CSO tanks and a total storage of 1401 m^3 (3 mm related to reduced area). Optimal RTC reduces CSO volumes by 285-607 m^3 per event for thirty-one events (average 398 m^3).

Rohlfing (1993) compares the same system with the large CSS of Bremen (approximately 100,000 m^3 = 6.5 mm storage) for six events. For Fehraltorf the CSO reduction is comparable to Almeida's results, for Bremen it is 50,400 m^3 per event. Related to the existing storage volume the reduction is 26% per event for Fehraltorf and 50% for Bremen. It is interesting that both studies show that optimum RTC becomes more attractive with growing storage size.

Nelen (1992) simulates a part of the Copenhagen CSS (203,000 m^3 storage = 10.4 mm) using 246 events. The simulated annual CSO frequency is 12.2. Using optimum RTC, the CSO event-volumes can be reduced by more than 75% of the no-control event volume for 50% of all overflow events, more than 50% for 60% of all events, more than 40% for 70% of the events, etc.

MODEL FOR RTC OPTIMIZATION

As indicated above, the methods used in this study for operation of CSS involve mathematical optimization as the control strategy.

The problem of finding the optimal control strategy is then reduced to a minimization of an objective function (cost function) subject to a set of constraints, which represent the system. Since optimality is defined for the entire system by the least cost solution of the objective function, the model will create a control strategy by which the objectives are fulfilled in the best possible way, within the limits of the constraints.

The RTC optimization model used in this study is the LOCUS model. This model uses the linear programming (LP) technique, where all the decision variables, i.e. state and control variables are linear. The procedure to apply linear programming for RTC is described in detail in Schilling and Petersen (1987). Once a control problem is formulated as a LP problem it can be solved with standard software routines. Besides the simulation of optimally controlled systems, LOCUS offers the possibility to simulate locally controlled systems as well. Since in both cases an identical description of the system is used, the differences between the results are due only to the way the system is operated. The effect of RTC can then be quantified by comparing the results. For detailed information on the LOCUS model, reference is made to Nelen (1992).

SETUP OF HYPOTHETICAL SEWER SYSTEMS

In this study, three different hypothetical CSS were investigated. The physical characteristics of each of these systems were varied in order to determine which system parameters are important with respect to quantification of the RTC potential. The physical characteristics that were varied were: Tank volume (static storage volume), flow times, distribution of storage, etc.

The systems were designed according to the Danish standard design methods, and therefore feature realistic dimensions.

To be able to compare the results obtained from the different setups, a number of parameters were kept at the same value in all the systems (total catchment area, total tank volume, total flow time etc.).

As an illustration, one of the investigated systems is indicated in Fig. 3, with a detailed description of the system characteristics. The other systems are indicated with less detail in Figure 4.

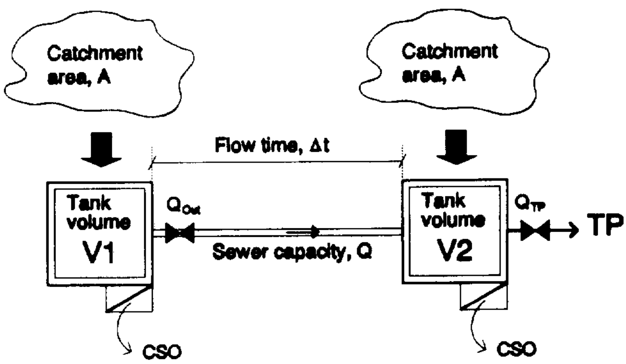

Figure 3. Setup of a two-tank serial system.

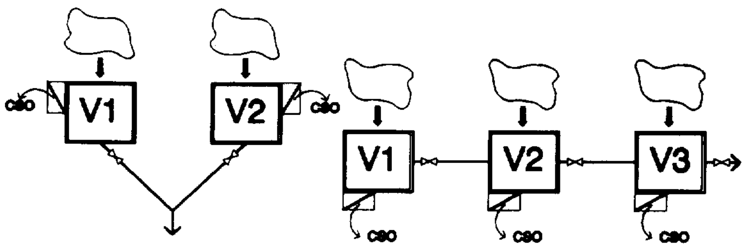

Figure 4. Setup of a two-tank parallel and a three-tank serial system.

RESULTS AND DISCUSSION

Some results are presented for the two-tank serial system (2ts) and the three-tank serial system (3ts) in the figures below. The potential of optimal RTC is illustrated by the difference in CSO volume between the locally controlled system and the optimally controlled system. The CSO-reduction then refers to $\Delta CSO = CSO_{local} - CSO_{optimal}$.

Since it is not only the absolute CSO values in m^3 that are interesting, but also the CSO reductions relative to the total static storage volume in the system, some of the results are indicated as relative values.
Twenty-nine representative rain events were selected from a long Danish data series for the computations. The average (of 29 events) and maximum values of CSO-reduction for these events are then used as an indication of the potential of optimal RTC.

In figure 5a and 5b, the average and maximum CSO-reduction, for all twenty-nine events, from the 2ts and the 3ts, are shown, when the static storage volume in only one of the tanks is increased at a time. The results are related to the total static storage volume and given as a percent reduction. It is seen, that as the tank volume increases, the relative CSO-reduction also increases, until a certain level - the maximum level of RTC potential is reached. For the 2ts it is seen, that the RTC potential when increasing the downstream tank, V2, is more than doubled compared to an increase of the upstream tank, V1. For the 3ts the effect of increasing the middle and downstream tank volume, V2 and V3, is almost the same. The effect compared to an increase of V1 is, however, more dramatic. When results from the 2ts and the 3ts are compared, it is seen, that the RTC potential of the 3ts is larger (max. average is 20% compared to 14%). It should be noted, that the total static storage volume has to be quite large before the maximum level of RTC potential is reached (approximately 10-15 mm).

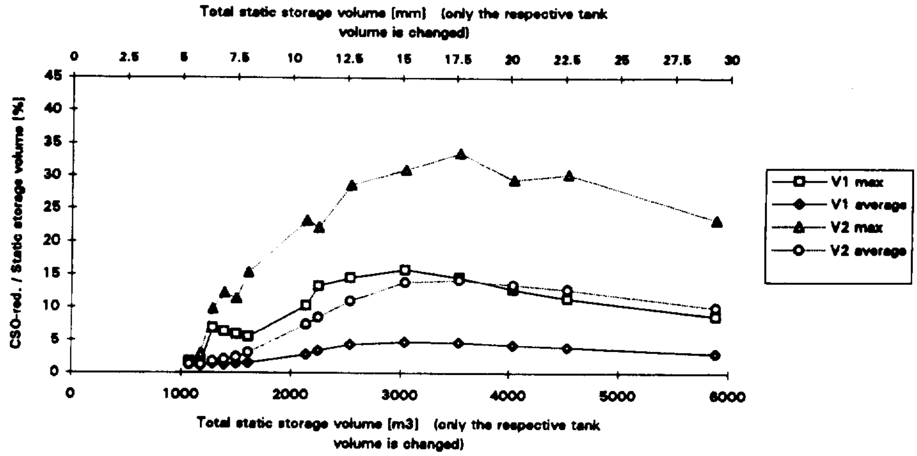

Figure 5a. Increase of static storage volume in only one of the tanks, in the two-tank serial system.

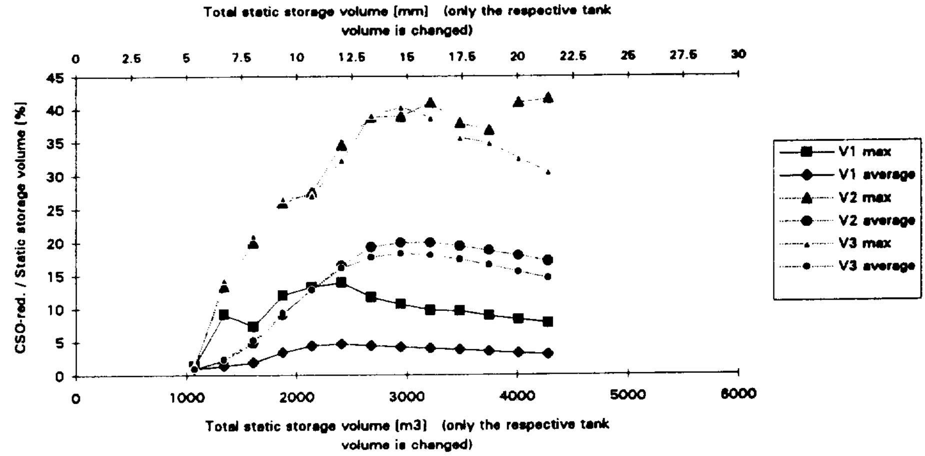

Figure 5b. Increase of static storage volume in only one of the tanks, in the three-tank serial system.

The results obtained by increasing the flow times between the tanks (in the interceptors) give similar results to those indicated in figure 5a and 5b. However, the flow time has to be quite large to see a significant effect.

In figure 6, the results of a change in the topographical distribution of the storage volume in the tanks are indicated, for the 2ts and the 3ts. The downstream tank is used as reference. The results confirm what is indicated in figure 5a and 5b. Large downstream storage increases the optimal RTC potential as compared to large upstream storage. In figure 6, the 2ts has the largest RTC potential.

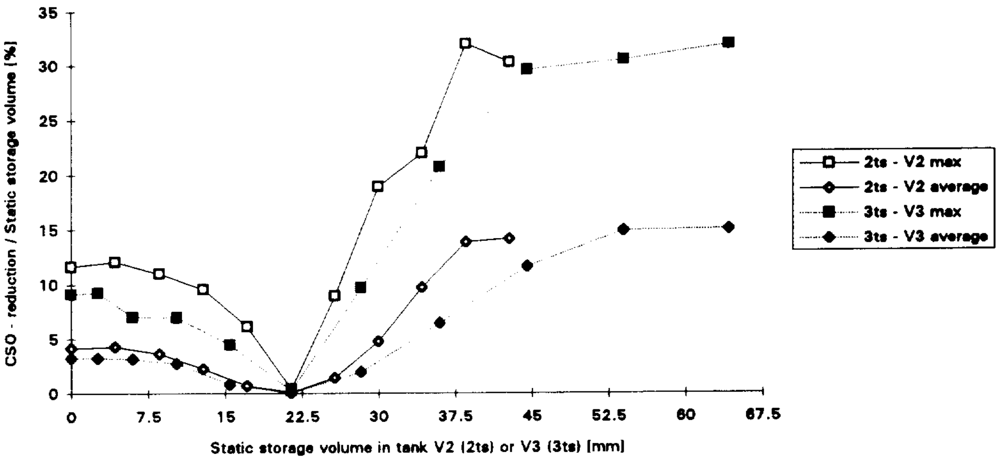

Figure 6. Change in the topographical distribution of the storage volume (Total volume is constant).

This is due to the fact that the two systems do not have the same dimensions, as was the case above.

In Figs 7 and 8, the absolute total overflow volumes for all twenty-nine events are given for different topographical distributions of static storage volume. It is seen that there is very little effect with regard to the storage distribution in a locally controlled system (upstream vs downstream).

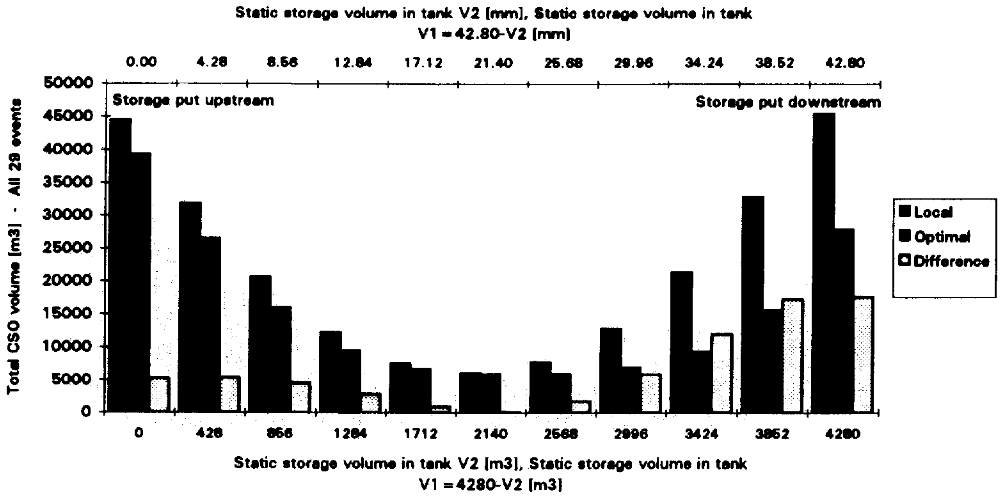

Figure 7. Absolute total overflow volumes for all 29 events for different topographical distributions of static storage volume – two-tank serial system (2ts) (Total volume in tanks is constant.

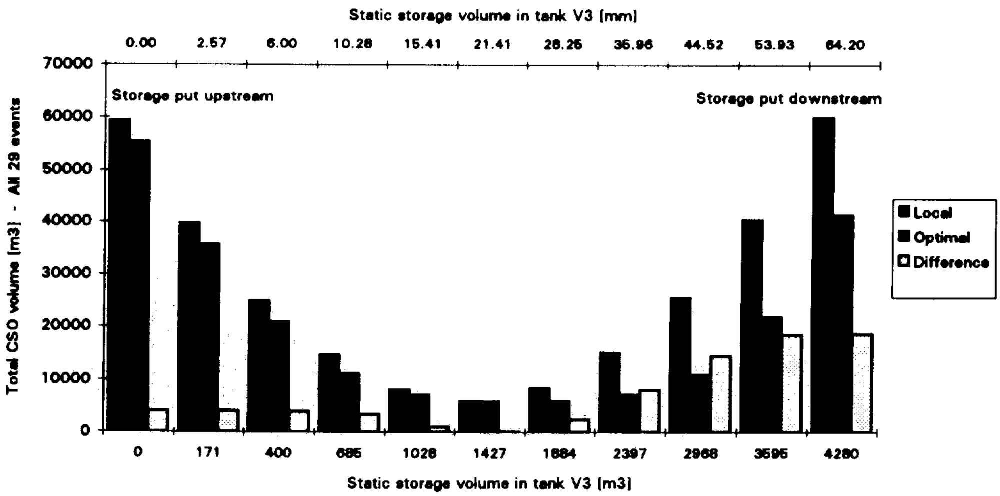

Figure 8. Absolute total overflow volumes for all 29 events for different topographical distributions of static storage volume – three-tank serial system (3ts) (Total volume in tanks is constant.

In a locally controlled system an unbalanced distribution of storage yields poor system performance, irrespective of where the storage is placed.

In the optimal control case, on the other hand, it is shown again, that downstream storage is better than upstream storage, since this causes less total overflow. The difference indicated in the figures illustrates the absolute CSO reduction, ΔCSO. In other words, especially if large storage volume has to be placed downstream, optimal RTC will compensate for a great deal of this disadvantage.

Besides flow time and static storage volume, the influence of the capacity of the interceptors has also been investigated. The results indicate, that there is a mutual relationship between the capacity of the interceptor and the flow time in the interceptor - the dynamic storage volume. Both static and dynamic storage have the same control potential, provided that optimum strategies are applied.

In this paper, the results focused on serial systems. With respect to increase of static storage volume, the two-tank parallel system showed results similarly to the two-tank serial system. The optimal RTC potential was a little smaller, though.

CONCLUSION

From the investigation described in this paper it can be concluded that some types of system benefit more from optimal RTC than others. These systems are:

- Systems with relatively large static storage volume. Maximum benefit is obtained at storage volumes up to six times larger than standard design methods prescribe.
- Systems with an uneven topographical distribution of storage volume, meaning that the system includes some very small and some very large tanks, in proportion to the respective catchment area and specific inte rceptor capacity.
- Systems with large flow times in the interceptors (long distances between tanks or systems in flat areas).

The system parameters that have the greatest influence on optimal control potential, are the static storage volume and the way in which it is distributed.

Furthermore it was found that as the benefit of optimal RTC increases, the more controllable elements there are in the system. This indicates, that the advantage of implementing optimal control will be greater for more complex systems.

The estimates of RTC potential in absolute numbers are probably at the lower end of what is possible, since most real world systems have more than two or three storage elements.

GENERAL APPLICABILITY

The results of the cited case studies and of this study of hypothetical systems indicate that CSO reductions can be related to the existing storage volume (both storage in tanks and in conduits). A rule-of-thumb might be that optimum RTC reduces "event CSO volumes" by 25% of the existing storage in large systems. This percentage increases with increased specific storage size (i.e. m^3/red.ha). In other words, optimum RTC becomes more interesting with larger storage per hectare. However, CSO reductions do not seem to depend very much on the characteristics of the specific event: There seems to be no relation between the absolute CSO reduction and the storm characteristics.

In this study of synthetic systems these results are confirmed. However, the average optimal RTC potential reaches a maximum reduction of 20% of the existing storage, – little below the 25% indicated for real world systems. This is according to the fact that the optimal RTC potential increases with the size and complexity of the system (more controllable elements etc.), and the hypothetical systems studied here have very little complexity.

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