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DERIVING DISCHARGE STRATEGIES TO REDUCE CSO IN URBAN DRAINAGE SYSTEMS

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ABSTRACT

This paper discusses the design of discharge strategies for urban drainage operation. The design procedure applies a tuneable strategy which can be adjusted to a specific situation by adjusting a few parameters which reflect the discharge priority of the various districts of the system. The actual design procedure, a procedure of simulation and analysis of the system performance, is explained in a case study. Apart form the method, the case study shows that a near optimal performance (maximum reduction of overflow volume) can be realised by applying an "event" average strategy (one strategy for all type of inflow events). Furthermore, the case study shows that the major part of the total overflow volume is caused by very heavy storm events.

KEYWORDS

CSO; improvement discharge strategy; urban drainage system;

INTRODUCTION

The heart of a decision model for urban drainage operation is formed by the discharge strategy. It can be described as an indispensable path needed for the determination of control actions in practical situations, in which complete and exact information on the future system load and the system performance is not available. Most discharge strategies consist of a few straight forward decision rules which, in contrast to the method to transform the strategy into control actions, were not subject to extensive analysis (EAWAG, 1990; IAWPRC, 1989; PREDICT, 1992). This paper focuses on the quality of discharge strategies. Next to the formulation of a general set up of a discharge strategy to minimize the overflow volume, we discuss a procedure to adapt the general strategy to a specific system. In this procedure we analyse the strategy in coherence with system load and the specific distribution of storage and discharge capacities. In an example we will illustrate the procedure and investigate the quality of the derived strategies. We end with the conclusions.

GENERAL SET UP DISCHARGE STRATEGY

An operation strategy should describe a system performance, which, in practice results in reaching the operational objective. With the operation strategy we can determine the desired system state as a function of the actual system state. To figure out which quantities best describe the system state we must find out which controllable quantities can influence the operational objective effectively. Once these quantities are found, we must derive intuitively clear relations between actual and desired system states that allow easy adaption of the strategy. For the reduction of overflows the storage level of the districts is a suitable quantity as it indicates the probability of an overflow and it can be influenced by the control actions (discharges, valve settings, etc.). Using this quantity, the operation strategy consists of relations between the actual and the desired storage (Leeuwen van, et al., 1996).

A few general principles can be given for the design of a successful operation strategy aiming at the minimization of the overflow volume. First the strategy should maximize the total system outflow. Second, discharges to overflowing districts should be avoided at all times. Finally, the structure of the strategy should allow priority to be given to the discharge in districts that form a bottleneck in the available discharge capacities. In the example, discussed later, we applied a central discharge strategy meeting these criteria. The priority of the outflow of the different districts is decided by a set of tunable functions. The tuning boils down to adapting the values of the parameters which influence the relation between the desired filling degree of a district and the filling degree of the total system.

TUNING THE STRATEGY

As stated before, we can best reach a minimal overflow volume when we adapt the discharge strategy to the bottlenecks in the system. The strategy must therefore be analysed in coherence with the existing distribution of storage and discharge capacities.

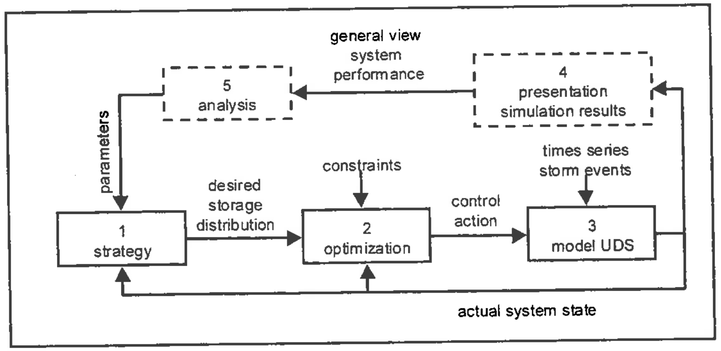

Figure 1. Process of deriving an operation strategy

Figure 1 shows a possible way to do so by stepwise adaption of an initial strategy, characterised by a set of parameters (block1). During the simulation the desired storage distribution is calculated on the basis of the actual system state. In the optimisation procedure (block2) the expected gap between the desired storage and the actual storage is minimised subject to the actual constraints (possible discharges, valve settings, etc.). Next, in block3, consisting of a hydraulic model of the urban drainage system (UDS), the actual system state for the given system load and control actions is determined. After analysing the system performance the strategy can be adapted by tuning the strategy parameters (block4 and block5). In the following paragraph we will present an example of this procedure.

EXAMPLE

Let us consider the operation of a UDS consisting of six districts aiming at the minimisation of the total overflow volume. The dimensions of the system are based upon a part of the combined UDS of the city of Rotterdam named *the left river bank Nieuwe Maas* (Gemeente Werken Rotterdam, 1996). We describe the hydraulic performance of this system, characterised by its pumped transport between the districts and its mild slopes, with a multiple reservoir model. Figure 2 shows the configuration of the six connected reservoirs and in Table 1 the system capacities are given. Next to the normal discharge in the direction of the treatment plant district 1 and 5 have the possibilities to discharge to the river Nieuwe Maas (pumped overflow). In the example for reasons of clarity these pumped overflows are operated according to a fixed local strategy.

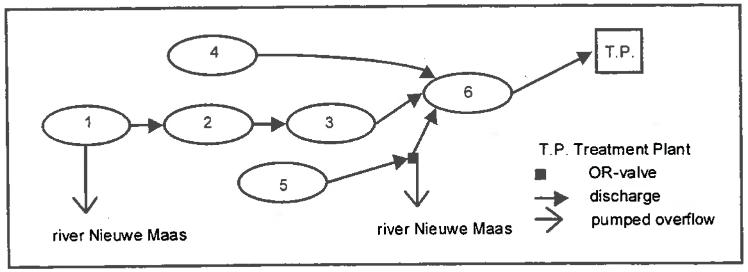

Figure 2. Layout of the urban drainage system

The pumped discharges are always started if the filling degree of the districts exceeds 80% and always stopped when the filling degree is below 60%. In the trajectory between 60% and 80% it depends on the level of increase and decrease whether the pumped overflow is started or stopped. The discharge capacities given in Table 1 are totally available for the discharge of storm water.

Table 1. Capacities of the urban drainage system

district number:		1	2	3	4	5	6
storage capacity	$[10^2 m^3]$	157	99.3	42.5	52.0	153	34.6
discharge capacity	$[10^2 m^3/h]$	13	32	48	21	33	90
pumped discharge	$[10^2 m^3/h]$	15	-	-	-	60	-

For the simulations we used a historical precipitation data collection of 15 years. We grouped the data to different storm events by assuming a storm event ended after a dry weather period of more than 300 minutes. Of all the storm events we achieved in this way we considered only the events with a total depth larger than 4 mm and an intensity that exceeded the 0.5 mm in 5 minutes at least once during the event. The resulting 492 storm events were transferred to system inflow data by subtracting an initial loss of 1 mm and the use of a linear reservoir model.

Before starting the adaption procedure we first excluded the inflow events too small to be considered. Therefore we carried out a simulation with the 492 inflow events and analysed the filling degrees in the districts. Next we skipped the inflow events during which the filling degree didn't exceed the level of 70% in at least one district. By this operation we reduced the original 492 events to 203 inflow events. To address the other side of the spectrum, the storm events so heavy that overflow cannot be avoided, we carried out a simulation with a single reservoir reflecting the total storage capacity of the system. The pumped overflow and the regular discharges were represented by two different outflows. The pumped overflow was equalled to the sum of the pumped discharges of district 1 and 5 and the regular outflow was equalled to the outflow of district 6. This single reservoir approach is an easy way to find the uncontrollable heavy inflow events as we assume infinite discharge capacities between the reservoirs in two directions. The inflow events leading to an overflow here cannot be prevented with any strategy.
In our case during 55 inflow events an overflow occurred which means that during the remaining 148 storm events an overflow can maybe be prevented. In Table 2 it shows that the 203 storm events with the initial strategy, in the distributed model, led to overflows during 86 inflow events, with a total overflow volume of $211.4 \cdot 10^4$ m^3. The single reservoir model resulted in 55 inflow events during which an overflow occurred, with a total overflow volume of $188.9 \cdot 10^4$ m^3. Apparently during 31 inflow events the available storage capacity was not used totally.

Table 2. Overflow volume of all 203 heavy inflow events for two different models

applied model	overflow volume [$10^4 m^3$]
six reservoirs / initial strategy	211.4 (86 overflows)
single reservoir / maximum discharge	188.9 (55 overflows)

To find out whether the total overflow volume can be reduced for the 203 heavy inflow events we carried out the adaption procedure. We started the procedure to derive a satisfactory operation strategy with an initial strategy meeting the criteria mentioned before and aiming at an equal filling degree in all districts. The discharges of the six districts were calculated by minimisation of the sum of the squared differences between the actual and the desired storage of the six districts subject to the constraints describing the flow process and the maximum capacities.

First the parameters were adapted such that the discharge of district 1 was given a higher priority (adapt1). In step two next to district 1 also the discharge of district 5 was given a higher priority (adapt2). Finally we tried a strategy (adapt3) in which only district 5 was given a higher priority. In Table 3 the overflow volumes for the initial strategy and three adapted strategies are presented for the 148 inflow events and the group of 55 very heavy inflow events.

To learn the quality of the discharge strategies we analysed the system performance of each of the 86 inflow events for which overflows occurred and derived strategies specially tuned on the particular inflow events. In total the overflow volume could be decreased to $5.3 \cdot 10^4 m^3$. As this volume will not be reached in practice (the inflow events are not known exactly in advance) this volume must be seen as a theoretical value.

Table 3. Overflow volumes of two inflow series for different discharge strategies

volume [$10^4 m^3$]	55 events	148 events	total
initial	204.3	7.1	211.4
adapt1	203.2	6.6	209.8
adapt2	202.3	7.5	210.0
adapt3	202.6	6.7	209.2
theoretical minimum			207.6

The results show that strategy adapt3, the strategy giving priority to the discharge of district 5, performs best with a total overflow volume of $209.2 \cdot 10^4 m^3$. The differences between the results of the four strategies are nevertheless very small. It can further be seen that adapt2 handles best the 55 very heavy events while adapt1 leads to minimum overflow volume for the series of 148 inflow events.

The reductions for the 55 events and the 148 events are of the same magnitude which implies that indeed both groups of inflow events had to be used to derive the discharge strategy. Comparing the total overflow volume of the initial strategy with the theoretical minimum value of $207.6 \cdot 10^4 m^3$ it can be concluded that also the initial strategy is near optimal.

To gain insight in the distribution of the overflow volumes for the different districts, Table 5 shows the overflow volumes per district for the 148 events and the 55 very heavy events. The given priorities in the different strategies can be recognised in the figures of both inflow series. Further Table 4 shows that the initial strategy results in a minimal overflow frequency (31+55).

Table 4. Overflow volumes of the two inflow series per district for different discharge strategies

volume [$10^4 m^3$]	inflow events	district number 1	2	3	4	5	6	totals and (frequency)
initial	148	3.7	0.44	0.00	0.13	2.4	0.39	7.1 (31)
	55	49.2	29.5	9.60	21.0	72.9	22.1	204.3 (55)
adapt1	148	2.2	0.96	0.47	0.35	1.9	0.73	6.6 (38)
	55	47.1	28.6	11.0	21.5	71.7	23.2	203.2 (55)
adapt2	148	2.2	0.97	0.86	1.1	1.3	1.1	7.5 (43)
	55	47.1	28.0	11.9	21.3	70.3	23.6	202.3 (55)
adapt3	148	3.0	0.79	0.24	0.65	1.2	0.82	6.7 (32)
	55	47.9	29.0	10.6	21.2	70.4	23.5	202.6 (55)

CONCLUDING REMARKS

Based on the simulations discussed above, we draw the following conclusions:

- The method to derive a discharge strategy aiming at minimisation of overflow volume, discussed in this paper, provides a clear view on the quality of the derived strategy and possible improvements.
- The major part of the total overflow volume is caused by a few very heavy storm events.
- The fact that all the applied strategies were near optimal implies that the exact execution of the discharge strategy will be important for only a few inflow events .
- The example shows that strategies using only actual system data may perform well.

Results of other studies related to the subject discussed here, carried out by the authors, indicate that:

- The general set up of the operation strategy discussed earlier proved to be successful not only to realise overflow related operational objectives but also to smooth the hydraulic load of the treatment plant and minimise the operational costs during dry periods.
- For other systems the adapting procedure resulted in reduction of total overflow volume varying from 1-5%.

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