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DEVELOPMENT OF A CONTROL STRATEGY TO REDUCE COMBINED SEWERAGE OVERFLOWS: THE CASE OF BREMEN – LEFT OF THE WESER

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ABSTRACT

In recent years, the population and authorities in West Germany have become very concerned with water pollution. In this respect, combined sewage discharges have been pointed out as a major source. Various measures can be considered, which can be ordered into three categories: a redefinition of the objectives of the Urban Drainage System (UDS), the reshaping of the UDS (e.g. extension of the storage capacity) or the modification of its operation. Among the latter measures, Real-Time Control (RTC) constitutes the main option. It aims at a better exploitation of the existing storage potential. As the city of Bremen (Germany) decided, several years ago, to renew the on-line survey and monitoring system of its UDS, the determination of on-line strategies to operate the pumps came to the fore. Methods and tools to investigate the possibility to reduce the pollution loads through improved control strategies have been developed. Some results are presented.

KEYWORDS

RTC of a UDS; Expert-System; Control Strategy; Control Rules; Simulation of UDS

SHORT DESCRIPTION OF THE UDS (FIG.1) [1],[2]

The network drains an urban catchment whose total area is 920 Ha (impervious 450 Ha). The older part – downstream – is composed of combined sewers, the new extensions – upstream – only drain sanitary water. Since the catchment is extremly flat (slope < 1/1000), the flow process within the canalisations must be controlled through pumps (around 40 stations), most of them sanitary water pumps. Every station is operated automatically or manually through water level information. The 3 important pumping stations are located in the combined drainage area (Rablinghausen, Krimpel and HPWL station).

HPWL is located at the outlet of the catchment and supplies the treatment plant. The survey and monitoring system is installed in HPWL.

Retention basins are located in Krimpel (8000 m^3) and HPWL (10000 m^3). The storage capacity in the canalisation amounts to 40000 m^3. Combined sewage discharges may occur into the river Weser (at the HPWL station and at the treatment plant), into the Wasserlöse (HPWL) and into the Krimpelfet (Krimpel).

During a rainfall event, 8 pumps are directly controlled by the operators in HPWL.

Pump	Location	Action
P1	HPWL	Supply of the treatment plant
P2	HPWL	Filling of the retention basin
P3	HPWL	Overflow to the Weser
P4	Krimpel	Pumping into the HPWL catchment
P5	Krimpel	Filling of the retention basin
P6	Rablinghausen	Pumping into the HPWL catchment
P14	HPWL	Emptying the retention basin
P15	Krimpel	Emptying the retention basin

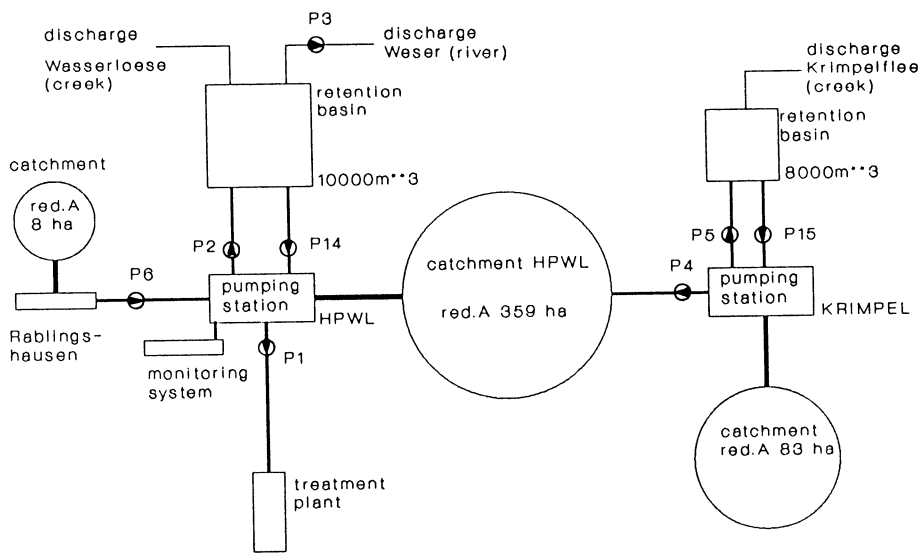

Fig. 1. The UDS 'Bremen left side of the Weser'.

OBJECTIVES OF RTC

The two main objectives are to prevent flooding and to prevent discharges. Other factors can be taken into account in the strategy research (e.g. the energy costs, other security aspects...). They are more constraints than objectives.

The network is so dimensioned that flooding should occur relatively seldom. The reduction of the discharges is therefore the main concern. Local laws prescribe that at least 85% of the combined sewage should be treated at the treatment plant. Even if this goal were reached, discharges into the small creeks (Wasserlöse and Krimpelflet) could nevertheless lead to disastrous ecological consequences (pollution shocks).

ANALYSIS OF CONTROL STRATEGIES

The first surveying and monitoring system in Bremen was built at the beginning of the seventies. It basically transmitted the same amount of information about the state of the UDS as the present system built in 1987. Amongst others, the following variables are available: measurements of rainfall intensities (3), water levels (18), pumping rates (40), flow rates (5), energy consumption (2). After the recent developments, the system offers more possibilities to visualize on-line and analyse the measurement data [3].

Experience with RTC has lead to the progressive elaboration of standard control instructions. These have been collected into a document and describe what will be referred to as the 'standard strategy'. Every instruction can be expressed as a 'control rule' (also 'control production'), which is constructed according to the following pattern; WHEN [some conditions are filled] THEN [the following actions should be performed].

In the standard strategy, the actions at a given station mainly depend on the water level at the corresponding pump pit . Consequently a local control is performed [4]. For example, the decisions on the pumps P1, P2, P3, P14 is strongly related to the water level at the pump pit of HPWL. Normally, the operator follows the standard instructions. However, he (or the responsible person) may rely on his own 'feeling' of the situation and actuate the pumps differently.

In order to systematically analyse and develop control strategies, two methods can be considered. The first one is based on the use of an optimization module, the other one on the use of an expert system (a so called 'rule based' system')

Optimization methods were developed in Operations Research. In this case, the proper strategy is defined as the one which minimizes (optimizes) a given 'cost function' provided static and dynamic constraints are met. Consequently, the given solution will be called 'optimum'. In the literature, linear optimization is mostly discussed [5]. Accordingly, the cost function as well as the dynamic constraints within the UDS are linear and the search algorithm is often based on the so-called 'simplex method'.

In the case of an expert system, the proposed strategy is based on the activation on strategy rules, which only apply, when certain conditions are met. This way of solving is very similar to the one which is actually used in practice. The difference is that, through simulations, the possibility is given to test any rule configurations. In this study, the second method was eventually preferred [2].

A reliable simulation of the flow processes within the network as well as a simulation of the decision process through an expert system are necessary. For this purpose, a simulation model was implemented in which an existing hydrodynamical simulation program (Extran,IFW) was connected to an expert system shell developed at the 'Institut für Wasserwirtschaft, Universität Hannover'.

The calibration of the simulation model was a first difficult step. On the one hand, the processes can only be properly described with a hydrodynamic model (slope, storage effects, backwater effects,...). On the other hand, the description of the UDS must remain relatively simple, otherwise the computation time will become intolerable. For 3 real events, the results of the hydrodynamical simulations were compared with the measurements gained and stored by the survey and monitoring system. Actually, the results can not be compared directly since the 'real' strategy in these cases does not exactly correspond to the 'standard' strategy, which had been transcribed into the knowledge base of the expert system. Anyway the simulation proved to be accurate enough to allow reliable conclusions by analysis of the simulation results. Since we want to develop an optimized strategy, there is no need to exactly reproduce what happened in a particular event.

To examine the influence of each single control rule, one has to simulate single events and retrace them in a very detailed manner. However, the only possibility to obtain a global evaluation of a strategy independently from the pattern of a given event is to perform a long term simulation.

The choice of single events for the detailed study is a critical point. Design rainfalls are a priori discarded, because there is no clear connection between the statistical characteristics of the rainfall and the statistical behaviour of the UDS. Interesting real events are in the first place those which generate such a run-off volume that the total capacity of the UDS is required without being overrun. Improper control decisions would lead to unnecessary disorders. If the runoff volume is small, there is no need for special measures. If the runoff volume definitely overruns the UDS capacity, inundations and discharges shall occur no matter which decisions have been taken. However, a 'clever' strategy should confine the disaster.

We dispose of a continuous rainfall record over 30 years (1955-1985) with a temporal resolution of 5 minutes. Within this period, 88 representative events have been selected according to the following rainfall parameters; duration, total depth, mean intensity, dry weather period before and after the event. Among these, events Nr 005 and Nr 015 exemplify the detailed analysis.

Rainfall Nr.	Duration [min]	Depth [mm]	Intensity [l/s/ha]	Total (*) Volume [m^3]	Remaining (**) Volume [m^3]
005	120	24.7	34.3	152 000	41 000
015	75	16.4	36.4	96 000	31 000

(*) Total inflow volume within 12 hours after the beginning of the rainfall (rainfall + sanitary water inflows).
(**) Remaining volume in the UDS 12 hours after the beginning of the rainfall.

Within 12 hours, the UDS can support around 100 000 m^3 inflow (storage capacity + treatment capacity). Clearly, event Nr 005 overruns the UDS capacity, while event Nr 15 should produce no disorder, if the whole capacity of the system is utilized.

The detailed study of the standard strategy has pointed out the following characteristics.

1) The water level at the pump pit of the corresponding pump is the decisive parameter (Local Strategy).
2) During critical events, the water level within the collector shall be kept as low as possible in order to always secure enough storage capacity, if a second rainfall peak should occur. Disadvantage: this could lead to unnecessary overflows.
3) The pumping rates stay at a much lower level than theoretically possible in order to prevent peaks of energy consumption. Disadvantage: this could lead to submersion of the pump pit during the rainfall peak.

According to the standard strategy, for event Nr 015 (Fig. 3), in HPWL, the retention basin is filled up. Discharge occurs (11 500 m^3 in the Weser). In Krimpel, the filling of the basin continues for more than 5 hours after the rainfall peak. Despite this, an overflow in the pump pit occurs (140 m^3) during the rainfall peak.

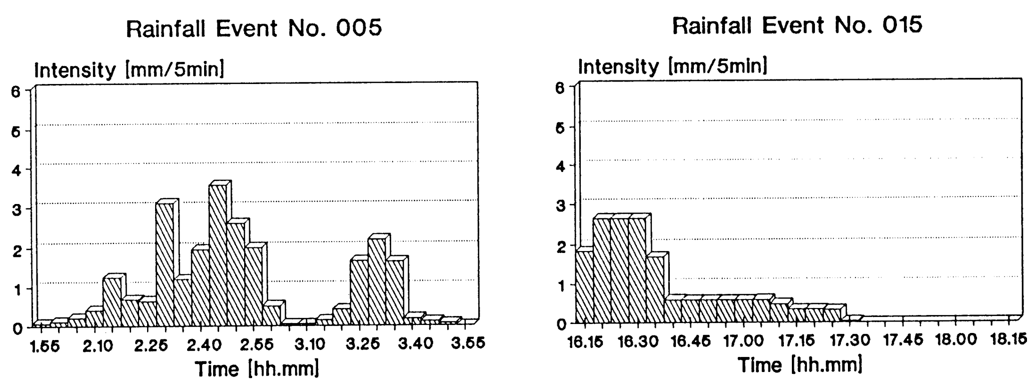

Fig. 2. Rainfall intensities of the two events.

A new strategy is proposed, which seems more risky. As long as 1/3 of the storage capacity within the network remains free, no filling of the basins occurs. In case of filling however, the pumping rates can occasionally be much higher. The decision concerning a pump depends not only on the corresponding water level but also on the rainfall intensities (if the inflow wave still goes on) and the existing storage capacities upstream and downstream. In this respect, the new strategy is a Global Strategy.

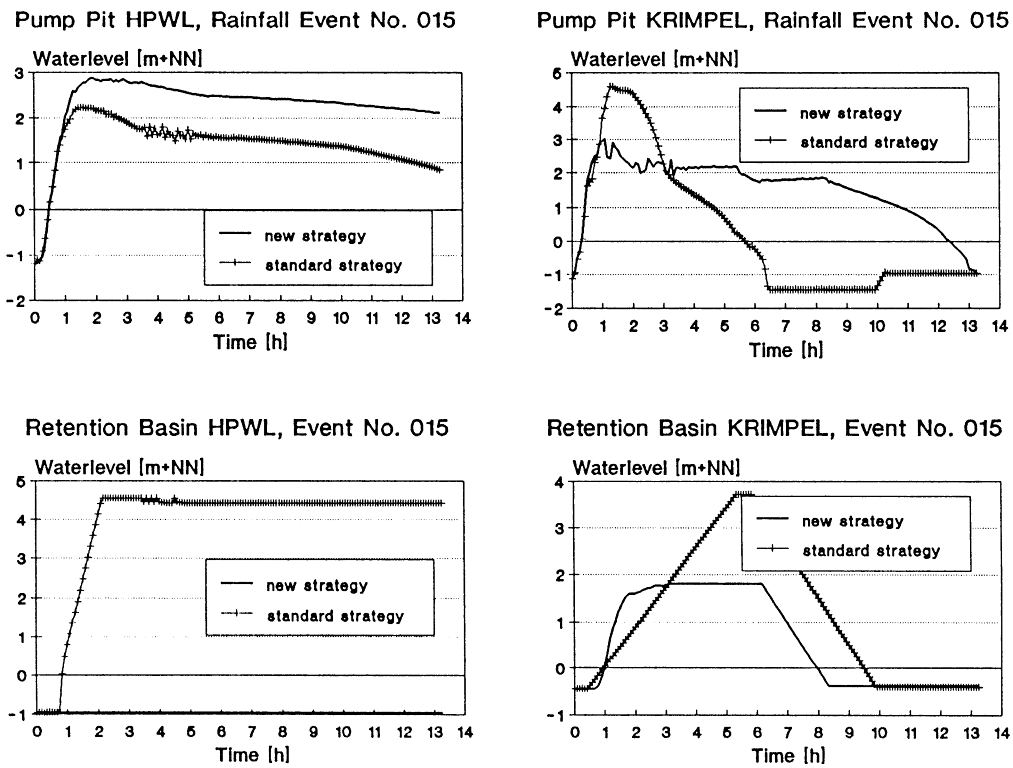

Fig. 3. Detailed analysis (event 015).

During event 015, the new strategy does not fill the basin in HPWL. In Krimpel, filling only occurs as long as the rainfall constitutes a danger. Instead of 6200 m^3 only 3400 m^3 are pumped. Due to the higher pumping rates, the overflow at the pump pit does not occur. In Rablinghausen, the strategy recognizes that the in-line storage capacity is big enough to store the whole inflow volume of the upper catchment as long as there is a danger of overflow downstream. As more combined sewage quantity is retained to be treated by the TP whose treatment capacity remains unchanged, it takes much more time till the water levels have regained their original levels (in HPWL 29 hours instead of 26 hours; in Krimpel 13 hours instead of 7).

During event Nr.005 (Fig. 4), overflows and discharges can not be prevented. In HPWL, according to the new strategy, the filling of the basin starts more than 25 minutes later. The basin nevertheless is full about 10 minutes sooner because of the higher pumping rates. As a consequence, the menace of flooding is diminished; the maximal water level at the pump pit drops more than 30 cm. However, as soon as the rainfall peak is gone and the in-line storage capacity for emergency case has been recovered, the pumping in the basin stops. As a result, the duration of overflow into the Weser is reduced from 6 to 2 hours. In Krimpel, due to the lower pumping rates in the standard strategy, the basin will be filled after 7 hours. 4500 m^3 inundation is registered. In the new strategy, inundation does not occur. As a price, the discharge quantity has been increased (5500 m^3 instead of none). This corresponds nevertheless to the established objective priority (first no inundation then no discharge). In Rablinghausen, the rainfall inflow quantity is retained till 25% of the total storage capacity downstream becomes available. Similarly to event Nr.015, it takes more time for the water levels to return to their initial state (in HPWL 36 hours instead of 31; in

Krimpel 22.5 hours instead of 11).

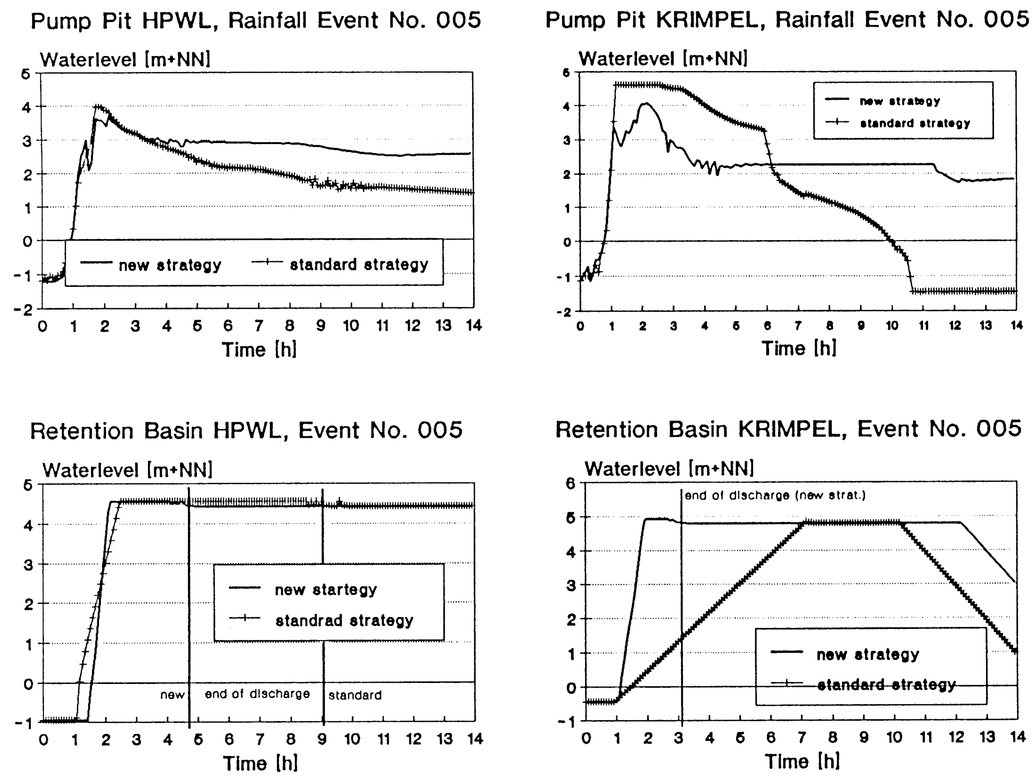

Fig. 4. Detailed analysis (event 005).

The results of the long-term simulation of the selected events have been evaluated according to 3 parameters: the security of operation of the UDS, the discharge quantities and the energy consumption of the pumps.

Figure 5 shows the percentage of manholes where overflows (resp. pressure flows) occur with a given frequency. Although the new strategy takes more risks, the security level (inundation frequency) is not affected. Regarding the discharge quantities (Fig. 6), a sensible improvement has been attained in HPWL. The reduction of the discharge quantities in the river Weser amounts to 73%. In Krimpel however, 32000 m^3 are discharged in the small creek with the new strategy, while with the standard strategy no discharges had occurred. Actually, it is not a deterioration, since corresponding flooding quantities have been reduced from around 39000 m^3 to 600 m^3 (!). The objectives are given their proper priority.

In Fig.7 the duration of activation is represented as a function of the pumping rate for pumps P2, P5. The quantity of water to be pumped into the retention basins is strongly reduced (reduction of the energy costs). The pumping rates, however, are much higher (increase of the energy costs).

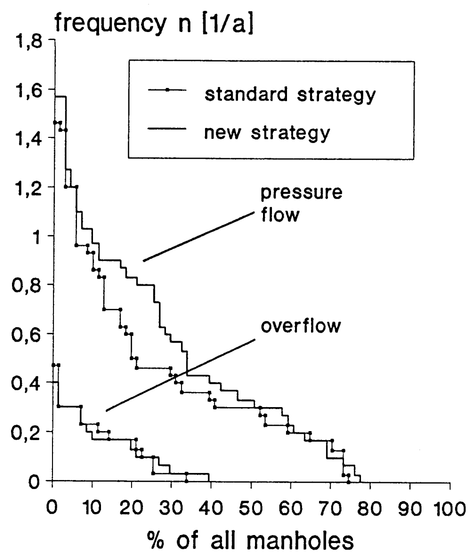

Fig. 5. Security of operation.

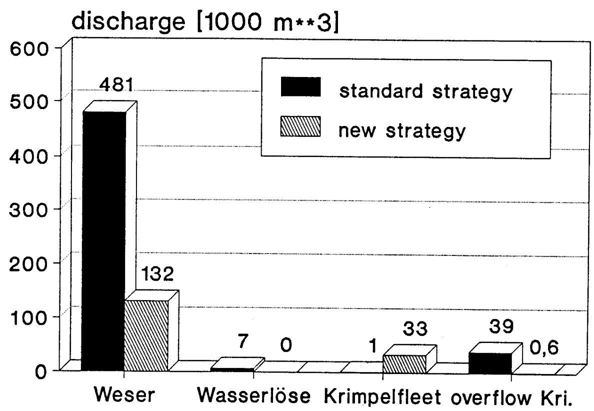

Fig. 6. Discharge quantities.

CONCLUSION

A reduction of the discharge quantities has proved to be possible, without alteration of the flooding frequency. The systematic utilization of the in-line storage capacity causes, however, a sensible increase of the frequency of pressure flows. It remains a political decision whether this degradation of the drainage facility will be accepted in order to achieve a better protection of the environment

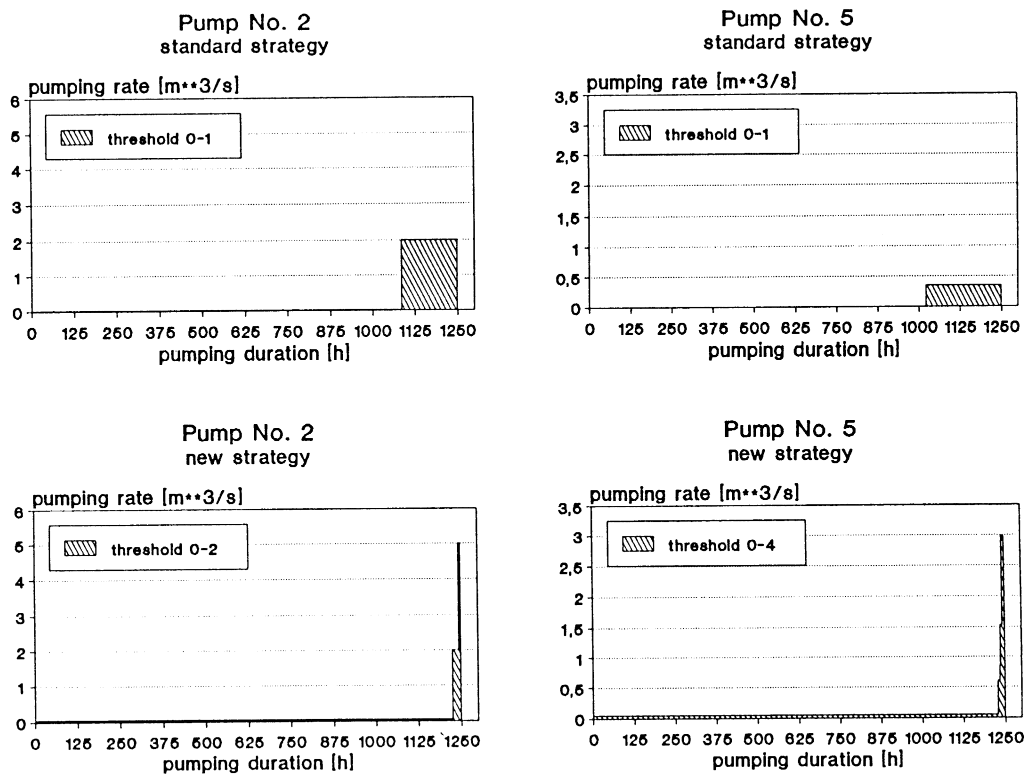

Fig. 7. Pumping durations to fill the retention basins.

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