Optimisation of operational management practices for the detention basins

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Abstract The objective of this study is to develop new operational management practices for detention basins during rainfall events in order to limit flooding risk and, at the same time, to reduce pollutant discharges by optimising the settling process. For this work, a methodology was developed to study the integration of the stormwater treatment into existing detention structures. In this article, it was applied on two experimental sites. The current operation of the basins and "on/off" regulation studies were first carried out to quantify the freedom to act to change the control schemes. Relying on the support of these studies, new operational rules based on the current or "on/off" principle were then elaborated and tested on the experimental basins using a hydraulic model. Finally, their efficiency to protect against flooding and to reduce pollutant discharges was assessed.

Keywords Detention basins; urban stormwater discharges; operational management practices; flood protection; pollutant control

Introduction

The new European regulations require member countries to deal with pollution due to urban stormwater discharges. Preventing wet weather pollutant discharges into the natural environment has thus become a major concern for local authorities, in addition to the traditional objective of preventing flooding. Therefore, the Urban Community of Bordeaux (CUB), France, has supervised since 1996 a major research program on stormwater management. Its main objective is to define, for the CUB urban drainage system, new operational management strategies which respect both requirements imposed by environment protection and constraints due to flooding risks (Briat *et al*., 1999). In these strategies, the favoured solution to reduce the pollutant loads discharged during wet weather events is to optimise the management of the existing infrastructures such as detention basins, by using real time supervision.

Most of the 34-detention basins (1,500,000 m^3 of storage capacity) situated in the CUB area are controlled in order to reduce floods by a real time monitoring system named RAMSES and a local automatic regulation named GASPAR. The GASPAR regulation relies on a simple principle: to maintain the maximum hydraulic capacity at all times. Consequently, the detention basins are often empty during rainfall events. This system is efficient to protect against flooding (10 years) but does not control the pollutant discharges (Jacopin *et al*., 1999). An important phase of the project was then to develop new control schemes for detention basins during rainfall events in order to limit flooding risk especially for heavy rainfall events and, at the same time, to promote the solids settling process in basins, especially for light and medium events.

This large experimental study was carried out by the Urban Community of Bordeaux and Lyonnaise des Eaux. The main stages were an assessment of the efficiency of detention basins to reduce pollutant discharges, the characterisation of settled solids and the development of a methodology for real time supervision to control flows and to optimise the pollution removal. This paper will be limited to the last stage of the project. It will describe the methodology used to elaborate new stormwater control regulations for detention basins and will present the results obtained for two experimental sites.

Sites and measurements

Two detention basins were chosen in the CUB area and equipped for the study: **basin of Bourgailh** on a separate stormwater sewer system (80,000 m^3, open, on-line, with grassy bottom) and **basin of Périnot** on a combined sewer system (39,000 m^3, underground, off-line, with a concrete base). The flood control capacity of these two structures is a 10-year storm (39.5 mm in 54 minutes).

The detention basin of Bourgailh (Figure 1) was constructed on the Peugue River on a 3.5 ha site in order to control high flows and to limit flooding risk downstream. During rainfall events, the Peugue River is used as a separate stormwater sewer system. The basin drains a 676 ha semi-urban area. In the upstream part of this catchment, the residential development is new and sparse with many wooded areas. Housing becomes more and more dense in the downstream part. The impermeability of the total catchment is estimated at 20%. The basin is also fed by a lateral collector from a adjacent catchment. Its area is about 98 ha with an impermeability of 26%.

The detention basin of Périnot (Figure 2) is situated, in the Bordeaux city centre, in a semi-urban and urban area of detached housing and blocks of flats. The tank was constructed shunt-connected on a combined sewer system on a 1 ha site. During rainfall events, it is fed by two collectors. The main collector (ϕ 1,800) drains a 171 ha area with an impermeability of 31% and the second collector (ϕ 900) drains a 25 ha catchment with an estimated impermeability of 34%.

To assess the efficiency of the tanks to reduce pollutant discharges, the following parameters are continuously measured on the two experimental sites: flow rates at tank inlet and outlet, water depth in the tank, and turbidity of influent and effluent. Automatic samplers are used to sample solids and to measure their physico-chemical characteristics: grain size distribution, pollutant loads and settling velocities. A rain gauge is also located at the basin sites.

Methodology

In collaboration with the centralised technical supervision RAMSES, new dynamic operational practices were examined and validated. Their aim is to reconcile flood risks management with the reduction of pollutant load discharging into the natural environment.

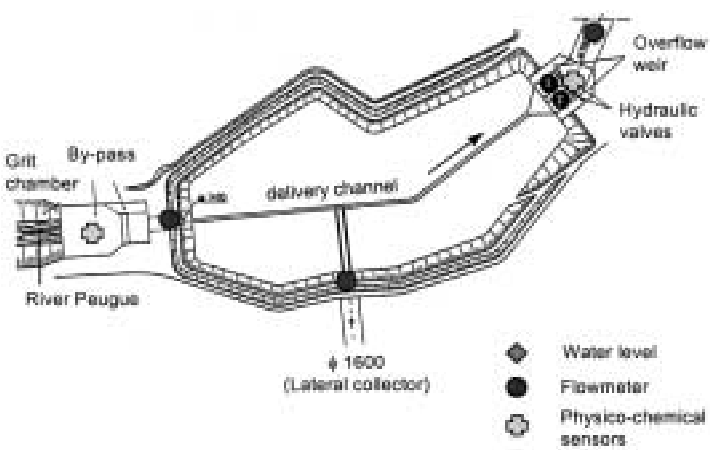


Figure 1 Bourgailh detention basin

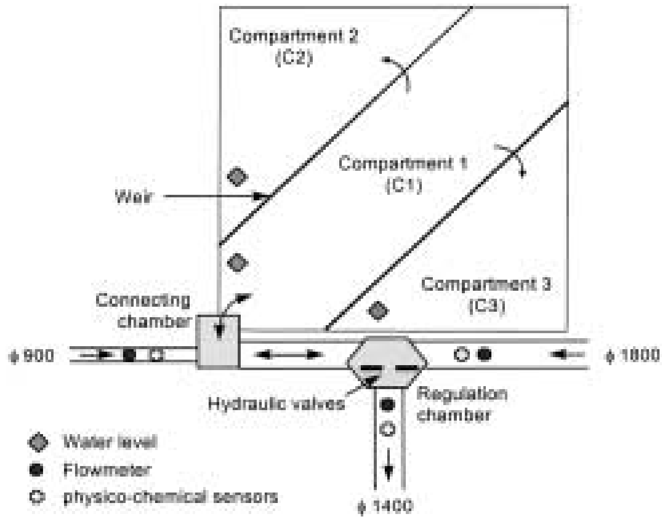


Figure 2 Périnot detention basin

Whatever the characteristics of rainfall events, flood protection remains the main purpose of the structures.

For this work, the following methodology was developed (Jacopin, 1999):

- As a first step, an analysis of the limitations in the use of detention basins to control pollution was done; its objective was to quantify the freedom to act to change the current GASPAR regulation rules of the structures, in order to include pollution control;
- As a second step, new dynamic control schemes were developed for detention basins and then, were applied on "significant" individual rainfall events for their preliminary appreciation;
- As a last step, the selected control regulations were tested on a one-year continuous rainfall series; their efficiency to protect against flooding and, at the same time, to reduce pollutant discharges was assessed.

Case study

This methodology was applied to the experimental sites of Bourgailh and Périnot. The main results of this work will be described in this section.

Analysis of the limitations in the use of detention basins to control pollution

Method (Jacopin *et al*., 1999). The possibilities to modify the current operational practices of Bourgailh and Périnot structures were assessed by analysing two "extreme" control schemes (Table 1):

- the current GASPAR regulation, developed to protect the CUB area against flooding: the downstream hydraulic valve, which controls the filling and emptying phases of the tanks, is regulated by a logic controller which takes into account the rainfall and the water depth in the sewers approximately one kilometre downstream of the tanks; this current control strategy was the lower bound of the project;
- a simple "on/off" regulation, with the basin outflow zero during storm events; this regulation is based on the total interception of runoff water; it is thus an optimum to capture pollutant loads and, consequently, to reduce pollutant discharges (Gromaire-Mertz, 1998); it was the upper bound of the project.

The operational data recorded between 1992 and 1998 for the two sites were used to carry out a statistical study of the basin operation, controlled by GASPAR and "on/off"

Table 1 Valuation of the extreme regulations concerning flood protection and pollution control

Objective	GASPAR regulation		On/off regulation
FLOODING	+++	← *area of investigations* →	
POLLUTION			+++

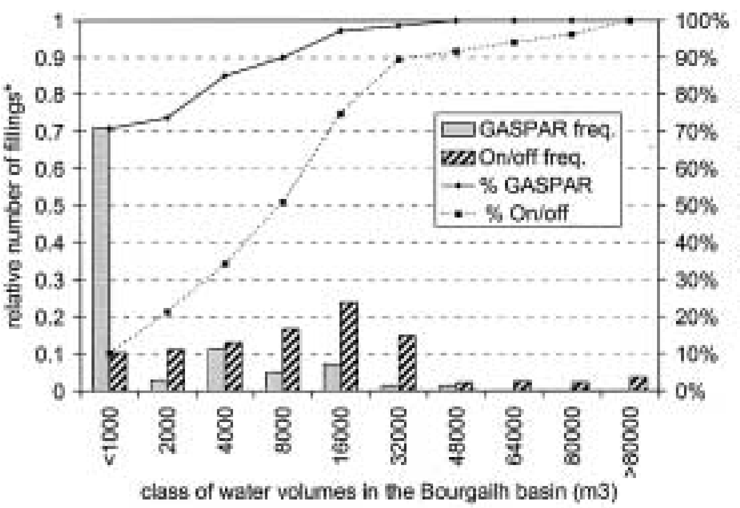
regulations. These data are: rainfall, water depth in the basin and in the downstream collectors, and valve level.

Results. Figure 3 illustrates the results of the Bourgailh site analysis; it shows the distribution of the stormwater volumes stored in the basin controlled by GASPAR and "on/off" procedures.

As shown in Figure 3, the number of runoff events resulting in basin filling and the percentage of storage capacity used were low with the GASPAR regulation. For the Bourgailh site, only one rainfall event out of three produced a tank filling and, 70% of fillings used less than 1.5% of the basin storage capacity (80,000 m^3). For the Périnot site, results were quite similar: the median storage capacity used was only 5%, i.e. 2,000 m^3. The GASPAR regulation therefore achieved its purpose: detention basins were empty most of the time. Consequently, with the GASPAR regulation and the centralised technical supervision of sewer systems, the CUB could manage an exceptionally heavy rainfall event at any time.

The filling frequency of the structures is higher with the "on/off" regulation than with the GASPAR regulation: 100% versus 35% for the Bourgailh site. Moreover, 90% of the Bourgailh fillings had stored water volumes smaller than 40% of storage capacity, i.e. 32,000 m^3 (Figure 3). The median storage capacity used was 9% for the Bourgailh site and 18% for the Périnot site. Nevertheless, for the given series of rainfall (1992-1998), the annual risk of exceeding the tank capacity with the "on/off" regulation was, one or two rainfall events for the Bourgailh site and, two or three events for the Périnot site.

According to these preliminary observations, the safety margin is very large between the two "extreme" control schemes, leaving room to modify the current regulation rules on the two experimental sites and to test new operational practices.



* GASPAR: 106 fillings for 304 rainfall events; On/off: 354 fillings for 354 rainfall events

Figure 3 Stormwater volume distributions in the Bourgailh basin controlled by GASPAR and "on/off" regulations

Development of new control schemes

Method. Relying on the support of the first stage of the study, two control schemes were studied:

- regulations based on the current GASPAR operation;
- regulations based on an "on/off" operation.

These new regulations were applied to the Bourgailh and Périnot basins and tested on a sample of eight "significant" individual rainfall events (summer and winter shapes, 10 year and 20 year storms, etc.). The work required for each studied site, a hydraulic model of the detention basin and contributing catchments. The Danish Hydraulics Institute hydraulic model MOUSE® was used to carry out the various simulations. This model was previously calibrated with hydraulic data (water level and flow rate) measured on the experimental sites for several stormwater events.

In the end, in order to accept or reject the new control regulations, two criteria were examined:

- the criterion to appreciate the "flood protection" efficiency: duration of detention basin drainage, maximum storage capacity used, water depth in downstream sewers;
- the criterion to estimate the reduction of pollutant discharges: tank filling frequency, duration of detention phase, runoff volumes stored in the basins.

These parameters were then compared with those obtained with the current GASPAR operation. Only the control strategies which respected both limitations fixed by the current basin management and constraints due to the dual-purpose operation of the structures were finally selected.

Results. Modifications on the two "extreme" regulations focused mainly on dry and wet weather hydraulic valve positions, set points values in the upstream, basin, downstream checking points, and the operation of the regulators.

Seven regulations based on the GASPAR operation were elaborated. The objective of the modifications was to integrate pollution control in the current operational rules. The GASPAR principle was then maintained, but the downstream set points were modified in order to increase tank filling frequency and filling rate. On the contrary, the aim of modifications on the "on/off" regulation was to integrate flood protection in its principle. To reach this goal, the "on/off" operation in the new regulations was limited to a "volumetric" portion of the runoff water (equal to a given percentage of the basin capacity) or it was used for a fixed period of time (equal to 12 hours or 24 hours).

At the end, only two new dynamic control schemes were satisfactory and then, were selected for the Bourgailh and Périnot sites: the current GASPAR operation with modified set points, and one modified "on/off" regulation. As an example, Figure 4 describes the principle of the selected new "on/off" regulation. As shown in this figure, it comprises three stages:

1. At the beginning of the storm event, the downstream hydraulic valve is closed; the basin outflow is then zero as long as the water volume stored in the structures does not exceed a given percentage of the basin capacity (V_{limite} of 20, 30 or 50% of the basin capacity);
2. Beyond this level, the excess runoff passes to the downstream collector;
3. At the end of the detention phase, the control valve is opened to a level compatible with the hydraulic capacity of the downstream collector.

Figure 5 shows the distribution of the runoff volume stored in the Périnot basin controlled by the current GASPAR regulation and the modified "on/off" regulation (20, 30 and 50% level) during the rainfall event dated 29/09/1996 (duration = 11.7 hours, water depth = 44.2 mm).

Efficiency of new control schemes

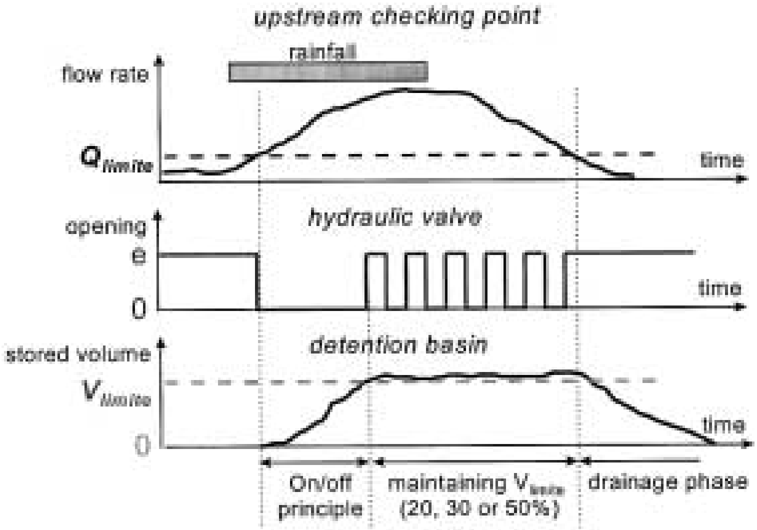


Figure 4 Principle of the regulations based on the "on/off" operation

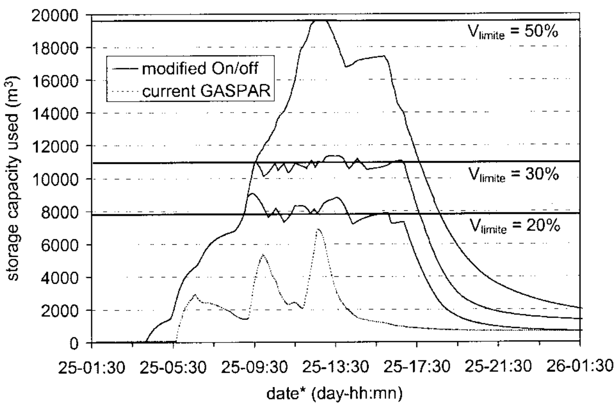


Figure 5 Distribution of the water volume stored in the Périnot basin (80,000 m^3) controlled by the current GASPAR regulation and modified "on/off" regulations

Method. For their final validation, the two selected regulations were tested on a one-year rainfall series. Long term simulation was carried out with the MOUSE® model for the 1996 year (53 rainfall events with a water depth greater than three millimetres, annual water depth = 871 millimetres). These series were very representative of Bordeaux climatic features: heavy storm events in summer and, events with long duration and light intensity in winter.

Then, the "flood protection" efficiency of each scheme was evaluated by using the criterion defined in the previous stage. To complete this criterion and to estimate the reduction of pollutant discharges, two other parameters were computed:

- annual hydraulic interception rate = water volume stored in the basin/runoff volume;
- annual pollution removal rate = mass of solids trapped in the basin/total mass of solids in the runoff water.

The second parameter depended on the basin pollution removal efficiency. Thus, an experimental model of the sedimentation process in the basin was elaborated with experimental data, for each studied site. As an example, Figure 6 shows the suspended solids removal efficiency measured in the Périnot basin (nine samples) and the experimental model build by regression.

Results. Table 2 gives annual hydraulic interception and pollution removal rates obtained

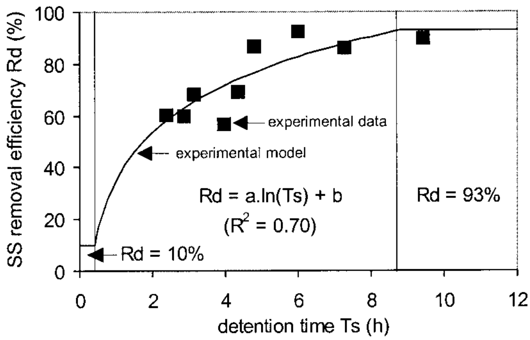


Figure 6 Experimental model of basin sedimentation efficiency build for the Périnot site

Table 2 Annual hydraulic and pollution removal rates obtained for the GASPAR regulations with the current and modified set points and the new regulation based on the "on/off" principle

	Bourgailh basin		Périnot basin	
Control schemes	**hydraulic rate (%)**	**pollution removal (%)**	**hydraulic rate**	**pollution removal**
current GASPAR	9	6	16	14
modified GASPAR	19	16	20	18
"on/off", 20% level	59	52	69	64
"on/off", 30% level	70	62	77	71
"on/off", 50% level	80	71	88	82

for the GASPAR regulation with modified set points and "on/off" regulation with a maximum water volume fixed to 20, 30 and 50% of the basin capacity. A comparison with the current GASPAR operational results is also done.

The new GASPAR regulation improved slightly the annual amount of pollution trapped in the detention basins: as an example for the Bourgailh site, the amount was estimated at 6% for the current GASPAR operation and at 16% with the modified set points. The pollution removal efficiency of the new "on/off" regulations depended on the water level fixed in the structures (20, 30 or 50%), but whatever the selected level, the efficiency was always higher than 50%, i.e. five times greater than for the GASPAR operation.

Both schemes gave satisfactory hydraulic results for the rain events tested. Nevertheless, it was necessary to check that these regulations offered a good protection against flooding. During the rainfall event and the basin emptying phase, the water level stayed compatible with the hydraulic capacity of the downstream collectors. But, the use of the "on/off" regulations increased both the water volumes stored in the basins (Table 3) and the detention time (Figure 5). Due to these effects, the protection against flooding could not be as good as it was with the GASPAR operation rules. Moreover, with the new "on/off" operation and a 50% level, the maximum storage capacity used was over 90% in the Bourgailh basin (Table 3). The remaining basin capacity and, consequently the safety margin, were very small; they did not allow management of an exceptional rainfall event at any time.

Discussion

Finally, the new procedures based on the two different schemes could manage flooding risks and at the same time pollution removal, but in an unequal way. For this reason, a new possible solution was studied and tested on the experimental sites: it consisted of combining the two strategies by using an "on/off" regulation to control small and medium rainfall events and a GASPAR regulation for the major events (Table 4). In this case, weather forecasting and eventually some hydraulic estimations must be used to determine which rain-

Table 3 Maximum storage capacity used in 1996 in the Bourgailh and Périnot detention basins

Control schemes	Maximum storage capacity used in 1996* Bourgailh basin	Périnot basin
current GASPAR regulation	16	43
new GASPAR regulation	34	50
on/off regulation, 20%-level	65	65
on/off regulation, 30%-level	78	64
on/off regulation, 50%-level	92	69

* maximum stormwater volume stored in the basin/basin capacity

fall represents a risk of flooding.

Conclusion

Detention basins have long been used for flood protection. But, with only new operational management strategies, these existing structures could be also used to reduce efficiency of the wet weather pollutant loads discharging into the natural environment. Moreover, our study shows that a pollution control objective is compatible with a high protection against flooding.

The current GASPAR operation of the experimental basins is a local reactive regulation which is depending on local hydraulic conditions. This regulation is efficiency to control heavy storm events. But, from a water quality viewpoint, detention of small and frequent floods are more important than large floods. Consequently, the current operational management practices should be improved for this category of rainfall events, in order to reduce pollutant discharges. In our project, a new control scheme was then developed : it consisted of combining two strategies by using an “on/off” regulation to control small and frequent rainfall events and a GASPAR regulation for the heavy events. The results of this solution were very satisfactory. For the Périnot site, the annual pollution removal rate was increased four times: it was 14% with the current GASPAR operation and 57% with the combined operational strategy (Table 4).

Our study allowed us to quantify the freedom to act between flood protection regulations and pollution control regulations. This main result will now be exploited to elaborate a global management control strategy for the CUB area. In order to apply the new schemes, an optimal global real time control system will be developed and used to optimise the decision-making process (Kopecny *et al*., 2000). Its control objective will be: find at all times the right balance between the risk of flooding and pollution of the environment.

Acknowledgements

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Table 4 Annual pollution removal rate and maximum storage capacity used obtained for the current GASPAR regulation and the combination of GASPAR and “on/off” rules

Control schemes	Bourgailh basin pollution removal (%)	Bourgailh basin max storage capacity used (%)	Périnot basin pollution removal (%)	Périnot basin max storage capacity used (%)
current GASPAR	6	17	14	43
“GASPAR + on/off”, 30%-level	47	34	57	50

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