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A New Intelligent, Dynamic and Real Time Management System of Sewerage

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***Abstract*—**The current tools for real time management of sewer systems are based on two software tools: the software of weather forecast and the software of hydraulic simulation. The use of the first ones is an important cause of imprecision and uncertainty, the use of the second requires temporal important steps of decision because of their need in times of calculation. This way of proceeding fact that the obtained results are generally different from those waited.

The major idea of this project is to change the basic paradigm by approaching the problem by the "automatic" face rather than by that "hydrology". The objective is to make possible the realization of a large number of simulations at very short times (a few seconds) allowing to take place weather forecasts by using directly the real time meditative pluviometric data. The aim is to reach a system where the decision-making is realized from reliable data and where the correction of the error is permanent.

A first model of control laws was realized and tested with different return-period rainfalls. The gains obtained in rejecting volume vary from 19 to 100 %. The development of a new algorithm was then used to optimize calculation time and thus to overcome the subsequent combinatorial problem in our first approach. Finally, this new algorithm was tested with 16- year-rainfall series. The obtained gains are 40 % of total volume rejected to the natural environment and of 65 % in the number of discharges.

***Keywords*—**Automation, optimization, paradigm, RTC.

I. Introduction

IN Europe, and particularly in France, sewerage systems exist, in their modern form, since the 19th century. Their initial functioning is based on a self-regulation of the flows assisted, if needed, by safety valves (combined sewer overflows CSO).

The network was, in fact, passive facing the rainfall vagaries.

With the development of urbanization and the increase of impervious surfaces, storm water flows through sewer networks did considerably increase and cause an over-operating safety valves at the cost of natural environment.

The idea of endowing networks by a dynamic functioning, capable to offset the lack due to passive self-regulation, has then emerged. This dynamic operating is obtained by the way of control structures managed by a human agent or an automat. The control is done through real-time data acquisition in addition to the use of forecasting and/or decision making processes. This approach is reinforced by an evolution of regulations or recommendations to protect the environment.

The development of regulations related to urban discharges during rainy weather, and especially the EU Directive of 21st May 1991 and the water law of the 3rd January 1992 supported by the decrees of 22nd December 1994 and 22nd June 2007, impose rigorous choices of possible improvements of devices (plenum chamber, pump, gate, valve...) with the aim to reduce the impact of discharges on their receiving environments.

The existing tools of RTC of sewerage rely on two types of softwares: weather forecasting softwares and hydraulic simulation programs. The use of the first ones is an important cause of imprecision and uncertainty [6], while the use of the seconds impose a significant time step to make decision due to their need for calculation time. This proceeding way makes it quite impossible to manage errors and unforeseen events which lead to a reduction of targets in terms of retention capacities optimization and minimization of overflows to the natural environment. A first constructive attempt has been already tested in 2003.

The main idea presented here is to change the basic paradigm by approaching the issue via the “automatic” side rather than “hydrological” one. The objective is to run a large number of simulations in a short period of time (a few seconds) allowing a great reactivity and the test of wide number of solutions. In this way, it is possible to dispense with the weather forecasting by the direct use of real time rainfall data given by rainfall recorders on site and by considering the runoff time the same as the decision making one.

Rapid calculation time allows, using data collected in real time over the network, to correct errors that may have been committed at previous calculation time step. The decision is based on reliable data and error correction is permanent. A first attempt based on the reduction of the computation time and the unique use of measured data has already been tested in 2003 [5]. It gave very good results but it concerned the management of a single controller. The aim here is going much further by allowing the management of a large number of controllers.

We propose in this paper a new approach to make possible the realization of a large number of simulations in a very short time (a few seconds) allowing a high reactivity and testing of a large number of solutions.

We start with the creation of a model representing the functioning of sewerage system on which control laws can be

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implemented and then we proceed to the validation of this model.

II. The Sewage System

The sewerage system is a set of underground pipes, interspersed with structures. At the outlet of these, is often installed a wastewater treatment plant (WWTP). This is an extended complex object in which many actors are involved. We can act on the network and control it, by automation on some actuators (pumps, treatment structures, valves, mobile overflows...) or by remoting these actuators [7], [8].

Technical and organizational means of the sewerage system make this task possible. The sewer system can be divided into controllable parts and uncontrollable ones:

Uncontrollable parts: Depending on the rain, watersheds produce an “uncontrollable” flow and concentrations of pollutants [7].

Controllable parts: The network receives volumes of water and solid masses from watersheds. It collects and transports them to the natural environment directly through outfalls or through the treatment plant [7], [3], [4]. They are “controllables” because a change in the configuration of weirs or pumping system, for example, may change the outputs.

Throughout this article, we will be using a test network described in Section III *B* to explain our approach and the results arising there from.

III. Modelisation

A. Problem Formulation

Most hydrological phenomena of a sewerage network can be modeled by reservoir models [1]. These are based on the continuity equation:

$$\frac{dVs(t)}{dt} = Q_e(t) - Q_s(t) \quad (1)$$

and a law of storage:

$$V_s(t) = f(Q_e(t), Q_s(t), t) \quad (2)$$

where “Vs” indicates the stored volume, “t” the time, “Qe” the inflow and “Qs” the outflow [2], [3]. These models are particularly robust and numerically very stable. It is the class of models that we will be using thereafter for the project. In this way, for our project, watersheds will be modeled by a reservoir model where Qe(t) is equal to C*i(t)*A (“C” indicates the runoff coefficient, “i” the rain rate, “A” the catchment area) and the network by a set of retention structures in series or in parallel where volume-height laws will be based on the network geometry.

B. Description of the Network Test

The test network is a fictive pluvial network type in which we installed five all-or-nothing automatons: three discharge thresholds (DT), a pump (P) and an excess flow valve (EFV). The network is composed of five elements: two watersheds and three books retention. The first retention basin (RB1) has two outlets: the first is an excess flow valve that rejects to the third retention basin RB3. The second is a weir that discharges to a second retention basin RB2. This last one has two outlets: the first is a weir that discharges directly to the environment while the second is a pump that sends flows to the third basin BR3. This basin has also two outlets: the first is a weir that discharges in the same way to the environment. The second is an uncontrolled excess flow valve that returns the flows to the treatment plant waste water (WWTP). The operating system of this test network and its settings are explained in Fig. 1.

IV. Control System

The purpose of the control system is to obtain automatically the solution to minimize releases to the environment while keeping the same level of protection against flooding. For this, we can act on the three weirs (opening or closing thresholds), the excess flow valve of RB1 (opening or closing) and the pump (on or off). The automata are operating on binary mode.

At each decision time step, using rainfall and water level data, we search across all combinations of actions which one is most relevant. This search is performed by modeling the functioning of the network on a floating horizon (30 minutes) built from the measured rainfall data and a trend curve. The error on this pseudo weather forecast will be corrected permanently since the computation time is very short. Fig. 2 shows the various steps of the optimization process.

The optimization process implemented is only based on field measurements (rain gauges and water level recorders). The advantage, here, is there is no uncertainty about the input data unlike systems using weather forecasts. While the downside is that the proposed paradigm shift can only be applied if the computation time is lower than the data acquisition one: That’s what we will demonstrate. The results obtained by the implementation of the control laws are as Table I.

TABLE I
COMPARISON OF THE DISCHARGED VOLUMES TO THE NATURAL ENVIRONMENT (VNE) ON THE TEST NETWORK WITH AND WITHOUT CONTROLS

Rainfall type	VNE with control (m^3)	VNE without control (m^3)	Obtained Gain (%)
Annual	0	150	100
Bisannual	0	2200	100
Quinquennial	8298	14306	42
Decennial	20965	27158	22

When the optimization algorithm was tested on the shown network in Fig. 1, we noticed that the calculation time for one iteration is a bit more than 2 seconds for 5 automata. This corresponds to our problem and yet it is not as satisfying as it sounds. Indeed, the optimization algorithm used in that calculation time following a power law in accordance with the number of controllers (Fig. 3) whereby if, for example, a calculation time is a controller second then it is about 6 days to 20 controllers. We have therefore developed a new optimization algorithm that improves the relation between the computing time and the number of controllers into a linear law

(Fig. 4). Thus, if, for example, a calculation time for one controller is a second then it is 20 seconds for 20 controllers.

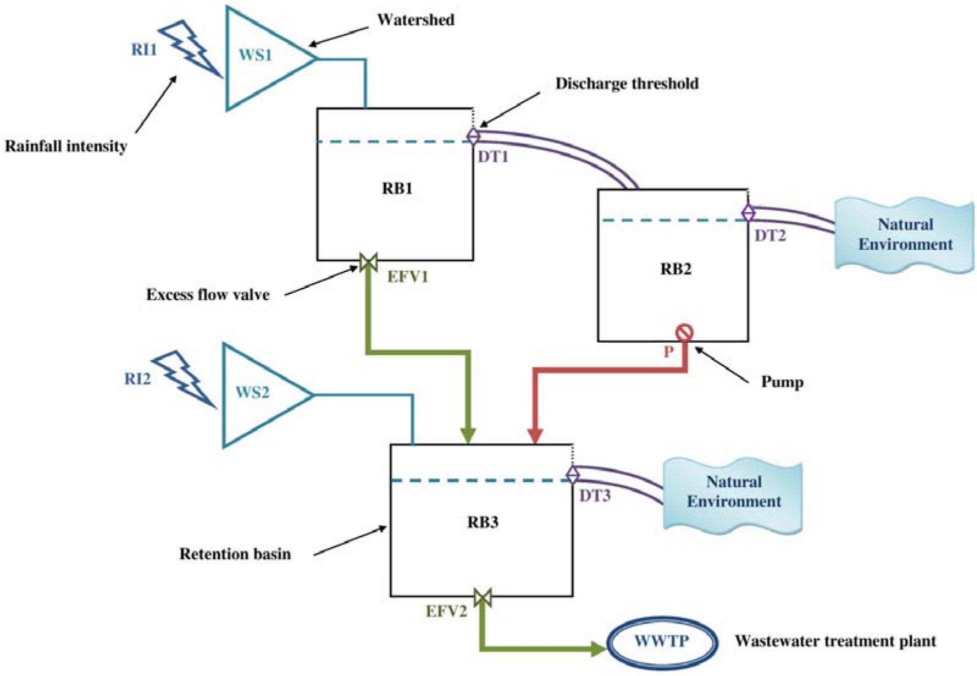

Fig. 1 Graphical representation of network test

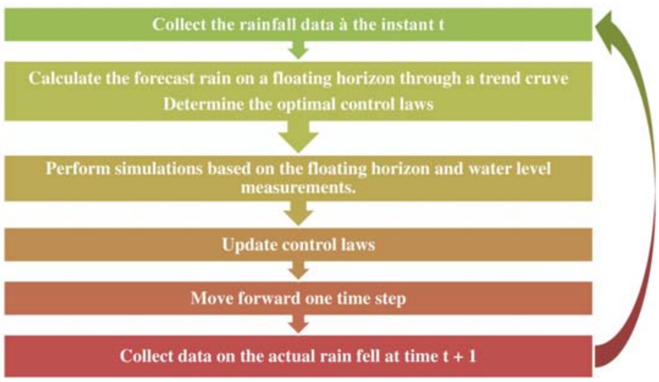

Fig. 2 Schematic organization of the proposed approach

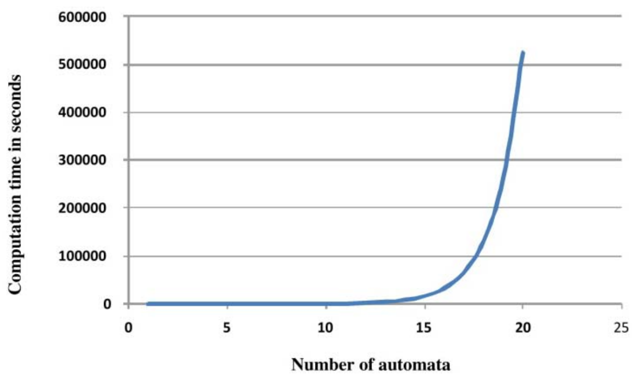

Fig. 3 Calculation time in function of the number of automata

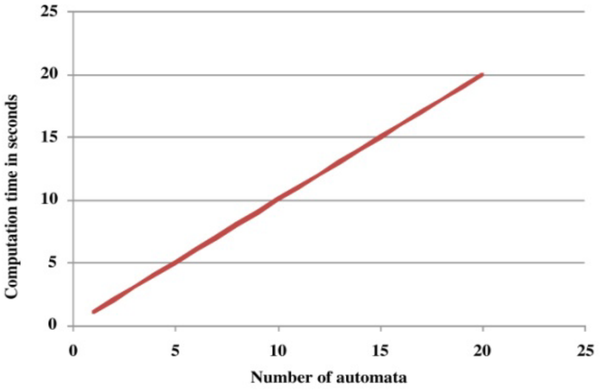

Fig. 4 Computation time in function of the number of automata (new algorithm)

In our tests, the computing time for an iteration is a half-second including 5 controllers which means an execution speed 4 times faster than the previous algorithm. We can also notice that the improvement in computing time hardly degrades discharges gains (Table II).

TABLE II
COMPARISON OF THE DISCHARGED VOLUMES TO THE NATURAL ENVIRONMENT (VNE) ON THE NETWORK TEST WITH AND WITHOUT CONTROLS (NEW ALGORITHM)

Rainfall type	VNE with control (m^3)	VNE without control (m^3)	Obtained Gain (%)
Annual	0	150	100
Bisannual	0	2200	100
Quinquennial	8584	14306	39
Decennial	21463	27158	20

TABLE III
GAIN OF DISCHARGES FOR A 16 YEARS RAINFALL TIME SERIES

	With control	Without control	Obtained gain (%)
Number of rainfalls that did cause discharges to the natural environment	43	122	65
Total discharged volumes (m^3)	288089	44799	20

The loss of efficiency is non-existent for annual and bisannuel and minimal for quinquennial and decennial rainfalls. Applied to a time series of 16 years of rainfalls (March 1988-December 2004), we obtain the following discharges gains (Table III). This new algorithm therefore allows a real optimization even with a large number of decision variables (here automatons). To give an idea about the effectiveness of the implemented algorithm, the calculation time for 100 automata is 10 seconds and is, consequently, less than the time of collection of rainfall and water level data. The computation time of optimization is therefore no more disadvantageous and allows adjusting continuously control strategies based on field measurements. This new procedure also reinforces the robustness of the network control. In fact, if a controller is defective, his defection is immediately and automatically taken into account by the optimization algorithm and the basic instruction (no overflow and discharges minimization) will continue to be respected.

V. CONCLUSION

All the conducted experiments in the field of dynamic management of sewerage systems are based on hydraulic simulation softwares on which control orders are inserted. Because excessive computation times, it is almost impossible to make calculations for a real optimization of retention capacities and thus minimization of untreated flows into the environment. Here we propose a paradigm shift: to take the problem under discussion through the way of "automatism" rather than the one of "hydrology". This new approach allows making decisions depending on reliable data and being able to correct continuously the control strategies based on the measured error between modeling and field measurements. Not being founded on preconceived scenarios, it also strengthens the robustness of the network control. Indeed, if a controller is defective, his defection is immediately and automatically taken into account by the optimization algorithm and the basic instruction (no overflow and discharges minimization) will continue to be respected.

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