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Decentralized Real Time Control in Combined Sewer System by Using Smart Objects

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Abstract

This study proposes a decentralized RTC of a combined sewer systems by using smart gates, which during high rainfall-runoff events, partially or fully close to use the actual storage capacity of the sewer pipes upstream. In this study the effect of gates is evaluated by modelling in SWMM two scenarios of the combined sewer systems. The use of smart gates provides beneficial effects to the overall hydraulic performance of the network during critical rainfall-runoff events, offering an alternative and valid solution for controlling flooding in urban areas.

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1. Introduction

Recently the phenomena of flooding have been more and more frequent in urban areas due to the increase of impermeable surfaces and the occurrence of extreme weather events related to climate change. Urban floods have also occurred due to the inefficiency of the hydraulic drainage networks in conjunction with intense rainfall events and/or eventual obstructions and blockages in drains and pipes due to an incorrect and poor maintenance [1]-[3].

To manage flooding in urban areas and to control the capacity of the drainage system below the set value of 75%, set by Italian regulation, stormwater measures, such as detention tanks and retention basins, have been introduced [7]. However, those solutions are very expensive from economic and technical-environmental perspectives. In recent years, thanks to the upgrading of hardware and software tools the scientific community has turned his interest in innovative

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technology solutions for real-time control (RTC) of urban drainage networks. These techniques provide many advantages enabling to optimize dynamically the storage capacity of the existing urban drainage network through the use of “actuators” [5], such as sluice gates or orifices and controllers, which adjust the “actuators” [4].

The use of the concept of "self-organizing" and emergency in RTC systems is a promising approach, but very complex. A self-organizing system is made up of several elements that interact at the local level, which can be either self-contained software elements, such as "agents," or autonomous elements of the real world with computing and networking capabilities, such as servers, mobile devices, etc. [7][8].

Because of their inherent flexibility, robustness, scalability, adaptability, and autonomy, emerging solutions of self-organization are mainly suitable for classes of problems characterized by high complexity and dynamism, aperture, large-scale, unpredictability, as well as suitable for classes problems with dynamic noise. Furthermore, when identifying the objectives of control for urban drainage systems, some criteria such as overflow volumes, frequency of flooding or peak flow rate reduction have been used. Sometimes those criteria are not easily measured or require large investments in practical applications. However cost saving is one of the main objectives of real time control which aims to use the existing infrastructures for implementing control. Control objectives for example, for treatment plants, may be maintaining effluent standards with a minimization of costs by managing the oxygen in the aeration tank.

Few studies have focused on RTC in urban drainage systems for controlling water quantity but also water quality of the receiving water bodies [4][5][9][11]–[14]. Campisano et al. [5] presented the results of the application of RTC by using local and global strategies for controlling moveable weirs. Those authors demonstrated that a global control strategy allows for reducing overflow volumes considerably more than a local control strategy. Magdeburg et al. [13] performed a cost-benefit analysis of several static (disconnection, storage tanks and adjustment of throttle pipes) and dynamic solutions (RTC) to mitigate CSO impact, based on the case-study in Flanders/Belgium. Zimmer et al. [14] proposed a hydraulic model for real-time combined sewer overflow modelling and decision support, which turned out to be applied to evaluate potential operating scenarios more quickly than SWMM. Campisano et al. [11] presented a detailed study on the local real time control of moveable sharp-crested weirs in sewer channels. A comparison between moveable weirs and sluice gates highlighted that the start-up procedure and the achievement of the set point level entailed shorter time for weir regulators thus allowing a quicker system response than sluice gates. Insignificant differences, instead, are evident in the proportional control phase between the two regulators. Creaco and Franchini [12] presented a new logic algorithm for real-time control of regulation valves in water distribution networks. This method entailed identifying in real time the appropriate closure setting of regulation valves in order to reach and keep the desired water level at the control node(s), by making use of measurements concerning both the water level at the control node(s) and the water discharge in the pipes fitted with regulation valves.

This study proposes a RTC of urban drainage system equipped with a series of gates, functioning as “actuators” that during intense events self-adjust to optimize the storage capacity of the actual sewer. The gradual opening of the gates is based on the storage capacity of the conduit downstream. The advantage of this system is to utilize the full storage capacity of the pipeline by accumulating the excess volumes of rainwater that otherwise would be spilled on the sidewalks and street paving in the pipes with a low water level. The advantage is also from the economic point of view, why do not they build new storage systems/reservoirs from scratch, but it takes advantage of the existing sewer system.

2. Methodology

The study was applied on an urban watershed situated in the city of Cosenza, Italy. The three-dimensional spatial representation of the selected watershed obtained through the Digital Terrain Model (DTM) was coupled with the network of buildings, hydraulic drainage systems and roads in the urban watershed in the Geographic Information System (GIS). Then the urban drainage system was modelled by using the Storm Water Management Model (SWMM) as reported in Fig. 1. The SWMM model allow to predict the hydrological/hydraulic behavior of the urban watershed and drainage system. In SWMM the infiltration process was model by using the Green-Ampt approach, while the wave dynamics method was used to model the flow routing in the conduits. The precipitation data were downloaded from the website of ARPACAL (www.cfd.calabria.it) on hourly basis for the year 2011. Three extreme events were selected from the year 2011 to investigate the response of the urban drainage system. A summary of the main hydrological/hydraulic parameters for three wet weather events is reported in Table 1. The selected events are characterized by a rainfall volume varying from 20 mm to 97 mm. The actual urban drainage system represents the scenario '0'. The watershed is divided into 52 subcatchments and is drained by a free surface system, consisting of a main egg-shaped conduit of 1.2 m and a series of secondary circular pipes of 0.5 m.

To explore the response of the system in the presence of sluice gates, the latter were introduced downstream each secondary pipe, before the connection to the main conduit, as reported in Fig. 2. The approach presented in this paper is characterized by a fully distributed system of self-organizing gates. Several computing nodes are widespread within the network of outflow and suitably connected to sensors which measure the water level, hence the storage capacity in each pipe. The sluice gates are designed to self-regulate in real time in emergency situations and to intelligently manage the capacity of the pipes themselves. The operating principle is designed as follows. If the threshold value of storage capacity is achieved in the downstream pipes, the "event" is recorded at the gate as an "emergency" situation. At this point, the decision process algorithm leads to self-regulation of the gates.

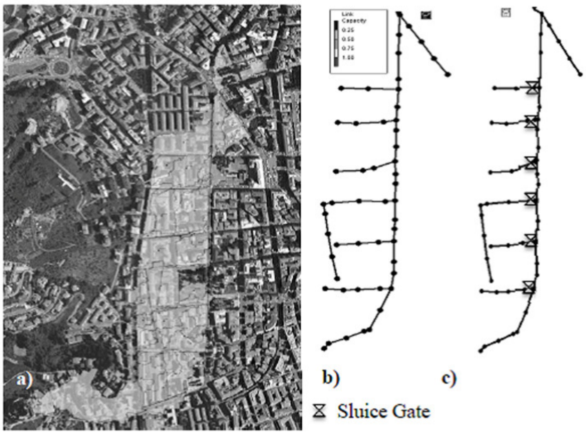

Fig. 1. Urban watershed (a) in the city of Cosenza with the drainage system modelled in in two scenarios: without sluice gates (b) and with sluice gates (c).

The gate was modelled in SWMM by using an object called 'outlet', to which a stage-flow rate relationship was applied. The decision process algorithm is implemented in control rules applied to each outlet. Such control rules adjust the opening of the gates based on the storage capacity of the main conduit, downstream the secondary pipes. This configuration represents 'scenario 1'. In this configuration six sluice gates were introduced. The hydrological/hydraulic simulations performed in SWMM allow to identify the critical sections of the system, where the placement of self-adjusting gates through the urban drainage system can provide a beneficial effect. The control objectives are, in decreasing order of priority: the minimization of overflows, the maximization of the use of the treatment plant capacity, the minimization of accumulated volumes and, finally, the minimization of variations of the set-points.

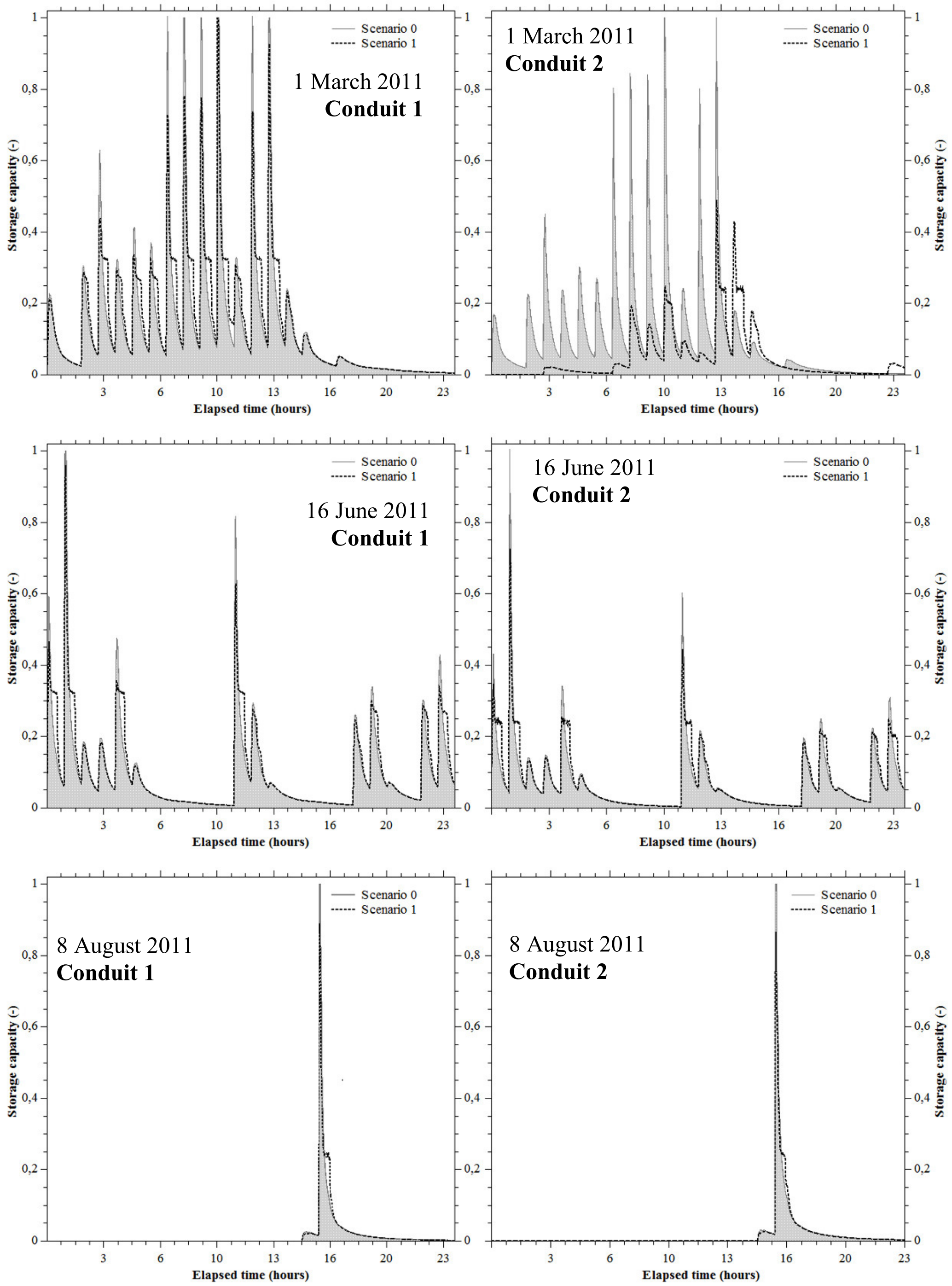

Fig. 2. Temporal distribution of storage capacity during three rain events for two conduits selected in the urban drainage system

3. Results

Two scenarios were analysed in SWMM. The first scenario, called ‘scenario 0’, represents the existing configuration of the urban drainage system in the city of Cosenza without sluice gates. The second scenario, called ‘scenario 1’, represents the configuration with sluice gates placed in the secondary conduits. To evaluate the effect of the presence of sluice gates on the reduction of storage capacity three events occurred in 2011 which put in crisis the system were analysed (March 1st, June 16th, October 8th). Specifically, in ‘scenario 0’ the two most overwhelmed pipes in the main conduit were identified and used, in this study, to demonstrate the beneficial influence of gates in alleviating the most critical sections of the system. The two pipes selected are called ‘conduit 1’ e ‘conduit 2’, respectively. The results obtained from SWMM simulations are reported in Fig. 2 for both scenarios. The temporal distribution of storage capacity throughout each rainfall-runoff event for the two scenarios is reported in Fig. 2. For the three rainfall-runoff events, the storage capacity in ‘scenario 0’ varies up to 100%.

This means that during the three events in some time points the two selected conduits get completely full. In Fig. 2 the distribution of storage capacity for ‘scenario 1’ is also reported. The findings show that the storage capacity in the two pipes in the main conduit is lower when sluice gates are used to control the storm-water volumes. This is due to the fact that when the water level inside the main conduit is higher than a targeted value set to 75%, the gate on the secondary pipe gradually closes creating a storage upstream and diminishing the volume released into the main conduit. The sluice gates provide an effect of delaying of the peak value of storage capacity of the two conduits and, more interestingly, a significant reduction of the water level inside the most overwhelmed pipes. The series of sluice gates in the system produces a transformation between the scenario ‘0’ and scenario ‘1’ storage capacity distributions with the conduit ‘2’, placed downstream with respect to conduit ‘1’, generating the higher reduction in storage capacity.

In Table 1 the average storage capacity reduction for each event is reported. The reduction varies from 22 to 77 %, showing lower value for the event with higher rainfall volume. However, the beneficial effect may be dependent upon the storm characteristics (such as hydrographs, intensity and duration).

Table 1. Three recorded rain events.

Rainfall event	Rainfall volume (mm)	Average Storage Capacity Reduction (%)
01/03/2011	97.40	22
16/06/2011	20.10	60
08/10/2011	48.60	77

This suggests that a series of devices inside the urban drainage systems are actually able to control the flow rate to drop the storage capacity to a reasonable value. The results demonstrate that the use of smart gates provide positive effects on the overall hydraulic performance of the network.

4. Conclusions

To manage flooding in urban areas and to control the capacity of the drainage system below the set value of 75%, set by Italian regulation, innovative technology solutions for real-time control (RTC) of urban drainage networks can be used. This study proposes a RTC of urban drainage system equipped with a series of gates, functioning as “actuators” that during intense events self-adjust to optimize the storage capacity of the actual sewer. The gradual opening of the gates is based on the storage capacity of the conduit downstream. The advantage of this system is to utilize the full storage capacity of the pipeline by accumulating the excess volumes of rainwater that otherwise would be spilled on the sidewalks and street paving in the pipes with a low water level. To evaluate the performance of sluice gates on reducing the storage capacity of the conduits, which are put in crisis, a part of the urban drainage system in the city of Cosenza was analysed. SWMM simulations are carried out to predict the hydraulic response of the system subject to three rainfall-runoff events in the year 2011.

The results demonstrated that the urban drainage system without gates, the GR of the pipeline is more than 75% for almost the entire duration of the event, the network equipped with gates opening with the gradual GR is significantly reduced during the critical event selected. The reduction varies from 22 to 77 %, showing lower value for the event with higher rainfall volume. However, the beneficial effect may be dependent upon the storm characteristics (such as hydrographs, intensity and duration). The findings show that a series of devices inside the urban drainage systems are actually able to control the flow rate to drop the storage capacity to a reasonable value. The results demonstrate that the use of smart gates provide positive effects on the overall hydraulic performance of the network. From the energy point of view, the use of gates can be controlled to minimize the cost of energy required to operate the adjustment parts. In future studies, we will analyse different scenarios of `critical aspects of the network, also taking into account the effects of all inertia of the partition.

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