A TAILORED GREEN-APPROACH FOR MANAGING CSOs IN HIGH DENSITY URBAN AREAS

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KEY POINTS

- *Combined sewer overflows (CSOs) contain untreated or partially treated human and industrial waste, toxic materials, and debris, along with stormwater. They are a priority water pollution concern for municipalities served by combined sewer systems, as it is the case for the Metropolitan city of Milan.*
- *Green-approaches appear suitable solution for mitigating flood risks and pollution hazard without requiring large investment and the allocation of big detention areas.*
- *Combining first-flush tank, constructed wetland system and flow regulation in the receiving water body, both pollutant load and peak discharge can be reduced by as much as 90%.*

1 INTRODUCTION

The rapid and frequently disordered urban development of many areas, associated with the tendency of increasing the mean and maximum daily precipitation heights, affect the rainfall-runoff processes and the pollutant dynamics in such areas, inducing a significant reduction of the efficacy of the existing urban sewerage systems. The consequences of such trends affect particularly the combined sewerage systems (CSS), where a unique network of laterals, mains, and outfall sewers serves for all types of sewage and runoff. These sewerage systems are common in many urban areas, in Italy and elsewhere (ANEA 2015). During severe storms, the flow capacity of this kind of sewers can be exceeded, and the overflow diverted into a receiving water body (RWB) through spillways. An increase in the frequency of spillways activation, in fact, has been observed in the last decades (Ashley et al. 2008), and this trend is expected to continue in the future. Consequently, combined sewer overflows (CSOs) in many cases produce significant water pollution and flooding problems in the RWBs (Casadio et al. 2010). To mitigate such problems the conventional approach in CSOs management is mainly based on large concrete first-flush tanks (FFTs), but the high cost of construction (including the related environmental damages) and the lack of available space in high-density urban areas, hinder the construction of these devices. To face the problem in a new more efficient and less impacting way, "green-approaches" for flow and pollutant loads controls can be implemented through natural water retention measures (NWRM) and constructed wetland systems (CWs). Such low-cost and low-energy treatment techniques through soil and vegetation (macrophytes) activity reproduces natural water purification processes (Toscano et al. 2015), and in combination with a small FFT provide significant reductions in flow and pollution load preserving ecosystem from wastewater (Masi et al. 2017). In addition, these "green-approaches" are strongly encouraged by several water agencies at the European, national, and local level also through laws and

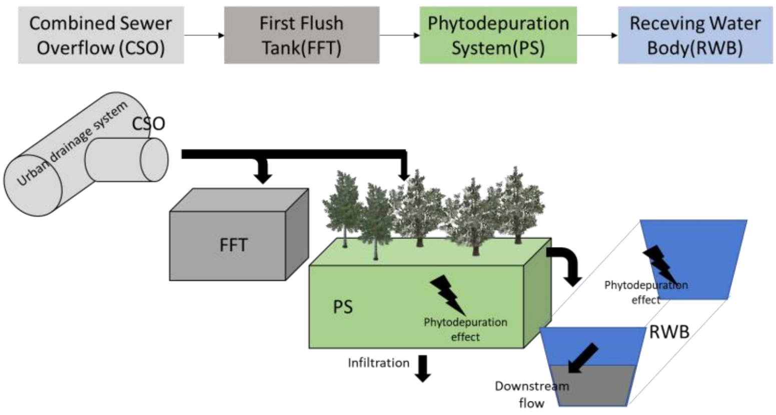

Fig. 1. Schematic representation of the integrated system.

regulations (WFD law 2000/60 CE, D.Lgs. 152/2006, Lombardy regulation 27/2016, Emilia-Romagna regulation 1860/2015). In this perspective, no single standardised solution can be considered conclusive at all locations, and combined structures must be developed. The complexity of the processes involved, asks models able to reproduce the behaviour of the different parts (i.e. FFT, CW, RWB) for a correct design the whole system. In this work, we present the setting up of a parsimonious simplified integrated model which provides both water-quantity and water-quality simulations for each component of the system. This modelling approach, in particular, is expected to respond efficiently to specific design questions frequently rising in several areas of the Metropolitan city of Milan (Northern Italy).

2 SIMPLIFIED MODELLING APPROACH

The approach is mainly based on exploitation of detention, infiltration and self-depuration capacities of CW and RWB components in order to mitigate respectively peak discharge, volumes and pollutions of CSOs. The FFT is anyway adopted, especially to reduce the heavy metal concentrations found in the very first foul flush, which might undermine survival of plants in the other two components and contaminate the environment. However, we consider the volume of FFT no defined a priori in according with regional recommendation (i.e. based on harvesting of the first 2.5-5 mm of rainfall) but designed together CW and RWB components in order that the whole system provides a pollution abatement close to the regional threshold. The proposed model simulates water-quantity and water-quality interactions between FFT, CW and RWB describing FFT, CW and RWB as well-mixed linear reservoirs connected in series (Fig. 1). The phytodepuration effect in the CW, as well as the RWB self-purification capacity, are represented by a first order kinetic of degradation. The interaction among components are described in the following: the CSO is diverted to FFT that, when full, is disconnected by the system (providing the so-called "vertical cut" of hydrograph and pollutograph). The water, therefore, flows downstream (in CW) through a weir. CW, first of all, a free water surface system (provided with storage capacity) but able to afford vertical fluxes (which account for infiltration) and horizontal runoff towards RWB. In general, RWB is usually part of extensive and ramified networks of artificial canals and natural streams, which in many cases may offer significant possibilities to storage. In this case RWB is conceived as a reservoir achieved using a regulating weir able to maintain both upstream storages and downstream flow controls. The phytodepuration effect in CW and RWB changes in according with the residence time of water in these two components. In the former, the residence time might be modulated mainly changing CW area or weir height, while for the latter only changing the weir height. The goal of the model application is to evaluate the discharge and pollutant load abatements depending on system dimension and flow regulation performed in the three components.

3 CONTEXT OF STUDY AND DATA

Metropolitan city of Milan is characterized by more than 70% of urbanized areas, 134 municipalities where reside about 3 million of people. In most cases the urban drainage network (managed by a single integrated water service manager – CAP Holding spa) is constituted by a combined sewer system, with about 2.500 spillways which deliver water especially to rural canals. The presence of residual agrarian lands interconnected with the urban fabric makes this territory suitable for testing the proposed approach. In particular, in the municipality of Sedriano (MI) (characterized by an impervious area of about 60 ha) (Fig. 2a) the water manager needs to deal with the problem of CSOs which currently are discharged in an abandoned area of about 0.1 ha close to the proximal side of a disused irrigation canal. The new requalification project based on the "green-approach" is sketched in Fig. 2b. The FFT volume and CW area will be designed in order to reduce as much as possible the pollutant load, whereas concerning RWB the maximum storage capacity (to avoid backflow in the upstream components) was fixed (about 1900 m^3) and detected by LIDAR data with 1x1m resolution. Since the quantity and quality of CSO in Sedriano is currently unknown, despite the water manager has in plans flow measurements and quality sampling soon, the model was tested with literature data provided by Freni et al. (2008) obtained over real rainfall events occurred in an urban catchment of the sewer system of the city of Bologna, whose constitutive characteristics are very similar to those of Sedriano. The phytodepuration effect is tested considering the whole load of a proxy of pollution level present in the CSO, and expressed as BOD (Biological Oxygen Demand). The same range of degradation constants is assumed for both the CW and the RWB (from 20 to 60 day^{-1}).

a b

Fig. 2. (a) Case study site location. (b) Rendering of the requalification project.

4 RESULTS

The CSO in input to the system is characterized by a peak of flow of about 275 l/s and a total volume of about 700 m^3. Instead, the pollutant load has a peak of about 1060 mg/l as shown in Fig. 3a. The results show that designing the volume of the three component in 100 m^3 of FFT, 350 m^3 of CW and 190 m^3 of RWB can lead to a flow and pollutant load peak reduction of more than 90% (Fig. 3).

a

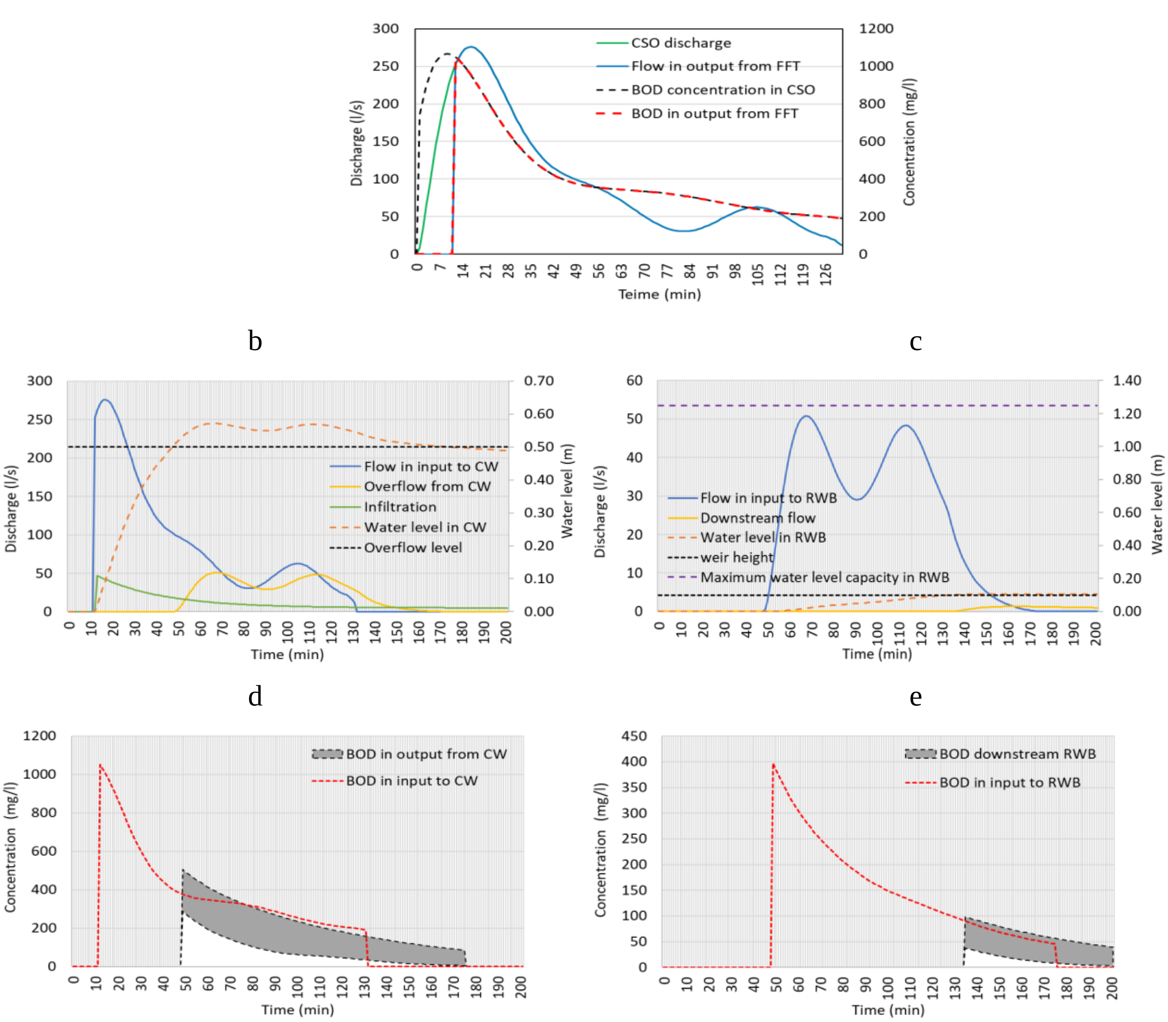

Fig. 3. (a) Flow and concentration in input and in output to FFT, (b-d) water and mass balance in CW, (c-d) water and mass balance in RWB.

The volume of FFT was assumed equal to 100 m^3 in order to delete the first foul flush just after the peak of the concentration in input. This volume is well below the operational standards which suggest to build a FFT of about 25-50 m^3 per hectare of impervious area (that in this case study should be 1500-3000 m^3). CW was designed as a pond of about 700 m^2 with an overflow weir of about 0.5 m high and 1 m long. The infiltration was modelled by Horton equation with a maximum and minimum infiltration rate of 250 mm/h and 25 mm/h respectively, and a decay constant equal to 2 (soil belonging to the group A of the SCS table – SCS 1956). The hydrograph in input to CW has a peak of about 270 l/s while the peak of concentration is about 1000 mg/l (Fig. 3a). The CW stores 350 m^3 of water while about 60 m^3 have been soaked into the soil. The peak of the outflow from the CW component is about 50 l/s (about 70% of reduction), and the corresponding peak of concentration ranges from about 300 to 500 mg/l (about 50-70% of reduction) (Fig. 3b). The remaining part of flow is delivered to RWB that was designed with a storage capacity performed by the introduction of overflow weir. In this case, in first approximation, the overflow weir was considered fixed at 0.1 m over the entire time of spill. By doing so, only a flow peak of about 1.3 l/s releases downstream, with a peak of pollutant load ranging from 30-100 mg/l (Fig. 3c). These values are very close to the threshold for BOD (25 mg/l) provided by D.Lgs. 152/2006 for a good quality of water body. Moreover, as shown in Fig. 3c, the pollution load is close to zero after about 3 hours from the initial input. A rough estimate of the costs shows that the total construction cost of the proposed system amounts to approximatively 150.000 € (50.000 € for FFT, 70.000 € for CW and 30.000 € for RWB requalification) contrary to the traditional approach based only on FFT where the overall cost of the tank of 1500 m^3 would has been about 750.000 €.

5 CONCLUSION

This study was aimed at providing evidence about the possibility to adopt low-cost "green-approaches" for mitigating peak flow, volume and pollution loads of CSO in areas where high density of urbanization occur. In particular, the proposed approach exploits detention, infiltration and self-depuration capacities of natural systems already existing in peri-urban areas, in order to achieve a tailored solution that is suited to the specific context. The findings presented in this work show that combining first-flush tank (FFT) with a constructed wetland system (CW) and finally managing the flows in the receiving water body (RWB) about 90% of pollutant load abatement can be achieved. Therefore, the system can be simultaneously designed to pursue flood risk reduction (abatement of flow peak) and improvement of receiving water quality objectives. Moreover, each component of the proposed system has some peculiarities. For example, CW performs a dual function, i.e. on one hand it cuts the peak of flow thanks to its storage capacity, while on the other hand it reduces the volume thanks to its infiltration capacity. This features are most important especially in the context of "hydraulic-hydrologic" invariance measures (that are becoming more and more present at local scale) where the reduction of peak discharge has necessarily to be accompanied by a reduction of volumes. Further improvements can be obtained through the control of flow in the RWB aimed to maintaining a correct ratio between upstream accumulation and downstream flow control according (i) the variability of flow in input to the RWB and (ii) the downstream canal hydraulic capacity. Flow control can be achieved by installing smart gates that operate automatically based on flow sensors and software-based actuators. Finally, the additional ecosystem services that can be provided by the green components of the system combined with the relatively low-cost of the interventions make the approach particularly attractive for small municipalities where large investments are seldom possible.

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