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Coordinated management of combined sewer overflows by means of environmental decision support systems

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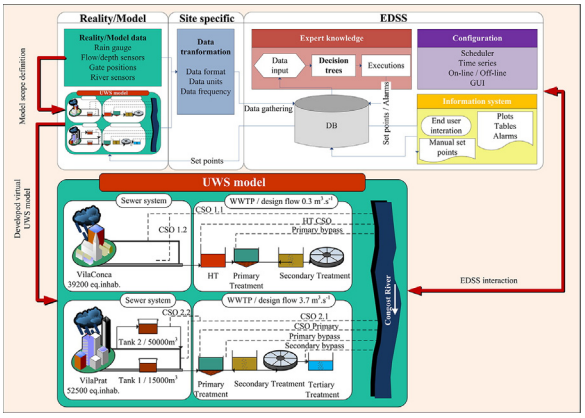
HIGHLIGHTS

- A decision support system was developed for CSO minimization during wet weather.
- The acquired expert knowledge was implemented in a set of 21 decision trees.
- The operational intercomparison illustrated better results for the EDSS mode.
- The expert quality evaluation exposed environmental and economic improvement.

GRAPHICAL ABSTRACT



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ABSTRACT

During heavy rainfall, the capacity of sewer systems and wastewater treatment plants may be surcharged producing uncontrolled wastewater discharges and a depletion of the environmental quality. Therefore there is a need of advanced management tools to tackle with these complex problems. In this paper an environmental decision support system (EDSS), based on the integration of mathematical modeling and knowledge-based systems, has been developed for the coordinated management of urban wastewater systems (UWS) to control and minimize uncontrolled wastewater spills. Effectiveness of the EDSS has been tested in a specially designed virtual UWS, including two sewers systems, two WWTP and one river subjected to typical Mediterranean rain conditions. Results show that sewer systems, retention tanks and wastewater treatment plants improve their performance under wet weather conditions and that EDSS can be very effective tools to improve the management and prevent the system from possible uncontrolled wastewater discharges.

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1. Introduction

During heavy rainfall, the capacity of urban wastewater system (UWS) elements (sewer system, retention tanks and wastewater treatment plants) can be surcharged resulting in uncontrolled wastewater discharges to the environment (Rauch et al., 2002). This phenomena, known as combined sewer overflows (CSOs), can seriously damage the water quality of receiving bodies (Butler and Davies, 2004; Montserrat et al., 2013). As Gasperi et al. (2012) states, it is not only important to reduce the number of CSO spills but also to undertake "control at source" interventions to minimize the presence of hazardous substances in surface water and wastewater with the aim to meet the Environmental Quality Standards (EQS) adopted by the European Commission through the Directive of July 17th 2006. However these may induce to structural-constructive measures which are not always applicable due to economical and physical reasons in real UWS. Besides, in Mediterranean regions, heavy storms are common and the urban network often has steep slopes. In addition the Mediterranean region is likely to suffer more CSO events in the coming years as most climate change models conclude that the it will be more affected by summer droughts, severe storms and higher flood frequency (Meehl and Tebaldi, 2004; Barceló and Sabater, 2010). Therefore, CSOs is still one of the main current and future challenges in UWS management. Even though, UWS elements are traditionally managed separately without considering it as a whole, there is an increasing interest to implement "river basin" approaches in which the different UWS elements, including sewer systems, wastewater treatment plants (WWTPs) and receiving waters are managed in an integrated manner. For medium and large UWS this coordinated management often involves several technical, environmental, socio-economic and political aspects, as well as dealing with large databases and different type of data. Thus, the control and minimisation of CSO loads becomes a complex task and there is a need of advanced management tools within the current setup and leeway of a given UWS. Environmental decision support systems (EDSS) are intelligent information systems that integrate models, databases or other decision aids in a way to help decision-makers in environmental domains (McIntosh et al., 2011; Rizzoli and Young, 1997). EDSS improve the time in which decisions are made as well as the consistency and quality of decisions (Cortés et al., 2000). Bach et al. (2014) state that the use of such type of tools has produced useful integrated models that can actively engage stakeholders, particularly in the water resources management sector. In the recent years new EDSS for the integrated UWS management have been developed as are Argent et al. (2009), Giupponi (2007), Hirschfeld et al. (2005), Makropoulos et al. (2008), Núñez et al. (2004), Paredes et al. (2010).

Hence they seem to be appropriate instruments to minimize CSO spills and therefore also to provide assessment to policy and management authorities in the environmental field. However, it is still difficult to find implementations of EDSS in real case studies (Volk et al., 2010). Besides, no previous bibliographic references exist regarding the use of EDSS for coordinated management of CSOs, where the role of experts, managers and stakeholders becomes increasingly important during the decision making process.

The aim of this work is to develop and test an environmental decision support tool, based on expert knowledge and mathematical modeling, capable of supporting managers in the coordinated management of sewer systems, retention tanks and WWTPs, taking into account the possible impacts on the receiving ecosystem. Effectiveness and benefits of the EDSS application were tested in specially designed virtual UWS mimicking parts of real drainage catchments and WWTP managed by Aqualogy, Clabsa and Sorea, the water utilities partners in this work. Specifically, the UWS under study included two sewers systems, two WWTP and one river subjected to typical Mediterranean rain conditions.

2. Materials & methods

The EDSS developed is based on the methodology proposed by Poch et al., 2004 and consisted of 6 steps:

1. Problem statement.
2. Data collection and knowledge acquisition for optimal CSO management.
3. Development of an integrated model for the UWS.
4. Knowledge base development for the UWS-CSO reduction.
5. EDSS Integration and implementation.
6. Application of the EDSS.

2.1. Problem statement

As stated in the introduction, wastewater discharged directly into the environment during rainfall events is a major problem faced by UWS operators. The management of sewers and WWTP under storm conditions is a complex task due to the number of factors to consider (rain intensity, state of sewers network, capacity of the WWTP) and traditionally has been carried out individually. The aim of this work is to develop an EDSS to improve the management of wastewater spilled from UWS during rain events. Specifically, to show the benefits of using an EDSS to reduce the volume of wastewater and pollution load discharged during SO events.

2.2. Data collection and knowledge acquisition for optimal CSO management

The second task was an analysis of the state of the art on the existing management practices in urban wastewater systems so as to identify current strategies and limitations, and thus to establish the basis for the development of the decision support tool. The analysis of present management strategies was performed by means of 3 sources of knowledge:

i) Study of real cases: performed by means of enquiries and on-site visits to UWS in order to learn from real experiences on management of urban wastewater systems, including examples on configurations, characteristics and dimensions of systems, current operations strategies (coordinated or not) and the problems arising from its daily operation. This task was carried out in close collaboration with managers and operators of sewers and WWTP from the Barcelona area including Aqualogy, Sorea and Clabsa, which have also wide experience in real EDSS applications (Murla et al., 2010; Suñer et al., 2008) and will be end-users of the developed tool.

ii) Analysis of available historical data: performed by means of data mining statistical techniques has contributed in defining statistical tools to acquire knowledge from data. Rainfall records over a period of 20 years (1992–2012) and 23 rain gauges in real UWS were provided by sewer systems and WWTPs operators and analyzed for rain patterns.

iii) Bibliographic research: a comprehensive literature research was carried out to obtain a state of the art of the design criteria and management practices reported world-wide. The traditional approach consists of the separate management of the sewer, WWTP and rivers carried out individually by the operators of each element. Information about the traditional operational was provided by the operators of the industry partners of the work, Aqualogy and Sorea by personal communication.

2.3. Development of an integrated model for the UWS

The third step of the methodology consisted in the development of an integrated model for the UWS under study to apply and test the