Development of a modular Environmental Decision Support System for the Integrated Management of the Urban Wastewater Cycle at River Basin Scale

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ABSTRACT

Most of Urban Wastewater Systems (UWS) have been managed separately, without considering any interaction between sewer systems, Wastewater Treatment Plants (WWTPs) and the receiving waters. Nowadays, the conventional practice has changed, introducing the integrated management concept into the river basin scale. The goal of the project is to develop a modular Environmental Decision Support System (EDSS) to optimise the integrated management of the UWS based on a rule based system as the reasoning core and a Knowledge Base, easily represented by means of decision trees and fully opened. The EDSS, based upon expert knowledge and simulation results, will allow proposing the best solution for each scenario focusing the attention on the water quality of the system. The full paper presented in the conference will illustrate preliminary results of the two first tasks of the modular EDSS development. One of the most relevant advantages of this EDSS tool is that it will be useful for both simple and complex systems and will provide wastewater managers with a decision support tool for the application of the Water Framework Directive, allowing e.g. wastewater managers to consider the effects that an action on the UWS or on the WWTP will have on the performance of the whole system and finally on the receiving ecosystem.

1. INTRODUCTION

In the last decades, an increasing awareness of viewing the Urban Waste Water System (UWS) as a whole system has taken place. This integrated manner includes, at least, the sewer system, Waste Water Treatment Plants (WWTPs) and the receiving bodies. Initially, this type of management was encouraged in order to achieve a design and process optimization of the system whereby water quality indicators had the aim of improving of the receiving environment. Since a few years ago, this motivation has been further inspired by the Water Framework Directive (WFD, 2000/60/EC), which has supposed a crucial change in the European policy on protection of water resources for its ambitious aim to accomplish a "good status" of both surface and ground waters. In order to carry out this objective, it is thus, necessary to consider water bodies as components of ecosystems to be managed at the level of "River Basin Scale".
This new approach results in more freedom in basin management, due to its expansion of the boundaries of the managed system as well as the interaction between them, which

can lead on the one hand, to a better allocation of economic resources in pollution abatement and introduces, on the other hand, complexity in the analysis, due to the synergies emerging from the implementation of different measures to different components of the river basin system

It is clear thus that developing adequate technologies and tools is nowadays a challenge for managers and operators in order to preserve water resources. In this sense, the development of a decision support tool is basic to progress towards a development and real-time control of the integrated wastewater system. It would allow planning and managing collectively all the hydraulic infrastructures (e.g. sewer systems, overflows or WWTPs), i.e. taking into account the effects of each unit when making decision of the management on any other component of the integrated wastewater system.

This paper describes a project whose aim is to develop and test an Environmental Decision Support System (EDSS) that integrates urban drainage and WWTP management, based on mathematical models and artificial intelligence tools fed by expertise knowledge. In order to achieve this objective, the assignment of different phases and subtasks reveals the methodology employed (Section 2). Each developed task produces its results discussed in Section 3 and, finally Section 4 analyses the strengths and weaknesses of the approach, together with concluding remarks and proposed elements for further research and EDSS developments.

2. METHODOLOGY

The path foreseen to achieve the goal of the project has been divided into 3 different phases:

Phase 1: A State-of-the-art of coordinated management of urban drainage systems and WWTP's has been carried out. It comprises the development and analysis of present strategies by means of enquiries, bibliographic research, technical visits, interviews and analysis of historical data.

Phase 2: Includes the development and testing of an EDSS prototype and comprises the improvement and the following subtasks: (i) ontology building (compilation and generalization of knowledge and representation in rules; (ii) proposal of strategies for integrated management; (iii) integration of mathematical models; (iv) development of the Environmental Decision Support System Prototype; (v) test of several scenarios on a virtual system; finally, (vi) development of guidelines for coordinated operation of the systems.

Phase 3: Includes pilot implementations of the EDSS prototype. Previously, two different scenarios are proposed: a complex dynamic network in a metropolitan area (Barcelona) and a de-centralized medium sized system (Osona). This final phase also includes the building of a development and implementation protocol of an EDSS for any other future scenario.

Virtual system requirements

In the one hand, it is clear that the definition of a virtual system has to be based on a real one in order to maintain in an accurate mode proportionalities of every component of the integrated system. But in the other hand, the virtual system to be modelled has to remain as open and modular as possible so as to be adaptable and suitable for any other case study.

As explained in previous sections, two different scenarios are defined:

(i) A complex urban area, with multiple catchments and several industrial discharges, and (ii) and medium de-centralized catchment area. For some particular cases, an interconnection between them is introduced allowing wastewater bypass from the small catchment area to the big one.

Storm tanks, pumped out pipes, flow sensors, quality stations, gates and Combined Sewer Overflows (CSO) points are the set of elements included in the sewer system for both systems. In addition, WWTP's enclose typical configurations as inclusive pre-treatment, primary settler, anoxic and aerobic reactors with nitrogen and carbon removal and finally secondary settlers

A single river is modelled as the only receiving environment of the produced wastewater.

Software definition

Once the virtual system to model has been described, a software package must be chosen. Of the several available software packages to model flow and water quality WEST® (Wastewater treatment plant Engine for Simulation Training and Automation) (MOSTforWATER N.V., Kortrijk, Belgium) version 3.7.2 has been chosen as unique software platform due to its swiftness to simulate the whole integrated system and to its communication simplicity linking each sub-system (sewer system, WWTP and receiving body).The main application of the software is the modelling and simulation of wastewater treatment systems, but actually, any kind of process that can be described by differential and algebraic equations (DAEs) can be represented in and simulated by WEST®. This gives the user autonomy to build or modify the model in order to suit the requirements of the system to be simulated. Simulations results in WEST® can lead to new knowledge of the system, which can be later useful to adapt the decision tree for each scenario tested.

In an analogous mode, the Barcelona sewer system management company provides the project the model of the sewer system of Barcelona and Mataró (Catalonia, Spain) modelled with the commercial urban drainage model MOUSE® (DHI, 2005) which is very useful as, they supply hydraulic robustness with the simulation results of the sewer system model, taking into account that a previous simplification of both systems must be made. The MOUSE® package is one of the most widely used tools for the analysis of urban drainage problems. Different modules are available within the MOUSE® package for describing the hydrological effects and the hydraulic performance of sewer systems. The hydrological processes are described with a general hydrological model, Mouse RDII (Rainfall Dependent Inflow and Infiltration). The hydraulics of the sewer system, e.g. overflows, storage, controllable structures, etc., are described using St Venant's equation in the hydrodynamic model Mouse PIPE.

From a computing standpoint, the rules engine used to develop the expert system is the software package Logic Programming Associates (LPA®). LPA allows designing and building much kind of Artificial Intelligence tools. In this case Rules are developed with Visirule, an editor's own software which allow developing rules in a completely visual form, much more intuitive and easier to develop in the point of view of a modular EDSS, so that the user can change rules without much informatics knowledge.

3. RESULTS

State-of-the-art review

One of the most remarkable results of phase 1, is the knowledge acquired through the State-of-the-art review, the enquiries performed, the bibliographic research and the technical visits which are extracted in Table 1.

Table1. Knowledge acquisition approach of Phase 1.

	Elements	Variables	Sensors	Control action
In-stream	Urban land Industrial discharges Raining events	Discharges: urban flows Toxics: Zn, Cr Forecasts - Radar images Quantity of water in raining events	Radars Rain gauges	Phone call Alarm Warning message
UDS	Pipes Weirs / valve Pumping stations Storm tank	Levels Flows Opened/Closed valves	Level sensors Flow meters	Flow control Wastewater retention Flow equalization
Waste Water Treatment Plant	Pre-treatment Mix Tank - 1 Primary treatment - 2 Settler2 Biological reactor - 2 O + 2 AO Secondary clarifiers - 2	Influent flow rate Level of tank Level of sludge blanket influent: MES, DQO, DBO, NH4+, NKT effluent: MES, DQO, DBO, NH4*, NKT OD aeration basins MLSS, Q w	Level sensors Flow meters Levels of sludge blankets OD aeration basins	Flow control : Tank, Primary, Secondary, bypass, sludge Oxygen control
Media	Discharges in the river	Flow Turbidlity, conductivity, pH, T DO NH4+	Flow sensor Quality sensors	

Ontology building

Once the knowledge acquisition is accomplished, a brief review of phase 2 is carried out in order to create a list with the main decision trees needed to be introduced in the EDSS prototype (Figure 1).The goal of this first decision tree approach is to identify the key problems occurring in the whole system with an integrated point of view, so that the resulting management strategy is designed to cope the Integrated River Basin management.

An important goal that must be also reached is the hierarchy of these decision trees as it is a requirement of the computing architecture of the EDSS prototype. Two types of meta-trees have been distinguished: (i) Rain tree and rain prediction tree, and (ii) Cascade trees (include industrial discharge; sewer anomaly; WWTP anomaly; sensible receiving environment; and finally dry weather flow).This hierarchical system works so that the negativity of all the decision trees converge into a diagnostics where no complication is going on and the EDSS considers dry weather flow operation

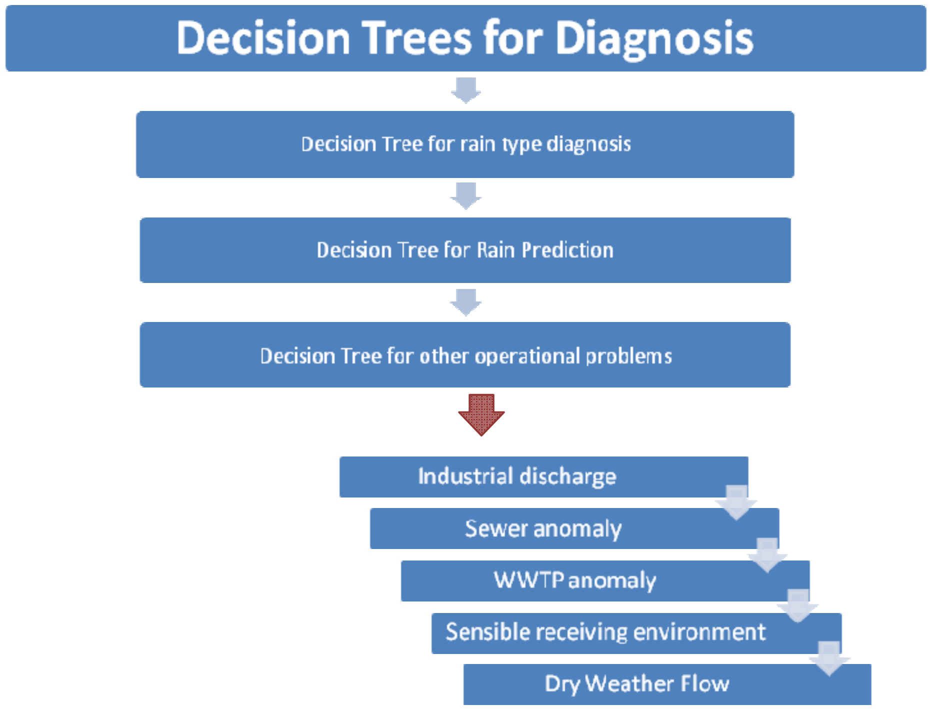

Figure 1. Hierarchy of decision trees for diagnosis

Decision tree development

As the decision tree for diagnosis has been done, each decision tree must be individually developed maintaining its hierarchy between them, i.e. each decision chosen by a decision tree cannot have any effect on the operation of any other decision tree. From the key problems of the whole integrated system acquired in phase 1, rain has the most significant weight as its effect on the system is major. Figure 2 shows how the decision tree for rain type diagnosis, developed in LPA software package, asks different questions to several key elements of the system in order to, not only detect whether it rains or not, but also if there are any predicting rain alarms in the immediate future, or if the wastewater retention tanks, are storing wastewater from previous events. For example, in the left side of the figure, the system detects if it is a new rain episode or not by making the question "rain event [REv]?" If the result is "=0" a new rain episode is starting, if the answer is "=1", it is still raining. After that, a new question is made "Storage 2 capacity [%St]"? If the answer is "=0", tank 2 has no storage capacity, if the answer ">0", rain water can be stored in tank 2.

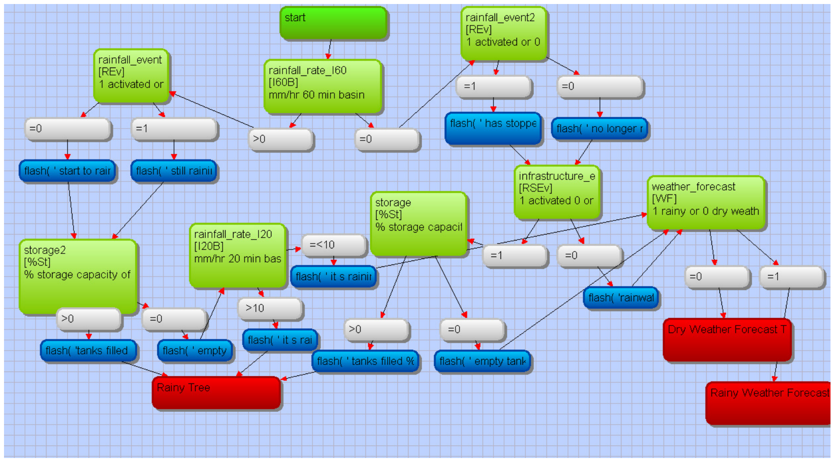

Figure 2. Decision tree for rain type diagnosis

Definition of the virtual system

Vic (Osona, Catalonia, Spain) and a generalization of Barcelona (Riera d'Horta and Bogatell neighbourhoods) constitute the two connected communities defined as the virtual system to work with for the EDSS prototype (Figure 3). The main features are summarized in Table 1

Moreover, the sanitation system has four CSO points. Two of them are in the sewer system, before the interceptor collector connection. A third point is located in the WWTP header and, finally, the last one is the discharge point of the treated wastewater. Finally, the receiving body is inspired by the Congost River on its way to Granollers with a total length of 15Km and an average flow rate of 0.4m3/s. This flow rate is subjected to very strong seasonal variations, due to its typical Mediterranean situation. Its quality is also highly variable depending on the effluent quality of the WWTPs.

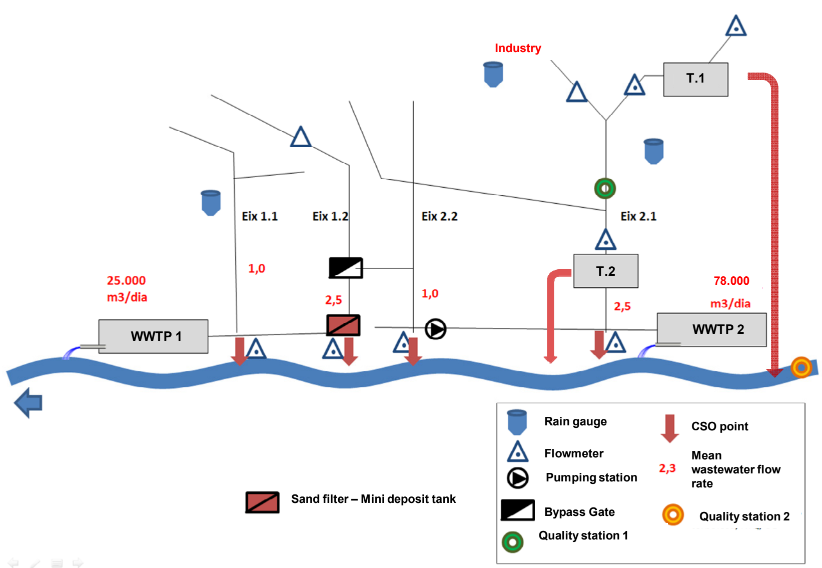

Figure 3. Virtual system scheme.

Table 1. Catchment and WWTP properties of the two studied communities

		Vic	Bcn
Catchment	Total surface area (Km^2)	30,6	19
	Wastewater production (m^3/d)	23.000	78.000
	Total inhabitants (IE)	39.200	525.000
	Number of tanks	1	2
	Pumping stations	Yes	Yes
WWTP	Basing WWTP	Mataró	35% Bcn
	Activated Sludge Model process	Yes	Yes
	Other components in WWTP	Homogenization tank	Tertiary treatment *

Model configuration

Integrated managing of the system is carried out by WEST®, used as single modelling platform. This software, allows simulating the system and to distinguish various management options on the whole system's effect.

A modified version of the KOSIM model implemented in the WEST model library (Solvi *et al.*, 2005) is the basing catchment and sewer system construction. The KOSIM model adopts the tanks-in-series approach to model flow and pollutants transport. The two WWTPs are modelled using the Activated Sludge Model no. 2d (ASM2d) (Henze *et al.* 2000). This model comprises carbon, nitrogen and phosphorous removal processes.

Finally, the River Water Quality Model no. 1 (Reichert *et al.* 2001) is used as the river model approach and, as the final step of the model construction. It will be stretched according to the main geometry characteristics of the studied river.

Testing scenarios

Several scenarios have been taken into account trying to emulate reality in order to acquire knowledge and to test the validity of the prototype:

The considered scenarios are:

1. Reducing the number of CSO discharges during rain or storm events is the goal of this scenario. As it has been mentioned, the main focusing managing strategy is the behaviour and running of the virtual system under different rain events in order to minimize direct pollutant discharges to the receiving environment.

2. Measure the discharging impact in the receiving waters under different conditions during rain events. The impact of the CSO episodes of the previous scenario will be considered under different river conditions (normal flow rates, low flow rates or poor water quality) trying to discover if a better sewer system management allows a significant improvement of the river quality compared with the normal management strategy of the sanitation system.

3. Dry weather flow conditions. This scenario is considered the reference one, which will be used to compare among the testing scenarios. No rain or storm events, as well as no trouble in the sewer system neither in the WWTPs and river in study set up the dry weather flow conditions.

4. Pumping problems in the WWTP inflow in dry weather conditions. Pumping stations can lead to diverse WWTP malfunctions and this can imply an impact to the final water quality in the receiving environment.

5. Industrial discharges can generate several problems with the sewer system and to the WWTP inflow too. As already mentioned an industry has been taken into account in the virtual system. Download flows and rare wastewater qualities are studied since they can cause severe impacts on the biological process of the WWTP and to the elimination of both carbon and nutrients of the wastewater.

4. CONCLUSIONS

The knowledge extracted in Phase 1, together with some experts and stakeholder's contribution has allowed defining the main requirements to be considered in the construction of the virtual system in study, as well as the different scenarios to be considered for the integrated system.
A new concept of EDSS has been taken into account. This point of view provides a global perspective of the whole system, with more freedom where all subsystems are involved each other due to its effect on the integrated systems. The development and construction of a modular EDSS must allow sufficient adaptability for other scenarios, and must be easily reconfigured in order to fit new goals and new challenges.

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6. REFERENCES

Benedetti, L., Meirlaen, J., Sforzi, F., Facchi, A., Gandolfi, C. & Vanrolleghem, P.A. 2007, "Dynamic integrated water quality modelling: A case study of the Lambro River, northern Italy", *Water SA,* vol. 33, no. 5, pp. 627-632.

Butler, D. & Schütze, M. 2005, "Integrating simulation models with a view to optimal control of urban wastewater systems", *Environmental Modelling and Software,* vol. 20, no. 4 SPEC. ISS., pp. 415-426.

Cortés, U., Sànchez-Marré , M., Ceccaroni, L., Rodríguez-Roda, I. & Poch, M. 2000 "Artificial intelligence and environmental decision support systems". *Appl. Intell*. 13(1), 77–91.

Devesa, F., Comas, J., Turon, C., Freixó, A., Carrasco, F. & Poch, M. 2009, "Scenario analysis for the role of sanitation infrastructures in integrated urban wastewater management", *Environmental Modelling and Software,* vol. 24, no. 3, pp. 371-380.

DHI (1994). Mouse trap vs.1.00. User manual and Technical reference.

EU 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal L 327, 22/12/ 2000, pp. 0001e0073,

Gelormino, M.S., Ricker, N.L., 1994. Model predictive control of a combined sewer system. International Journal of Control 59 (3),793e816.

Harremoës, P. and Rauch, W. (1996). Integrated design and analysis of drainage systems, including sewers, treatment plant and receiving waters. *Journal of Hydr. Res.*, **34**(6).

Meirlaen, J., Huyghebaert, B., Sforzi, F., Benedetti, L. and Vanrolleghem, P. (2000). Fast, parallel simulation of the integrated urban wastewater system using mechanistic surrogate models. *Wat. Sci.Tech.*, **43**(7), 301–309.

Poch, M., Comas, J., Rodríguez-Roda, I., Sànchez-Marré, M. & Cortés, U. 2004 Designing and building real environmental decision support systems. *Environmental Modelling and Software*. 19(9), 857–873.