Development of an integrated system for early warning of recreational waters contamination

Développement d'un système intégré d'alerte précoce de la contamination des eaux de loisirs

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RÉSUMÉ

Un système d'alerte précoce des évènements de pollution des eaux de loisir est en développement, dans le cadre de trois projets de recherche. Le système est appliqué à l'estuaire du Tage et prend en compte la décharge du bassin versant d'Alcântara, le plus grand de Lisbonne. Ce système intègre explicitement la surveillance et la modélisation des différents processus physiques et de contamination, du bassin versant jusqu'à l'estuaire, aux échelles temporelles et spatiales appropriées. Ce travail inclut les activités suivantes: 1. la sélection de la zone pilote et la collecte de données; 2. la modélisation numérique (du réseau d'assainissement et de l'estuaire); 3. des levées expérimentales; 4. le suivi en ligne de paramètres hydrauliques et de qualité des eaux (réseau d'assainissement et estuaire); 5. l'intégration des modèles et des données de surveillance au sein d'une plate-forme informatique pour le contrôle en temps réel, basée sur une plate-forme existante pour l'hydrodynamique de l'estuaire (http://ariel.lnec.pt); 6. le développement d'un système-prototype d'alerte précoce basé sur le système intégré de modélisation et de surveillance en temps réel. Les trois premières activités sont sur le point d'être terminées. Des stations de surveillance de qualité des eaux sont en cours d'installation et l'intégration des modèles au sein de la plate-forme est en cours de développement. Cet article décrit la méthodologie et les résultats préliminaires de ce système d'alerte précoce.

ABSTRACT

An early warning system for pollution events of recreational waters is being developed, within the scope of FP7 "PREPARED – Enabling Change" project and the Portuguese SIMAI and SI-GeA projects. The system is being applied to the Tagus estuary, accounting for the impact of the outfall from Alcântara combined catchment, the largest catchment of Lisbon.

This system explicitly integrates the monitoring and modelling of the different physical and contamination processes from the catchment to the receiving water, at the appropriate spatial and temporal scales. The work includes the development of the following key activities: 1. Selection of the pilot area and gathering of data; 2. Mathematical modelling (sewer system and estuary); 3. Experimental surveys; 4. On-line monitoring of hydraulic and water quality parameters (sewers and estuary); 5. Integration of the models and monitoring data within a computational platform for real-time control, based on an existing platform for the estuary hydrodynamics forecast (http://ariel.lnec.pt); 6. Development of a prototype early warning system based on the integrated monitoring and modelling system and on the real time forecast platform. The first three activities are almost completed. Water quality on-line monitoring stations are being installed and models integrated within the platform. This paper aims to describe the methodology and the preliminary results for this early warning system.

KEYWORDS

Early warning systems, Integrated modelling, On-line monitoring network, Real time management, Recreational waters

1 INTRODUCTION

The quality of bathing and recreational waters can be significantly affected by the discharge of wastewater, stormwater or combined sewer overflows (CSO) from urban drainage systems.

The EU Water Framework Directive (2000/60/EC), establishing a framework for Community action in the field of water policy, provides in a new vision for water management, which enforced Member States to develop several concerted actions to achieve the good status for water quality by the end of 2015. This policy defined various stages for water resources planning and implementation of measures, which include the identification of pressures, water monitoring, public information and the application of strategies for pollution control, namely for the control of point and diffuse discharges. In this framework, two new EU Directives of great importance were published later: the Directive 2006/7/EC, concerning the management of bathing water, and the Directive 2007/60/EC on the assessment and management of flood risks. The Directive 2006/7/EC provides for the establishment and maintenance of surveillance systems and early warning systems to identify pollution incidents that may have an adverse effect on the quality of bathing water, including those resulting from extreme weather conditions. This Directive is limited to bathing water, not covering recreational waters, although warning systems can be applied to other cases, promoting preventive attitudes and timely intervention actions.

Surveillance and early-warning systems require real-time monitoring networks as well as forecasting tools that enable the anticipation of critical events and assist decision-making to mitigate their effects. These systems have received a great development in the last decade, particularly in estuarine and coastal areas, to predict the hydrodynamics and propagation of sea waves (e.g. Jesus et al., 2012; Baptista, 2006). However, monitoring and forecasting processes related with water quality still involve a number of challenges to allow for reliably early warnings, particularly when involving processes with very different spatial and temporal scales as well as receiving waters with a very complex environmental matrix, such as estuaries.

Within the EU “PREPARED – Enabling Change” project (http://www.prepared-fp7.eu/) and the Portuguese SIMAI and SI-GeA projects, a pilot early warning system for the contamination of recreational waters is being developed. The system is being applied to the Tagus estuary, accounting for the impact of the outfall from Alcântara combined catchment, the largest catchment of Lisbon.

2 METHODOLOGY

The system explicitly integrates the different processes involved from the catchment to the receiving water, at the appropriate spatial and temporal scales. The work includes on-line monitoring, experimental surveys, data analysis and laboratory techniques and the use of mathematical models. The integrated use of models and data provided by diverse monitoring and forecast networks is managed within a real-time forecasting platform. The methodology includes the development of the following key activities:

1. Selection of the pilot area and gathering of data;
2. Mathematical modelling (sewer system and estuary);
3. Experimental surveys and calibration of models;
4. On-line monitoring of hydraulic and water quality parameters (sewer system and estuary);
5. Integration of the models and monitoring data within a platform for real-time control, based on existing platform for the estuary hydrodynamics forecast (http://ariel.lnec.pt);
6. Development of a prototype early warning system based on the integrated monitoring and modelling system, on the real time forecast platform and on innovative predictions of fecal processes based on field data and laboratory experiments.

The first three activities are almost completed. Water quality on-line monitoring stations are currently being installed and models being integrated within the platform.

3 PILOT AREA SELECTION

The city of Lisbon has an extended water front to the Tagus estuary and is divided in several stormwater catchments, as shown in Figure 1. Despite the sewer systems are separate in most upstream catchment areas, the downstream sewers are combined and therefore there are several combined sewer overflows (CSO) in the low-lying area.

The city is served by three wastewater treatment plants (WWTP), of which the Alcântara WWTP serves the larger area. The Alcântara WWTP is located at the downstream area of the Alcântara urban catchment, which has about 3200 ha from Lisbon and Amadora Municipalities and is the largest catchment of Lisbon.

Currently 60% of the dry-weather flow reaches the WWTP by gravity (through the main interceptor sewer, caneiro de Alcântara) and 40% is pumped from downtown areas and neighbour catchments. The WWTP was designed to serve 670 000 inhabitants equivalent with secondary treatment. The WWTP effluent is returned to the Alcântara trunk sewer and is discharged in the Tagus estuary 2 Km downstream (David et al., 2011).

The main sewers of the Alcântara catchment are 250 km long, having about ten different cross-section profiles, with widths varying from less than 0.80 m to 8 m. The riverside downtown area is subject to flooding due to several factors, namely the low slopes, the influence of the Tagus estuary tide level and the conditions for deposition of sediments and organic matter.

The stormwater and wastewater urban cycle management in the city of Lisbon is closely linked to the Tagus estuary, the receiving body for the effluents. The outfall from the Alcântara catchment is the largest stormwater and WWTP effluent discharge point to the estuary and, therefore, the Alcântara catchment was selected for the pilot study.

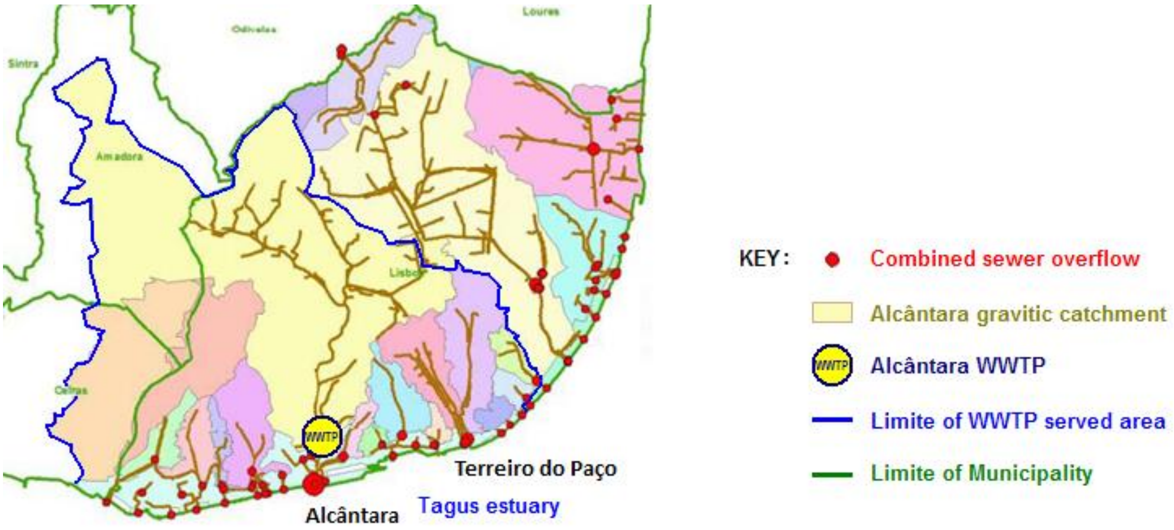


Figure 1 – Alcântara and other catchments of Lisbon

4 MATHEMATICAL MODELLING

4.1 Urban drainage model

The mathematical model of Alcântara catchment was built in SWMM (Rossman, 2007). It only represents the main sewer network and catchments, having 39 nodes, 40 links and 22 catchments (Figure 2). The model was preliminary calibrated for two successions of events (Figure 3a and b) and verified for two events (Figure 3c) (Frazão, 2012). Despite acceptable results have been obtained for more recent rain events (Figure 3d), the model is being recalibrated for a much larger set of data.

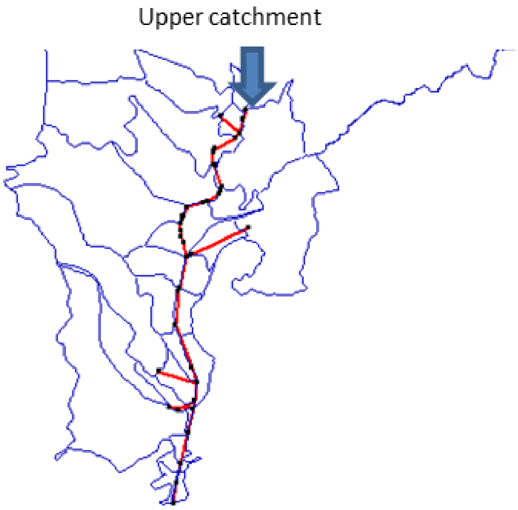
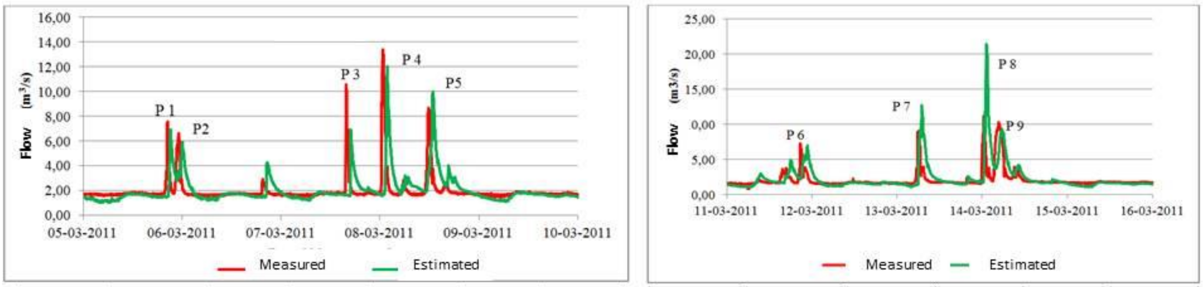
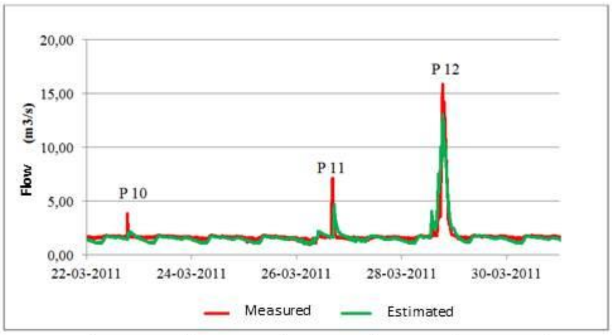


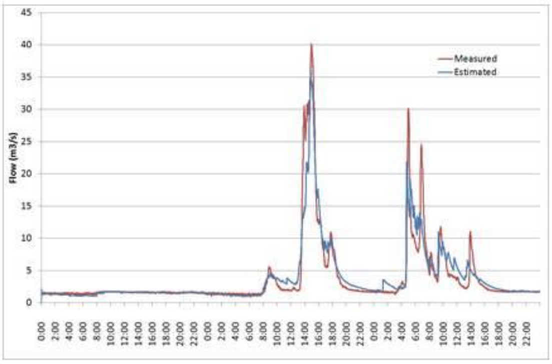
Figure 2 – Alcântara catchment model.



Errors (%)	Volume	Pic Flow 1	Pic Flow 2	Pic Flow 3	Pic Flow 4	Pic Flow 5
	-1,86	8,3	16	46,4	9,9	-15,4

Errors (%)	Volume	Pic Flow 6	Pic Flow 7	Pic Flow 8	Pic Flow 9
	-7,8	4,0	-41,1	-91,3	10,1





Errors (%)	Volume	Pic Flow 10	Pic Flow 11	Pic Flow 12
	5,37	42,8	34,3	18,0

Figure 3 – Model calibration and verification: a) and b) events used for calibration; c) events used for verification; d) model results for a recent large event (adapted from Frazão, 2012).

4.2 Estuary model

The coupled hydrodynamic and fecal contamination model of the Tagus estuary is based on the model by Rodrigues et al. (2011). The model application in the Tagus estuary derives from the three-dimensional barotropic application of the hydrodynamic model SELFE in this estuary, as described by David et al. (2012), extended to account for the outfall from the Alcântara catchment (Figure 4a). The baroclinic model was validated with salinity and temperature data from 1988 (Figure 4b), covering a range of environmental conditions.

A preliminary analysis of the coupled hydrodynamic and fecal contamination model was also performed to evaluate the area of influence of the discharge from the Alcântara outfall (Costa et al., 2012). These scenarios accounted for different environmental and discharge conditions (dry- and wet-weather periods) (Figure 5). The model will be further validated with the data acquired during the experimental surveys and the on-line monitoring.

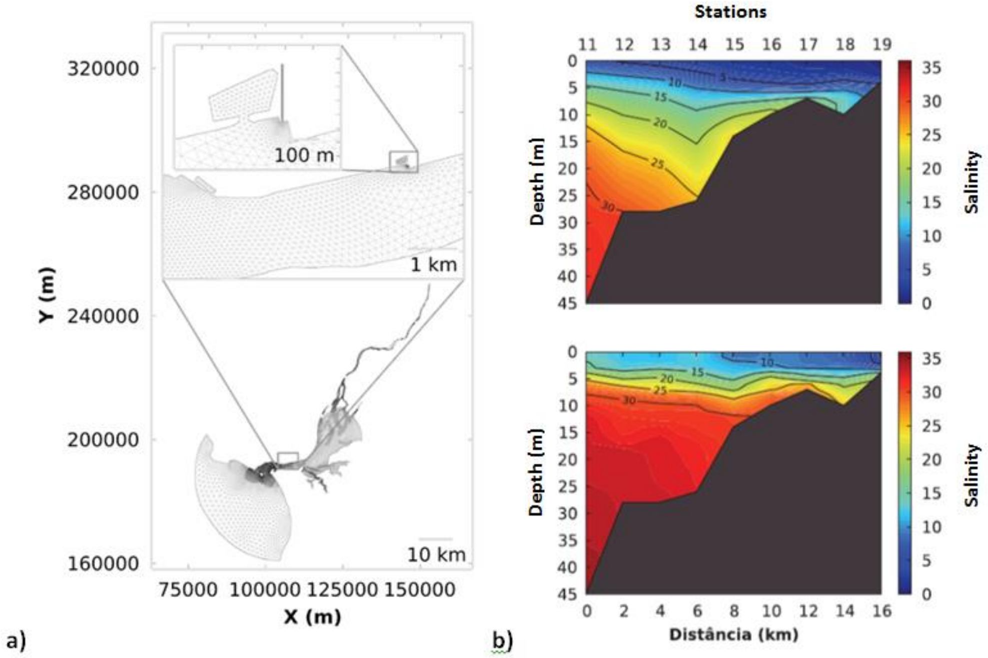


Figure 4 – (a) Horizontal computational grid and detail of the discharge from the Alcântara main trunk and (b) simulated (top) and observed (bottom) salinity vertical profile along a longitudinal section of the Tagus estuary (adapted from Costa et al., 2012).

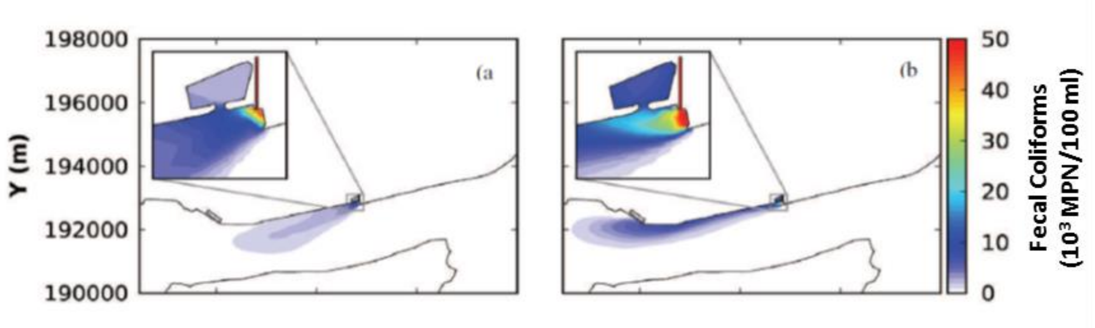


Figure 5 – Preliminary analysis of the area of influence of the discharge from the Alcântara outfall, during ebb, for: a) dry-weather (23/07/2011) and b) a wet-weather event (23/01/1996).

5 EXPERIMENTAL SURVEYS

Aiming to improve models validation and integration, a set of field surveys was planned to synoptically characterize hydraulic and water quality parameters from the sewer and the estuary. Four water quality stations were selected in the sewer system and three in the estuary (Figure 6). The sewer stations are located at: the Alcântara main trunk, just upstream the WWTP (section 5 of Figure 6); the WWTP outlet to Alcântara main trunk (section 4); one important pumping station in the low lying area (section 6); and the downstream manhole of Alcântara main trunk, just upstream the outlet to the estuary (section 2, with joint influence from the sewer and estuary). The estuary stations are located: near the discharge of the Alcântara outfall (station 3), donwsntream the discharge under the Bridge 25 de Abril (station 1), and upstream of the study area at Terreiro do Paço (section 7), in order to evaluate the water quality of the estuary in an area away from the influence of the Alcântara outfall.

Two experimental surveys were carried out in the summer, both for dry-weather conditions and for 13 hour-periods, to allow the characterization of a complete tidal cycle (8:30 to 21:30): one during spring tides (amplitude of 3.2 m) and the other during medium tide (amplitude of 1.7 m). Two additional surveys are planned for wet-weather conditions.

For the 13 hours of each survey, hourly and synoptic measurements of the following parameters were measured by probes: temperature, pH, conductivity, salinity, dissolved oxygen and ammonia. Every four hours samples were collected for laboratory analysis of the following physic-chemical and microbiological parameters: pH, turbidity, conductivity, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD5), ammonia, nitrite plus nitrate, phosphates, fecal coliforms and *Escherichia coli*. In sewer sections 5 and 6, UV-Vis spectrophotometric probes (from S::SCAN) were installed for continuous measurement of parameters such as TSS, COD, CODf, BOD and nitrates. Concentrations measured by these probes during sampling were very close to those determined by the laboratory, for the two dry-weather surveys.

Figure 6 – Location of the water quality stations (blue circles for the sewer stations; yellow circles for the estuary stations)

Results from these surveys were used in the preliminary analysis of scenarios presented in section 4 and will contribute for the integrated model calibration for dry- and wet-weather conditions.

Additionally, a number of surveys will be carried out in sections 5 (sewer) and 3 (estuary) of Figure 6, where UV-Vis spectrophotometric probes are being installed for on-line monitoring (see next section). The main aim of these surveys is to assess the quality of the measurements provided by the UV-Vis spectrophotometric probes, mainly for wet-weather conditions, and to study relationships between parameters that may assist the establishment of contamination warnings. These relationships will constitute the core of the forecast for fecal contamination and part of the support for early-warning system.

Complementarily, the fecal contamination indicator *Escherichia coli* will be determined by standard methods and a biochemical methodology that is being developed in the laboratory.

6 ON-LINE MONITORING SYSTEM

Data from several online monitoring networks will be used to validate and continuously assess the quality of the predictions of the integrated modelling and to provide confidence to the produced alerts.

The rapid monitoring of water quality is a top research topic, for which there are still no reliable sensors on the market for several parameters. Thus, ammonia measured by sensors and parameters measured by UV-Vis spectrophotometric probes (such as SST, CQO, CBO, nitrates) may be used as base parameters for continuous verification of the real time water quality modelling.

Within this pilot study, two on-line monitoring stations will be installed, one in the estuary and the other in the sewer main trunk (sections 3 and 5 of Figure 6), despite a greater number of stations would be desirable given the system's complexity. The monitoring system will be working over a period of several months.

Local conditions were decisive for the selection of the location of monitoring stations. Many factors were considered for the selection, namely: guaranteed power supply, accessibility for normal and exceptional maintenance, stability of the measuring conditions, and the protection of the submerged probes from waves, flooding, shocks, debris accumulation, robbery and vandalism. Full details for the permanent installation of the equipment are currently being finalized.

The validity of this methodology will be evaluated by carrying out a number of experimental surveys that allow characterising the water quality in laboratory and seek relationships between the parameters measured by the two methods.

The monitoring system from SIMTEJO, the WWTP and main interceptors utility, allows for the transmission of on-line data from three raingauges and from some flowmeters installed in the sewer network, including one in the Alcântara main trunk, just upstream of the WWTP. In addition to this network, data provided by other on-line networks will be added to the system, as for example the on-line rainfall data from several raingauges provided by the Wunderground internet system (http://portuguese.wunderground.com/global/stations/08536.html).

Throughout the project the quality and robustness of this additional information will be analysed in order to evaluate the potential benefits from its use in the on-line monitoring system. These benefits may allow not only a greater quantification of the rainfall spatial distribution, but also increase the system robustness in case of information failure from other stations. Figure 7 shows the raingauge networks used. As an example of the preliminary treatment given to the collected information, Figure 8 compares the accumulated values during the first 5 months of 2012 measured by the several raingauges available on the Wunderground internet system. The application of the accumulated double mass method already allow to identify some raingauges with systematic biases in relation to the other raingauges, which should not be attributed to the spatial rainfall distribution.

Other on-line data from Lisbon Port and from the National Information System for Water Resources (SNIRH) are also being included.

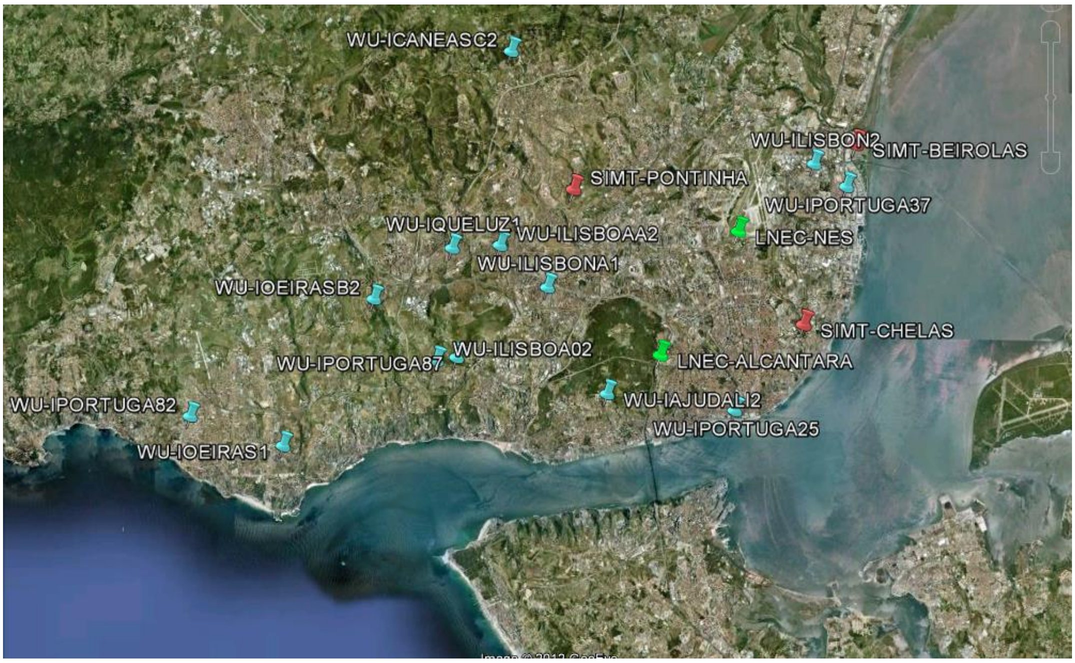


Figure 7 – Raingauge networks.

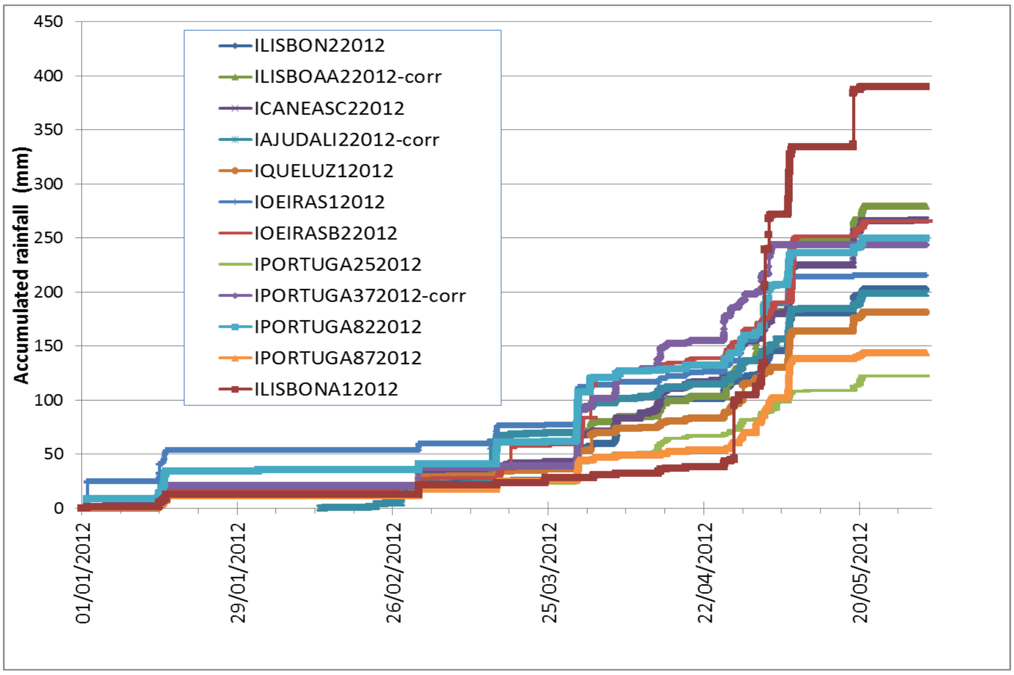


Figure 8 – Accumulated rainfall for selected raingauges from the Wunderground network.

7 REAL TIME WATER QUALITY MODELLING SYSTEM

The real time water quality modelling of the integrated system Alcântara outfall – Tagus estuary, will be performed using the RDFS-PT platform (http://ariel.lnec.pt). This platform integrates numerical models and field data, a set of scripts and programs, and an interface for visualization (Jesus et al., 2012). The numerical models currently integrated in the RDFS platform allow for the prediction of the water levels, currents, salinity, water temperature and waves in several coastal systems (Portuguese coast, Tagus estuary and Ria de Aveiro).

Two sources of rainfall forecast will be used for the study: the University of Aveiro model forecasts and the Windguru internet site forecasts (http://www.windguru.cz/pt/). Figure 9 show both rainfall forecast networks.

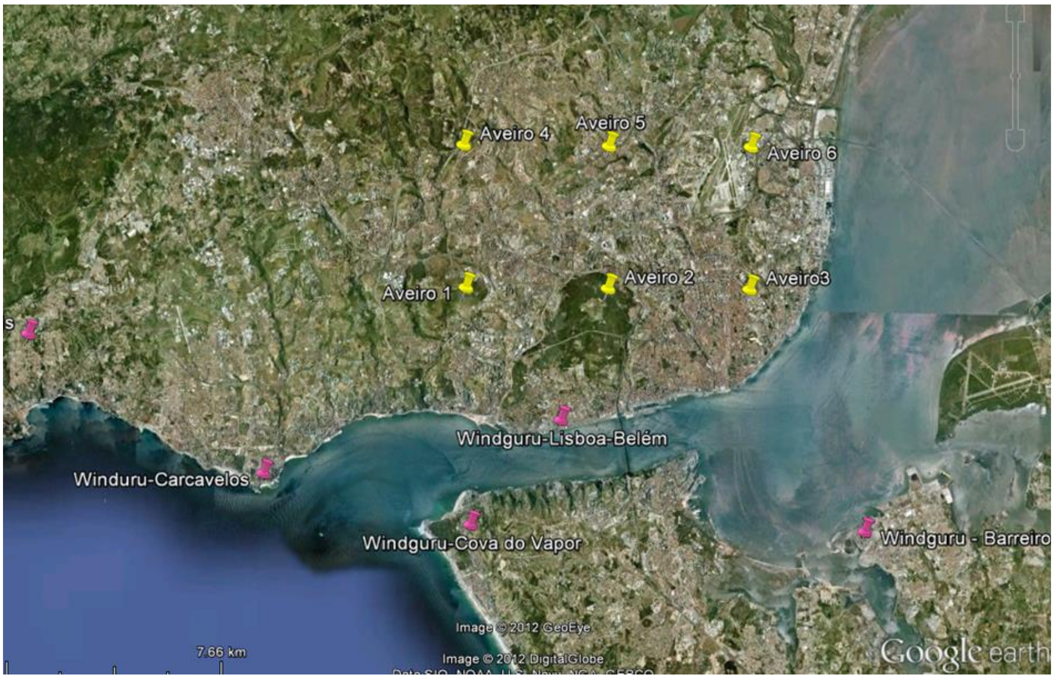


Figure 9 – Rainfall forecast stations.

In the Tagus estuary, the forecasts are compared automatically against data from the Cascais and VTS tide gauges, which are available on-line daily (Figure 9). Results put in evidence a good agreement between the data and the model predictions, with errors of about 10 to 20 cm. These errors are mainly associated with storm surges due to the atmospheric pressure, which are not accounted in the model. The comparison between the data harmonic analysis (which retains only the tide) reveals errors of less than 5 cm.

The integration of the sewer model (section 4.1) and of the estuary model (section 4.2) in the RDFS platform is currently under development.

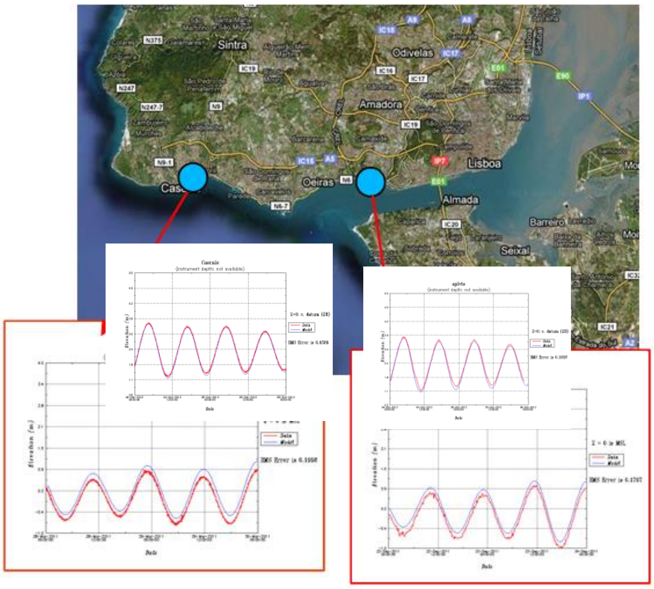


Figure 10 – a) Location of the tide gauge stations used for the automatic comparison with the model forecasts.

8 FINAL REMARKS

The methodological approach and the current developments of a prototype early warning system to support the water quality management of estuarine receiving waters, which is under development within the EU “PREPARED – Enabling Change” project (http://www.prepared-fp7.eu/) and the Portuguese SIMAI and SI-GeA projects, was presented.

This system accounts for the integrated use of models from the catchment area to the receiving water body, supported by a forecast platform that allows real time predictions for the next 48 hours, automatically validated against on-line data.

This paper describes the methodology and preliminary results concerning modelling, modelling integration, experimental surveying and on-line monitoring. Water quality on-line monitoring stations are currently being installed and models being integrated within the platform. The validity of this methodology will be evaluated by carrying out a number of further experimental surveys. The quality and robustness of additional on-line rainfall data provided by the internet will be analysed in order to evaluate the potential benefits from its use in the on-line monitoring system.

Besides the complexity of solving processes at different spatial and temporal scales, these integrated early-warning systems have additional issues that need to be considered. The process of cascade modelling used leads to errors propagation between the models that need to be quantified. The uncertainty propagation and its impact in the final predictions (receiving water) should be further analysed in order to provide robust and reliable alerts.

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