

COWAMA (Coastal Water Management) Integrated and Real Time Management System of Urban Water Cycle to Protect the Quality of Bathing Waters

COWAMA (Coastal Water Management) Système de gestion intégrée en temps réel du cycle urbain de l'eau pour la protection la qualité des eaux de baignade

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RESUME

Le projet COWAMA, suivant l'esprit de la nouvelle Directive d'Eaux de Baignade, développe un système d'aide à la décision pour la gestion des eaux de plage. Ce système intègre plusieurs modèles avec prise de données automatique en temps réel pour modéliser les débits et la qualité de l'eau dans le réseau d'assainissement, les stations d'épuration et les eaux côtières. Il peut être utilisé en temps réel en tant que système d'alerte pour les baigneurs et les responsables des plages, avec une prédiction numérique de l'évolution de la pollution des eaux, ou bien comme un outil off-line pour la planification de l'effet de nouveaux ouvrages pour combattre l'impact des décharges des réseau unitaires. Un premier site pilote vient d'être établi à Barcelone, qui sera complètement opérationnel en 2007, ainsi qu'à Biarritz, Alicante et Sitges.

ABSTRACT

Following the spirit of the new European directive for bathing waters, the COWAMA project is developing an application for decision support in bathing water management. It integrates different models with real-time sensor data to simulate flow and water quality throughout the sewer network, WWTP and the receiving waters. It can be used in real time, as an alert system for bathers and authorities, producing accurate forecasts of contamination hazards, or as an *off-line* tool, helping assessing new infrastructures in their effectiveness against CSO impacts. A pilot case has already been implemented in Barcelona. The full application will be operative by 2007 in Barcelona, Biarritz, Alicante and Sitges.

KEYWORDS

Bathing waters, beach management, CSO, numerical modelling, water quality forecast, Introduction.

INTRODUCTION

In the year 2000, the directive establishing a framework for Community action in the field of water policy (water framework directive or WFD) [2] was approved, instituting a new conception of water resources management, which will undoubtedly affect in a significant manner sewer systems management [3]. Moreover, scientific and technological advances achieved in this field during the last 25 years have stimulated a complete reformulation of the bathing water directive 76/160/EEC [1], which has been replaced in February 2006 by the European Commission Directive 2006/7/CE concerning the management of bathing water quality (bathing water directive or BWD) [4]. The main principles of this new directive had already been outlined in a document of the European Commission dated 21/12/2000, "Elaboration of a new policy for bathing water":

1. Change in pollution indicators and strengthening of water quality standards. As a result of epidemiologic studies, new indicators have been elected for assessing water quality and also new standards for water quality have been defined.
2. Evolution from monitoring to an integral management of water quality. The previous bathing water directive required very limited action of member states, mostly constituted of periodic field surveys. In coherence with the WFD, the new BWD promotes the management of the water cycle as a whole and enforces responses in case of non compliance with directive standards. These responses may be infrastructural, like the building of water detention tanks, or contingent, like beach closures or installation of warning signs for bathers.
3. Information to the public. According to the new directive, the public must be kept informed of water quality. Moreover, when bathing waters are subjected to short duration pollution events (namely CSO or Combined Sewer Overflows), it requires putting in place alert systems with brief response time.

In response to necessities dictated by the new BWD and even anticipating future demands, the COWAMA (Coastal Water Management) project is being developed with funds from R+i Alliance by CLABSA with the collaboration of Lyonnaise-des-eaux, and other international partners. It will be fully operative by 2007 in Barcelona, Biarritz, Alicante and Sitges. In the near future it will be installed in other Spanish municipalities with important affluence of beach tourists: Benidorm and Torrevieja.

As an instrument of support for beach management entities incorporating the exigencies stated in the new BWD (2006/7/CE), the COWAMA project focuses on two aspects:

- the design of infrastructural responses to pollution issues, and
- the implementation of contingency measures for short duration pollution events (CSO)

1 THE COWAMA APPLICATION

1.1 Description

The COWAMA project consists mainly of a computational application that links a sensors network with fluid flow simulations models in order to produce statistics on water quality to be supplied to local authorities and be published for public information (Figure 1).

The core of the application couples five different fluid flow and quality models, each of them simulating a subsystem: watershed, river basin, urban drainage network, WWTP and receiving waters (may be coastal or inland). Those models are fed either with real time or historical data obtained from sensors signals (rain gauges, water level probes, etc.), satellite imagery (remote sensing) and large scale forecasts (coastal model).

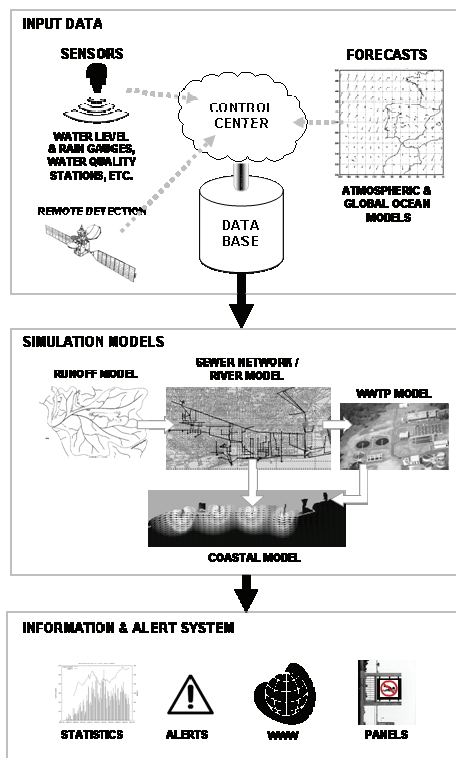


Figure 1 – General scheme of the COWAMA project.

The system is designed to work both online and offline:

- Offline mode: simulations based on historical data to reproduce past pollution events and retrieve long term statistics. These statistics allow the definition of beach profiles as required by the new BWD. Indeed, for beaches submitted to short duration pollution events, the directive imposes an evaluation of the estimated frequency and duration of contamination episodes. The same kind of long term simulations may be used to elaborate a cost-benefit analysis or measure the effectiveness of planned modifications of the water collection system or of any relevant coastal infrastructure that may influence polluted masses transport.
- Online mode: Real time data on rain and sewer water levels are to be used for fast CSO detection and results from real time models are used for the alert systems and water quality forecast.

1.2 Input data

The input data may be classified in static and dynamic. The static data is set for each simulation and does not change in the course of a simulation. It includes mostly the relevant physical data of the simulated domain (topography, bathymetry, pipes networks, catchments definition, etc.) and some fixed hydraulic (ocean bottom roughness, capacity curves, infiltration coefficients, etc.) and numerical parameters (advection scheme, turbulence parameterization).

The dynamic data may continuously change during one simulation. An example would be the opening of an operated gate at the inlet of a detention tank. This information needs to be supplied all along the simulation. Dynamic data includes essentially data collected by sensors (in real time or differed in time) and results of other models needed for boundary conditions (large scale ocean models). If data is to be forecasted, then boundary conditions require forecasted data, for what the larger scale models should also provide forecasts.

Different types of sensors are used in the project to feed the simulation models, detect pollution events but also to calibrate the models and validate their results:

- Rain gauges
- Water level gauges
- Waste water automatic sampling stations
- Current meters (hydrodynamic coastal model calibration).
- Tidal gauges
- Multi-parametric sensors for receiving waters quality
- Pyranometer
- Automatic bacteriologic probes (bacteriological concentrations measured by fluorescence), onboard buoys

To ensure results reliability of the different models the calibration is a crucial phase, based on measurements obtained from sensors, treatment of satellite and aerial imagery, and also from field campaigns directly in bathing areas. In the framework of this project, intense sampling campaigns have been planned with dry weather and during rainstorms. The principal parameters to be analyzed are the main bacteriological pollution indicators: faecal coliforms, *Escherichia coli* and intestinal enterococcus.

Apart from sensors data, satellite and aerial imagery provide very interesting data for qualitative comparisons. Remote sensing may give water colour, water elevation and sea surface temperature (SST) with definitions up to 50m, while aerial photography allows locating pollution plumes as seen in the pictures and model results.

1.3 Simulation models

Each of the simulation models corresponds to one subsystem of the water cycle (Figure 1): catchment, river, collection system, WWTP and receiving waters. These models must be coupled in a single application that allows simulating the flow and the transport of contaminated matter carried by rainfalls, from surface runoff to pollution dispersion in receiving waters. This articulation of models initially thought to work independently constitutes one major difficulty and is one of the tasks to be accomplished in the framework of the COWAMA project.

- The watershed model for surface runoff calculation is based on semi-empirical methods (like the rational method). It gives flowrates at the different inlets of the drainage network and rivers of the studied area. This model is fed in real-time with data from rain gauges.

- The river and sewer network models are based on a very similar formulation. They solve numerically the Saint-Venant equations in one dimension and one equation for advection and dispersion of polluting substances. Additionally, bio-chemical degradation or production may be incorporated. Boundary conditions are normally provided by the watershed model, but may also be deduced real-time from water level gauges near the inlets of the system.
- The WWTP model is used for calculating flowrates and water quality parameter of the WWTP discharges to receiving waters. This model uses the sewers network model results as an input.
- The receiving waters model is a three-dimensional coastal model, and may be used for costal zones as well as for estuaries and inland bathing areas. Model forcing (i.e. boundary conditions) includes wind, waves and tides, data that may be historical or forecasted. This model solves numerically the free surface flow equations and the transport equations of relevant physical quantities (temperature, salinity, etc.). Ecological models for polluting substances degradation and production are also included, in particular for simulating bacteriological inactivation mechanisms. Input data is given by the river, sewers network and WTP models, in the form of hydrographs and contaminants concentrations curves. The result of this model is a three-dimensional map of polluting substances concentrations, with ability to obtain statistics at any location within the model domain.

1.4 Information and alert system

An information and alert system is incorporated in the computational application. It is based on collected information and on the results of the models.

This information system consists of a website and electronic panels installed in bathing areas. The information appearing on the panel is updated at distance by a designated operator and consists mainly of water quality forecasts, presented synthetically, and warnings when needed. Any other relevant kind of information might be added (current air temperature, solar radiation intensity, etc.)

The website presents two levels of information: one for the public in general and the other for bathing sites managers. The public information consists of the bathing water quality forecasts presented in an intuitive manner, beach profiles as required by the new BWD, as well as other useful information (air and water temperature, wind velocity and direction, etc.).

The information available at beach manager level is much more detailed and contains extensive reports on models results, and rainfall and CSO events summaries.

The alert system emits warnings (by SMS, phone calls, or other) to an operator. According to the information available from the COWAMA application (water quality forecast, CSO and rainfall reports) and any other pertinent sources the operator will take adequate dispositions following a predefined protocol to avoid bathers' exposition to contaminated waters.

2 BARCELONA'S PILOT PROJECT

A preliminary and simplified version of the COWAMA project has been installed in Barcelona with the purpose of proving the viability of the project and detecting future implementation difficulties.

The pilot project does not include a runoff model, neither a river nor sewers network model. Discharges are directly calculated based on data supplied by the water level gauges located in the main CSO outlets of the systems. A constant mean FC

concentration is considered. This mean concentration has been chosen based on different studies involving field measurement campaigns in Barcelona and other Spanish cities [5, 6, & 8] and also on a bibliographical survey [9, 10 & 11].

The time series of discharges are then used as an input to a coastal model. This model is two-dimensional and contemplates only wind forcing, disregarding other forces generating currents (waves, tides and density gradients).

The implemented model, illustrated in Figure 3, works with two independent processes: a cycle for discharges (reads outlets hydrograph from a database, detects if there are CSO and writes a discharge file for the coastal model) and a simulation cycle (launches simulations of receiving waters).

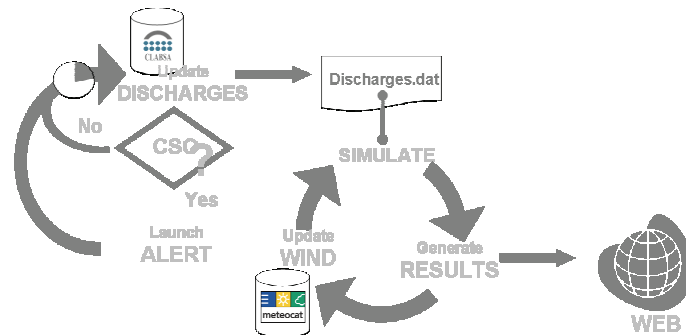


Figure 3 – General scheme of real time operation of the pilot application implemented for Barcelona

Catalonia's Meteorological Service (SMC) supplies CLABSA twice a day with files with a 48 hours forecast of wind data for all Catalonia area. Each simulation includes a 48 hours hindcast period and a 48 hours forecast period (where CSO event is supposed to be over), and takes about 1 hour.

The model used to simulate coastal waters is an ocean model largely tested in littoral zones and estuaries, developed by the Lisbon Technical University (UTL): MOHID [12]. This three-dimensional (used as a 2D) model solves the equations for free-surface flow using the finite volumes method, and may be used with curvilinear structured meshes. Three nested grids are used in the simulation, from large scale (geostrophic scale, $L \sim 100$ km) to convective scale ($L \sim 1$ km). Advection/diffusion of polluted discharges is calculated with an eulerian transport model, with a first order (lineal) decay model for bacteriological decay.

The bacteriological inactivation (decay) is due mainly to solar radiation, but also depends on other factors as water salinity, temperature and turbidity. The influence of these parameters is known and may be studied in laboratory. However the determination of the inactivation coefficient cannot be determined rigorously from lab experiments, because in their natural environment, pathogen organism are subjected to a random mortality factor: depredation. In face of the difficulty to obtain a reliable value for bacteriological decay coefficient, it was decided to use it as a calibration coefficient. To contemplate the important variation due to solar radiation, a diurnal and nocturnal value for this coefficient was considered.

Once the simulation is finished, results are generated and then published in a webpage. Two webpages were developed, one for the public in general and another for the municipality of Barcelona, the later being obviously much more detailed. In the page destined to the public, one can consult current state of water quality and general

information (wind speed, air temperature, solar radiation, etc.). In turn, municipal authorities have access to 48 hours water quality forecasts, aerial pictures of bathing zones, as well to rainfall and CSO reports.

Two CSO events, both in 2005, were used for calibration purposes:

- August, the 2nd. Model results and aerial pictures of bathing areas were confronted and a clear correlation between faecal coliforms concentrations and the contamination plumes visible in the pictures was obtained. The hydrodynamic and transport models, as well as wind forecasts have proven to be consistent with direct observations (Figure 6).
- September, the 6th. Samples taken a few hours after the rain event in different beaches of Barcelona showed good agreement with model results (Figure 7).

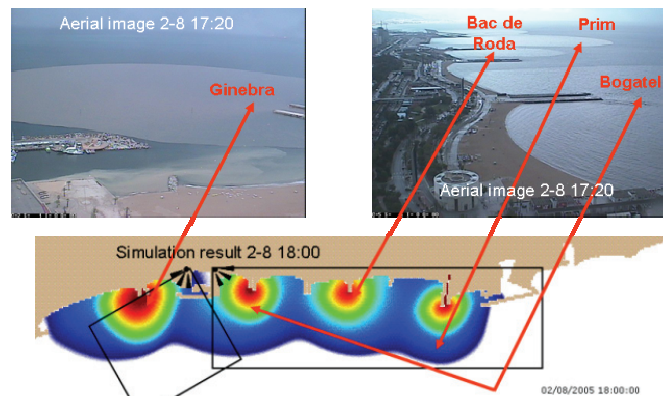


Figure 6 – Model comparisons with aerial images.

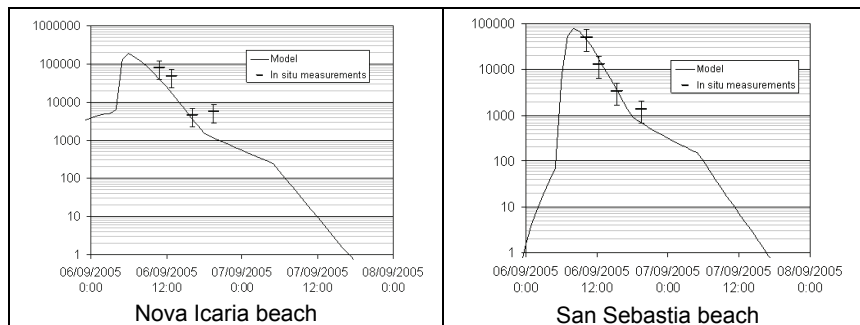


Figure 7 – Comparison between sample analysis results and model results for the 6/9/2005 CSO episode. Results are given in UFC/100ml.

3 CONCLUSIONS

The environmental policy defined by the water framework directive and above all by the new bathing water directive promotes clearly the development of projects such as COWAMA that allow an efficient management of bathing water quality.

As the work done so far puts in evidence, it is possible to develop a support instrument that combines real time information of sensors, meteorological forecasts and numerical modelling. This allows local entities in charge of beach management to take early dispositions to avoid the exposition of bathers to contaminated waters. The measures taken may include warning signs advising against bath or beach closures depending on the magnitude of the event. Beach management based on this instrument will undoubtedly be more rigorous and will bring advantages to the bathers as well as to the locality itself. Indeed, the precise knowledge of the mechanisms underneath pollution dispersion allows reducing to a minimum duration the application of restrictive measures as the ones described above. It may even avoid the unwanted consequences of an unfavourable sample analysis.

Due to the new exigencies formulated by the BWD, a number of initiatives similar to COWAMA are expected to appear in the following years.

Finally, the COWAMA system will improve with time by the incorporation of new and better sensors, the integration of maritime and meteorological forecasts more reliable and with increased definition, and the completing of more field campaigns to adjust models calibration.

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