11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

# A WEB-BASED HYDROINFORMATIC PLATFORM FOR WATER QUALITY MODELLING IN A RIVER BASIN

JOSÉ PINHO (1), JOSÉ VIEIRA (1), JOSÉ ARAÚJO (1), RUI PINHO (1)
*(1): Department of Civil Engineering, University of Minho, Portugal*

This paper presents a hydroinformatic platform specifically designed for a Portuguese north-western river basin (river Cávado) in order to define, simulate and analyze hydrodynamics and water quality management scenarios. The software solution was designed to be operated in a web environment, taking advantage of the integration capabilities of this software environment and the user friendliness of web interfaces.

## INTRODUCTION

In recent years a major effort has been done to make water quality modeling tools available for water resources management at a river basin scale. The European water framework directive clear states that these tools must be used in making the diagnostic of surface water bodies water quality status and to anticipate the impact of measures to be implemented in order to achieve a good ecological status by 2015 in European waters. In order to make modeling tools usable by all the actors enrolled in water resources management process at river basins, these tools must be simple, user-friendly and robust.

Water managers have shown strong interest in the integration of model tools throughout the use of graphical interfaces in their activities [1]. These tools must be able to establish water management scenarios but it is well known that water managers have lack of time for training in the use of complex systems. Also software and hardware costs appear to be an important constrain in implementing these tools. Several solutions are being implemented throughout European countries, resulting from the development and integration of different software packages using different integration technologies.

The solution presented in this work is composed of the following main components: water monitoring data-bases; hydrodynamics and water quality river models; and reports facilities for the presentation of output results. The applicability of this hydroinformatic environment is demonstrated in the study of waste water treatment plants discharges impacts on the river water quality for different river flow regimes.

## HYDROINFORMATIC PLATFORM

The technological platform is mainly based on a database system and a set of hydrodynamic and water quality models, operated using web interfaces. It comprises functionalities for query and analysis of the river network (information system), hydrodynamic and water quality models operation (modeling system), and results analysis (analysis system). The website which is responsible for the system interaction with the end users is divided into four main sections that allow access to the features mentioned above: Project, Information, Modeling and Analysis. These sub-menus are the main options from the navigation menu. Further details about these components can be found in Pinho et al. [2].

Information section includes data of the river network, data from monitoring stations and the river basin Geographic Information System. The Modeling section allows the users to define new simulations and remotely start the execution of new hydrodynamic and water quality models. This interface not only allows the remote operation of the models, but also displays the simulation results from different users. Finally, the Analysis section provides access to several simulation results for a posterior detailed analysis and generation of reports. Each one of these sections includes graphical user interfaces, specifically designed and developed for that purpose, considering imposed requisites of its potential users. The main modeling system interface is presented in Figure 1.

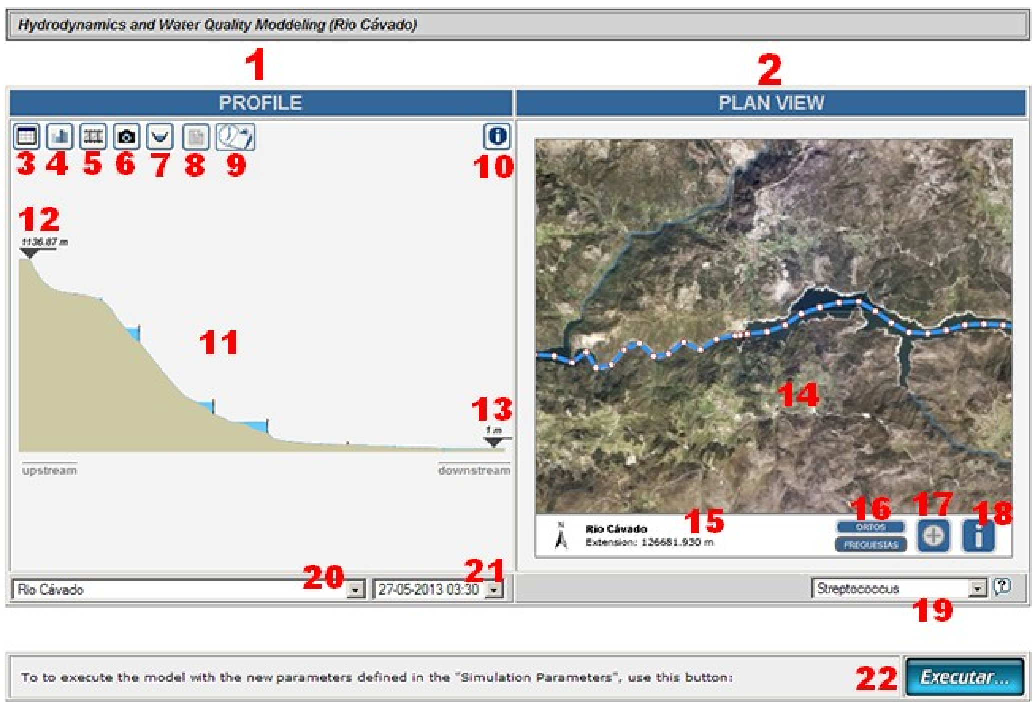


Figure 1. Web interface for model results displaying and scenario simulations set up.

Functionalities of this interface are highlighted by the red numbers and comprises: (1) graphic representation of the active river longitudinal profile; (2) active river plan view; (3) table results; (4) chart results; (5) presentation of animated water level during the simulation period; (6) river profile with zoom functionalities for the selected simulation time; (7) cross sections displaying; (8) automatic generation of a report about the current simulation; (9) definition of new simulation parameters; (10) information about the active simulation; (11) presentation of river longitudinal profile; (12) water level at upstream node, for the selected time simulation; (13) water level at downstream node; (14) representation of the river axis in the plan view, with information about nodes water levels and river reaches discharges; (15) river name and length; (16) buttons to enable/disable the ortophotomaps and administrative boundaries displaying; (17) button to display the plan view in a new window, with increased spatial resolution; (18) display information data stored in the system database; (19) selection of the water quality variable to display; (20) river selection; (21) simulation time selection; (22) button to activate a new model execution after setting new simulation parameters.

Platform databases stores geometric features of the river network, hydraulic structures, monitoring data, and point and non-point pollutant discharges into the river network and are managed using MySQL server [3]. The one-dimensional hydrodynamics and water quality models were implemented applying SOBEK software developed and maintained by DELTARES [4]. Additional web-based interfaces were implemented in order to directly establish the simulation boundary conditions, run the model and visualize model results. All the developed applications are freely available and can be tested at www.hydroinformatics.pt.

**Water quality model mathematical formulation**

The flow is modeled using one-dimensional formulations of free surface flows based on the conservation of mass and momentum equations. In addition to these equations the flow discharges at hydraulic structures included in the model segmentation are computed using specific expressions for each type of structure: bridges, culverts, siphons, orifices, pumps, and weirs. In these structures the flow depends on the upstream and downstream levels, on its dimensions and on a set of specific parameters. Water quality variables are modeled based on the one-dimensional transport equation.

$$\frac{\partial A_f}{\partial t} + \frac{\partial Q}{\partial s} = q_{lat} \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial s}\left(\frac{Q^2}{A_f}\right) + gA_f\frac{\partial H}{\partial s} + \frac{gQ|Q|}{C^2RA_f} - W_f\frac{\tau_{wi}}{\rho} = 0 \tag{2}$$

$$\frac{\partial(A_f C)}{\partial t} = -\frac{\partial(QC)}{\partial s} + \frac{\partial}{\partial s}\left(DA_f\frac{\partial C}{\partial s}\right) + SA_f \tag{3}$$

where, $Q$ = flow discharge, $t$ = time, $s$ = one-dimensional coordinate, $A_f$ = wetted area, $g$ = acceleration due to gravity, $H$ = water level above plane of reference, $C$ = Chézy's coefficient, $R$ = hydraulic radius, $W_f$ = superficial width, $q_{lat}$ = lateral flow, $\tau_{wi}$ = wind shear force, $\rho$ = water density, $C$ = Substance concentration, $D$ = Diffusion coefficient, $S$ = Source, sink and reaction term.

Sources are considered as point sources using lateral discharges into the main rivers. River water quality parameters are: dissolved oxygen, biochemical oxygen demand and three bacteria indicators (total coliform, faecal coliform and streptococci). First order decay reactions were assumed in modeling microbial and chemical transformation mechanisms. Mechanisms include river water deoxygenation and reaeration and bacteria mortality.

## STUDY SITE AND MODEL

River Cávado basin is located in the north-western region of Portugal. This basin occupies an area of 1589 $km^2$ and the river network considered in the model is about 360 km length corresponding to 16 rivers. Figure 2 depicts the river basin and the modeled river network.

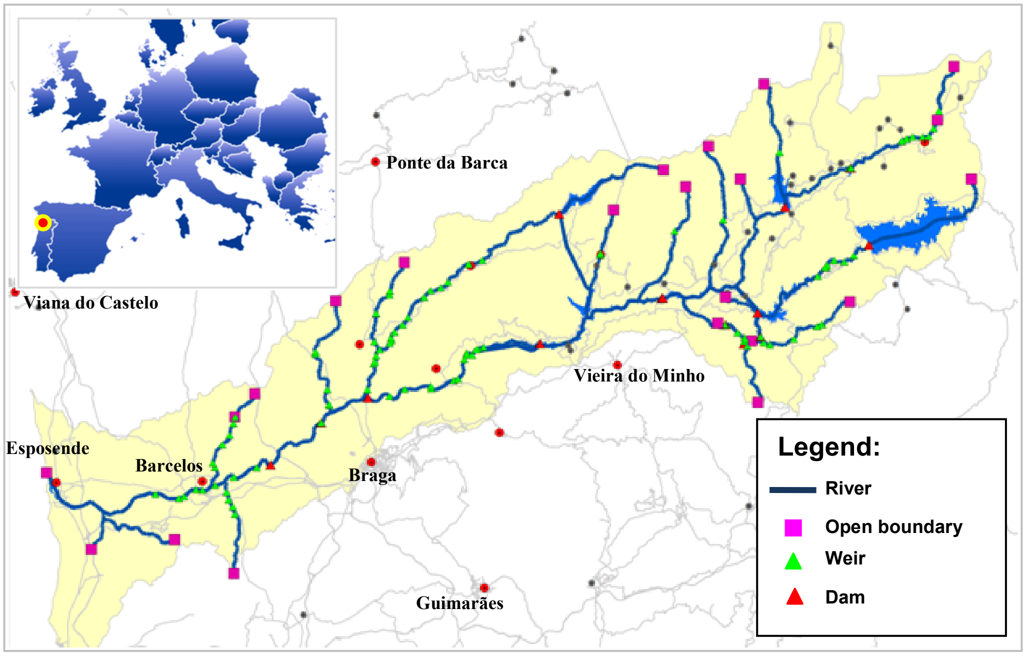


Figure 2. Study site location and river Cávado model

The model includes the river Cávado and its main tributaries: Homem, Beredo, Borralha, Cabreira, Cabril, Cavadas, Caveiro, Covo, Febras, Gerês, Milhazes, Pontes, Rabagão, Toco, and Tojal.

River cross sections were established using bathymetric and topographic data available for this river basin. The one-dimensional grid comprises 1722 computational nodes, 22 open boundaries, 51 controlled discharges at hydraulic structures and 105 non controlled hydraulic structures. The rivers channels geometry was introduced considering 1854 cross sections. Pollutant sources are simulated considering 84 different locations within the river basin. All hydraulic structures with a significant influence in the rivers flows regime were included with emphasis for weirs and dams.

The segmentation of the model was defined considering the important influence of the upstream reservoirs in the river flows and the intense occupation (industrial, agriculture and urban areas) of the basin in the downstream areas.

In the calibration procedure a hybrid approach was followed: several parameters were established either according to proposed values in the literature ( [5], [6]), from previously developed works ([7]) or based on available field data.

## RESULTS AND DISCUSSION

### Hydrodynamics

The hydrodynamic behaviour of the water bodies at river Cávado basin is influenced primarily by rainfall regimes and dam discharges. A conceptual framework (Figure 15), where the main structures influencing the hydrodynamic regimes are identified (numbered from 1 to 28) was adopted in order to characterize the data to define the simulation scenarios. For each scenario the rainfall hydrographs and the pumps and turbines operation must be defined.

Thirteen hydrodynamic scenarios were worked out in order to estimate average monthly flows and the average annual flow considering available historical data. Turbines were considered fully operational during simulation periods and the water levels at reservoirs are considered near its average level for the month associated with each simulation. It was also considered that other outflow gates at dams are closed. Finally, on the oceanic boundary of the model, no tidal variations were assumed. It was considered that the water level remains at the mean sea level during the simulation period. All simulations were defined to have duration of 7 days and a computational time step of 15 minutes.

From Figure 3 it is possible to find a close proximity between the average observed discharge flows and the obtained simulated results, with the exception of locations 5, 6 and 12. In the first two locations the difference of 5.6 $m^3/s$ is due to the introduction of flow contribution of intermediate sub-basins at the upstream nodes of the river reach. A similar situation occurs in location 12. In general, all the other simulations results present a notable approximation to the monitored values. Similar results were obtained for scenarios involving monthly average river discharges.

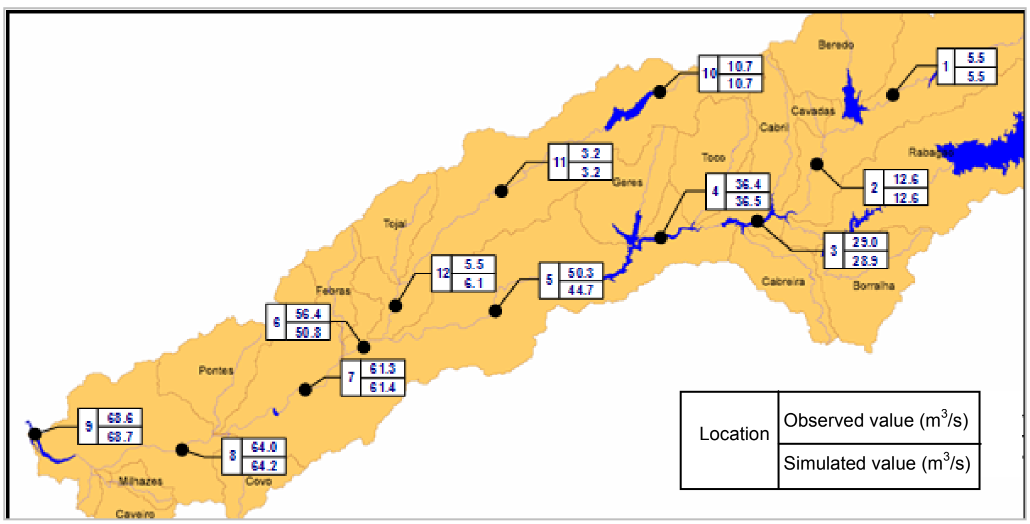


Figure 3. Annual average rivers discharge flows and simulated results.

**Water quality**

Water quality simulations scenarios were based on hydrodynamic results and on the consideration of different characteristics for the discharges of wastewater treatment plants (WWTP), industries, and livestock units. Establishment of different values for these pollutant discharges result in different simulation scenarios. Considering the WWTP efficiency related to their treatment schemes and the hydrodynamic scenarios it were defined thirteen different simulations (water quality scenarios 1 to 13). Additionally, for the wettest month (January) and the driest month (August) the effects of discharges from WWTP considering extreme values of their efficiencies were worked out (scenarios 14 to 17). Finally, three scenarios were considered (scenarios 18 to 20) associated with the failure of each one of the three main WWTP: Frossos, Esposende and Vila Frescaínha.

Characteristics of pollutant discharges from WWTP were estimated for the following water quality parameters: biochemical oxygen demand ($BOD_5$), total coliform bacteria (TCB), faecal coliform bacteria (FCB) and streptococci bacteria (SB).

Loads associated to industrial pollutant discharges were also estimated. A simplified method was used based on typical effluent load values for specific industries. However, most of the industrial effluents are treated in private WWTP before discharge to the public sewerage infrastructure. Pollutant sources from livestock farms discharges were also estimated considering typical values for specific domestic animals.

At the rivers upstream open boundaries it was considered with a value of zero for $BOD_5$ concentration and bacterial number. Dissolved oxygen concentrations at those boundaries were assumed near the saturation concentration (10 mg/L). Initial conditions for simulated water quality variables were established considering the average values of concentrations at the monitoring stations.

Results were obtained for the twenty scenarios, using a simulation time of seven days for each scenario. Figures 4 and 5 present the obtained simulated results for scenario 1 (annual average discharge flows) at the last simulation time and the average observed values near the water quality monitoring stations.

It appears that for the rivers where monitoring data is available, the water quality profile related with organic matter discharges, inferred from the results of concentrations of $BOD_5$, presents nearly uniform values (around 1 mg/L). It was possible to achieve good approximation between the monitored values and model results for this scenario.

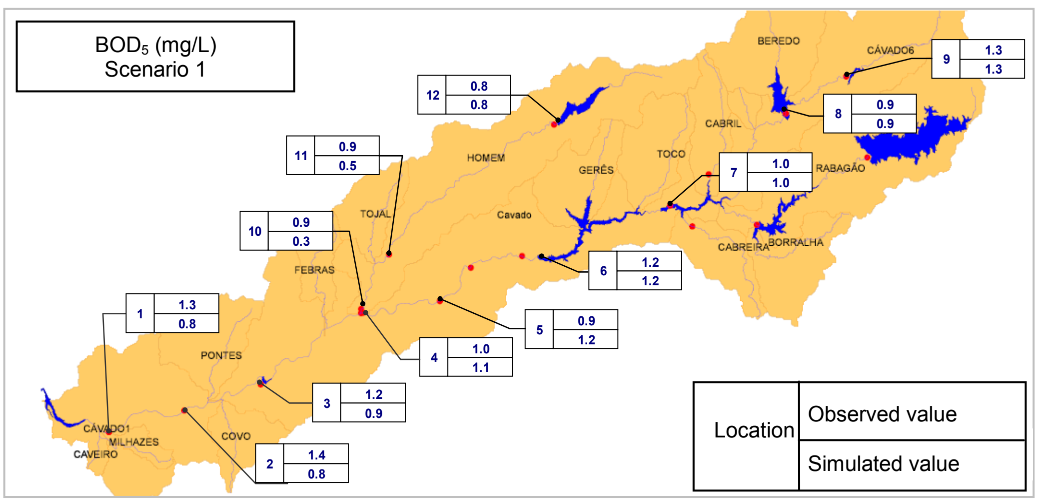


Figure 4. Water quality model results in the vicinity of monitoring stations for scenario 1.

The installed treatment capacity of wastewater (mainly from domestic sources) in the river basin, based on the removal of organic matter is reflected in the monitored values, resulting in low concentrations of $BOD_5$.

Regarding results of FCB concentrations, the differences between simulated and observed values in scenario 1 are more significant at the regions located in the most urbanized areas (similar results were obtained for SB and TCB). Differences between observed and simulated values arise primarily from the uncertainty associated with quantification of bacterial loads (a sensitivity analysis was performed concerning adopted calibration parameters, and it was concluded that these parameters cannot justify the differences found). The values used in the estimation of these loads (mean values of bacterial loads) are highly variable and may justify the simulated behavior (underestimation of bacterial loads).

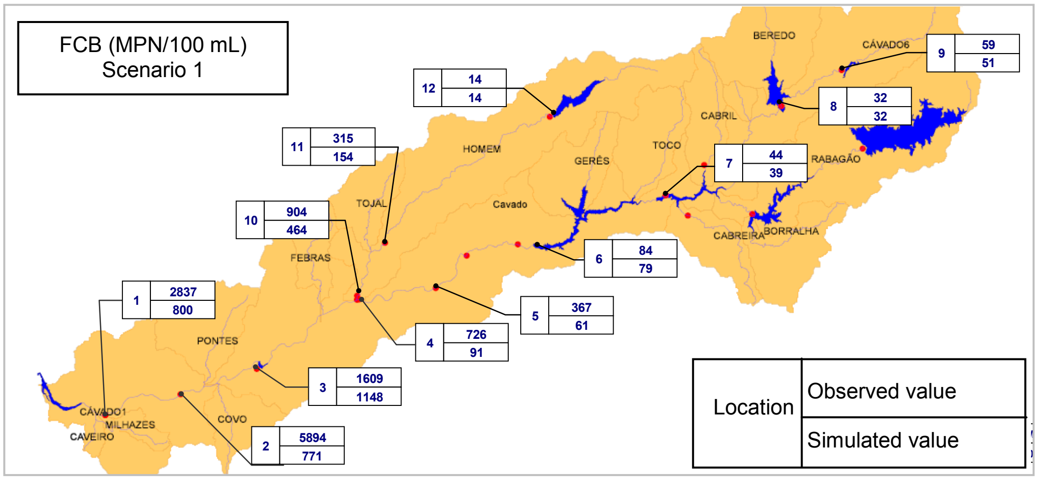


Figure 5. Annual average rivers discharge flows and simulated results.

Results for this scenario showed that the bacteriological pollution in the river Cávado basin downstream the confluence of the river Homem is a reality that the wastewater treatment technical solutions have failed to solve the problem in this basin. The bacteriological pollution also occurs during the dry season which decreases the likelihood of contamination coming from diffuse sources.

Adopting the same conditions of pollutant discharges of scenario 1 but now considering the average monthly rivers flows discharges, with the simulated scenarios 2 to 13 it was possible to assess the influence of seasonal flows variation on water quality behavior. Obtained results reveal a strong influence of the seasonal river flow regime variation on water quality parameters concentrations. The variations reach values of around 70% of the concentration values in the wettest months in the case of bacteriological parameters and about 40% for $BOD_5$.

## CONCLUSIONS

Developed operational modeling platform allows the simulation of an unlimited number of scenarios. Several scenarios were implemented in order to evaluate the performance after a judicious effort for model calibration and validation.

Main results obtained for the water bodies within the basin reveal an almost uniform longitudinal profile for $BOD_5$ concentration with a good agreement between observed and simulated results. The installed wastewater treatment capacity in the watershed (domestic and industrial wastewater) is reflected in the observed values leading to low concentrations of $BOD_5$. However, a quite different situation is observed for bacteriological indicators. In the lower part of the basin, results of concentrations for all simulated scenarios are always lower than the observed ones even in the dry season. The reason for this fact can be the existence of untreated discharges or the lack of disinfection in WWTP.

The presented decision support tool for the river Cávado basin constitutes a robust and efficient technological platform to support water management at a river basin scale. Obtained results allow predicting that this new tool will be extremely effective and important to achieve the objectives of water management at river basin scale. In the next years, the use of all the potentialities of this kind of platforms in practical situations under different water management problems constitutes a major challenge for the evaluation of the developed tool. Moreover, water authorities once decide to use this kind of management tools will certainly see improved their analysis capabilities, and strengthening their technological skills for the adoption of more sustainable water management policies. Especially it is adequate for developing big projects since it facilitates collaborative studies in one common platform and the modeling results become much more transparent for all project partners.

## REFERENCES


[1] *Borowski, I. & Hare, M. "Exploring the gap between water managers and researchers. Difficulties of model-based tools to support practical water management", Water Resources Management 21 (7), (2007) 1049-1074.*

[2] *Pinho J., Vieira J., Pinho R., and Araújo, J." Web-Based Decision Support Framework for Water Resources Management at River Basin Scale", Current Issues of Water Management, Dr. Uli Uhlig (Ed.), (2011) ISBN: 978-953-307-413-9, InTech, DOI: 10.5772/27383.*

[3] *MYSQL "MySQL database server" (2009), Available from:<http://www.mysql.com/>.*

[4] *DELTARES "SOBEK software", (2013) Available from:< http://www.deltares.nl/en/software-alg />.*

[5] *Thomann R. V., and J. A. Mueller. "Principles of Surface Water Quality Modeling and Control". Harper and Row, Inc., New York, (1987).*

[6] *Chapra, S. "Surface water-quality modeling", The McGraw-Hill Companies, Inc, (1997).*

[7] *Vieira, J. M. P., Pinho, J. L. S., and Duarte, A. "Eutrophication vulnerability analysis: a case study", Water Science and Technology, 37(3), (1998), pp 121-128.*