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Towards A Decision Support System For Flood Management In A River Basin

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TOWARDS A DECISION SUPPORT SYSTEM FOR FLOOD MANAGEMENT IN A RIVER BASIN

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Abstract: A platform for flood forecasting (FEWS-LIMA) in the Portuguese river Lima basin was implemented applying Delft-FEWS software. This platform integrates SOBEK Sacramento hydrological model, SOBEK rivers hydrodynamic models (working together in predicting river hydrodynamics behaviour), and a comprehensive hydrological database. The calibration of these models was achieved using historical river flow data of different rainfall events for two different periods: after the dams construction and before its construction. Models predictions use rainfall time series as input data obtained from Numerical Weather Prediction models. The performance of forecasting platform was verified in real rainfall events, using a backcasting approach for four flood events occurred in the years 2006, 2010, and 2011 in order to demonstrate the accuracy of the modelled processes. In addition, a forecasting event was also considered in order to show the applicability of this methodology in future situations. It was verified, in this case study, that the obtained results have a high correlation to the actually measured typical flood hydraulic parameters.

1. INTRODUCTION

The world is experiencing a countless number of impressive and devastating floods causing a range of health impacts and risks with hundreds of thousands of people losing their lives or becoming homeless in a matter of hours. These hydrological extremes are of growing concern for global, national and regional authorities due to the human tragedy and the associated socio-economic losses. EU Floods Directive [2] requires the development of flood hazard maps, which may include information on hydrological and hydrodynamic characteristics of vulnerable regions, i.e. inundated areas, river flow rates and water levels. Prediction of flood events can accurately be achieved by applying mathematical modelling for describing rainfall-runoff phenomena as well as surface waters hydrodynamics.

Methodological approaches to deal with flooding problems recommend the incorporation of decision support tools in the process to better investigate which planning options and remediation actions need to be taken at a river basin scale [9], [11]. Flood forecasting and flood management imply a comprehensive data collection, statistical analysis of relevant data, and hydrological and hydrodynamical model implementation. Hydroinformatics is a new scientific branch linking informatics tools with hydraulics and environmental concepts and models [4], [5], [6], [13], [10]. The ever increasing computational resources and geographical information tools give the support for applying new methodologies in flood management.

This paper presents the application of a platform for flood forecasting created for the Portuguese river Lima basin, FEWS-LIMA, integrated with SOBEK Sacramento hydrological model and SOBEK river hydrodynamic model that work together rainfall runoff and flow propagation processes in the river basin [12]. Simulated rainfall runoff events results demonstrate the validity and accuracy of the modelled processes.

2. METHODOLOGY

2.1 Overview

Model construction is based on different techniques supported by a GIS tool and data, namely aerial photos, topographical and bathymetric data, river flow rates, and water levels data. The river basin hydrology is studied by means of Sacramento theoretical approach implemented with GIS support. The river hydrodynamics are simulated using the SOBEK software [14]. Models calibration and validation are performed using historical data series of rainfall, streamflow and water levels, reservoirs water levels, measured in the period of 1932-2012. This set of hydroinformatics tools is integrated in the Delft-FEWS [1] platform to construct the overall Decision Support System (DSS) aiming at an operational application.

Modelling and simulation are conducted for the basin of the Lima River. Flood forecasting results (streamflow and water levels) are obtained for different scenarios. The flow chart of the adopted methodology is shown in Figure 1.

2.2 SOBEK

SOBEK is a software package developed by Deltares for the one- and two-dimensional hydrodynamic modelling of rivers, estuaries or drainage networks. It is based on a robust numerical method that permits obtaining solutions for complex simulation setups. The governing equations are based on the Saint Venant equations and schematized by a finite difference scheme [14].

The software come along with a graphical interface through which all tasks of pre- and post-processing are performed. The spatial discretization of the model was performed on that interface using the map of the river basin as support (in a GIS compatible format).

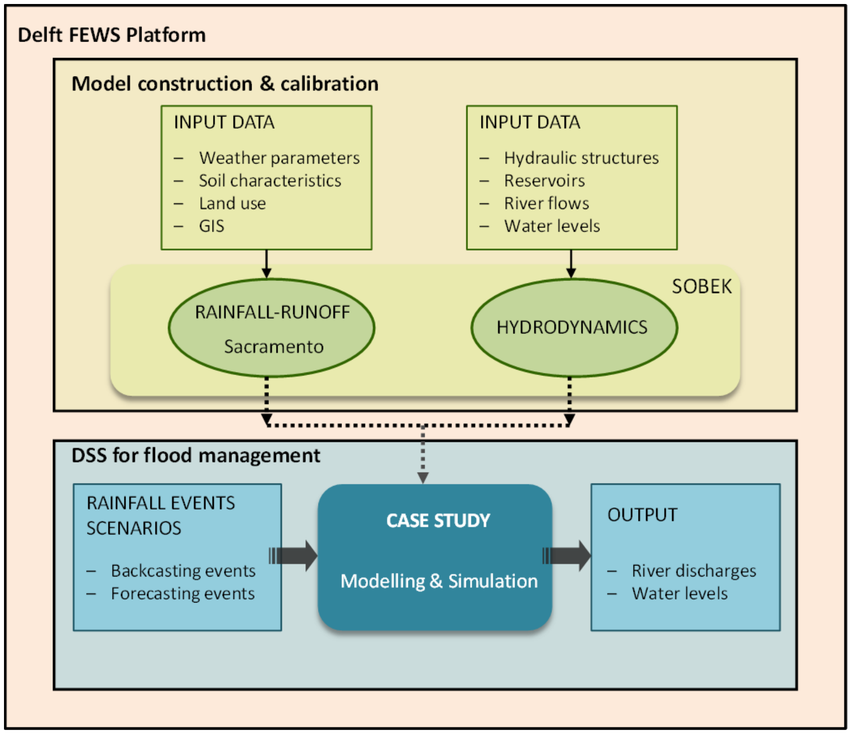

Figure 1. Methodology flow chart for DSS const

2.3 Sacramento Hydrological Model

The Sacramento hydrological model is a rainfall runoff component available in SOBEK. It allows the quantification of streamflow using the average precipitation and evapotranspiration in the (sub-)basin as input [7].

In this model, the soil is divided into two main layers: (i) the upper layer in which the fast processes occur near the soil surface: evaporation, percolation, surface and sub-surface flow; and (ii) the lower layer where the slow processes of the unsaturated soil region occurs: transpiration, aquifer recharge and base flow.

2.4 Delft-FEWS

The main purpose of the Delft-FEWS framework is to provide a building box for the data-model-integration in operational forecasting systems. It provides an open shell system for managing forecasting processes and/or handling time series data, incorporating a wide range of general data handling utilities, while providing an open interface to any external forecasting model. The modular and highly configurable nature of Delft-FEWS allows it to be used effectively for data storage and retrieval tasks, simple forecasting systems and in highly complex systems utilizing a full range of modelling techniques. This platform can either be deployed in a stand-alone, manually driven environment, or in a fully automated distributed client-server environment. Delft-FEWS system contains no inherent hydrological modelling capabilities within its code base. Instead it relies entirely on the integration of (third party) modelling components.

3. CASE STUDY

The Lima basin is a Portuguese and Spanish basin with an approximate area of 2450 km^2; about 1140 km^2 (46.5 %) is located in the Portuguese territory. The average altitude of the basin is 447 m. The higher sectors of the basin correspond to the Serra da Peneda at the north, (-1416 m) and Serra Amarela at the south (-1361 m). From the Spanish border to its river mouth in the city of Viana do Castelo, the Lima River is about 67 km long (Figure 2).

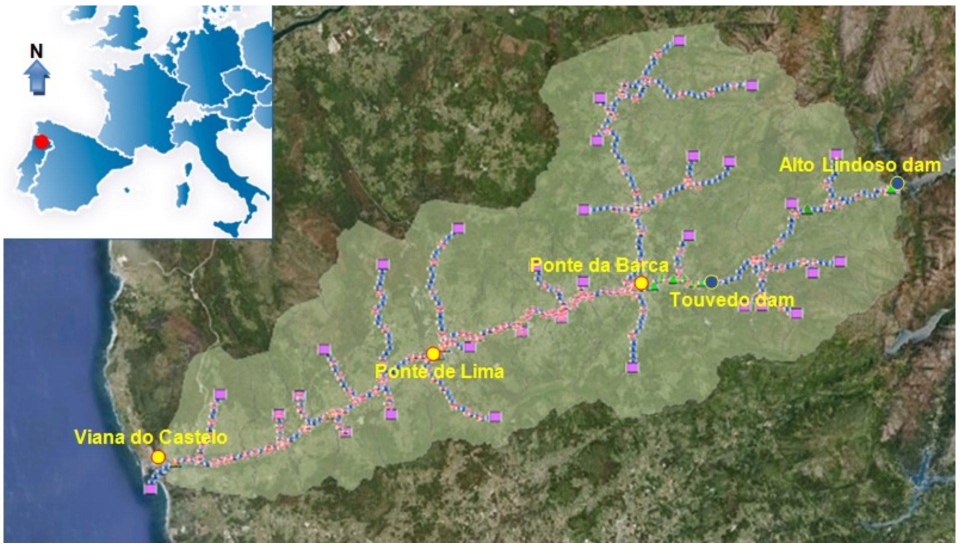

Figure 2. Study site location.

4. MODELLING

4.1 Hydrological model

From a wide range of different conceptual hydrological model approaches, one of the more precise and complex theory is the Sacramento model [14]. It is fully integrated in the SOBEK software.

The River Lima basin is subdivided into 30 sub-basins to reproduce the variability of the basin's topology. One Sacramento node is implemented for each centroid of the sub-basins receiving an average rainfall each. Since in river Lima basin the available meteorological stations not cover all sub-basins considered in the model a rainfall time series for each sub-basin was estimated. For this, an interpolation technique based on Thiessen method was used. In this work, active and inactive meteorological stations were considered so two different spatial distributions have been worked out.

4.2 Hydrodynamic Model

The hydrodynamic model of the Lima River extends from the Alto Lindoso dam at the upstream boundary to the river mouth at Viana do Castelo. It is composed by 322 cross sections, defined based on data obtained with bathymetric surveys and satellite topographic data, 8 bridges, 8 weirs, and 2 dams. The modelling of the bridge is performed individually for each one of the arches of the bridges, using the model type "Fixed bed" in which it is necessary to set the bed level, as well as the opening width. The two dams were meticulously modelled in order to integrate all operating hydraulic structures and their characteristics: flood gates, bottom outlets, and turbines are modelled through orifice nodes in which all the geometric and hydraulics coefficients were defined [15].

4.3 Model Calibration and Validation

The adopted process of the SAC-SMA hydrological model calibration is complex and time consuming. A Sacramento sub-basin includes 16 different parameters which need to be identified in the scope of this work. For each Sacramento node, it is possible to define a different set of parameters values. Since 30 different sub-basins exist, the model calibration process goes through the parameter identification of the most acceptable and realistic parameters for each sub-basin.

In order to use all available historical time series data two periods were considered: one before the construction of dams (Alto Lindoso and Touvedo dams) and the other after 2002 (beginning of dams operation). In the first calibration period, SOBEK model was adapted and Touvedo and Alto Lindoso dams were neglected. The purpose of this stage was to calibrate the hydrological model of river Vez sub-basin using data of its hydrometric station, and afterwards continue with the remaining sub-basins that contribute to the river Lima discharges.

After the initial definition of the calibration parameters a sensitivity analysis was conducted using a version of the SOBEK model without dams. Because the computational time for each run is relatively long a Sacramento model was implemented using Visual Basic for Applications. This tool allows the fine tuning of the calibration parameters values.

The second calibration period considers the Touvedo and Alto Lindoso dams in operation. The sub-basins located between both dams as well as their operational processes (discharged and turbinated flow, effluent flow rate and reservoir water levels) are considered. The goal of this calibration is to create operating rules of the hydraulic structures in SOBEK that can reproduce the historical data.

5. FEWS-LIMA

Recent developments in weather forecasting, the availability of radar data and on-line meteorological and hydrological data from gauging networks require state-of-the-art forecasting system such as Delft-FEWS [16] to integrate and process these data feeds. A challenge in modern forecasting systems is the integration of large data sets, modules to process the data and integrate various existing models. The FEWS-LIMA system has been developed for the Lima river basin with a sophisticated collection of modules designed for representing the specific requirements of the basin. It appears as an monolithic tool to the user, however, it integrates diverse external modules.

UGrib is a meteorological forecast service that allows instant and fully customizable access to global weather forecast data. Within a user friendly interface it is possible to download and view weather forecast data [3]. Through this service, it is possible to download a "grib" file of a selected area. The underlying meteorological model originates from the Global Forecast System (GFS) and it is updated every 6 hours. The service provides a 7-days forecast with 3 hour time steps on a spatial resolution of 0.5º.

The SNIRH database [8] serves as the hydrological database of observed data in the basin. Existing data for all the considered meteorological and hydrometric stations were thoroughly inserted in order to get an archive for all simulations in river Lima basin system. The hydrological and hydrodynamic models play the essential role as the core of forecasting system. The models are executed through the FEWS general adapter in combination with the SOBEK model adapter. The interface format is the Delft-FEWS Published Interface (PI) which permits the exchange of time series data, model parameters, diagnostics etc. in XML.

The forecasting system created with the aforementioned components constitutes a platform to provide information on the streamflow state within the Lima river basin. An update run is implemented to run daily for approximating the system state as good as possible in comparison with the observed data. It serves as the initial condition for the forecast runs during the next day. The forecast runs have a lead time of seven days. The system supports the modification of uncertain model inputs such as rainfall to assess the sensitivity of model results, for example water levels and streamflows.

6. RESULTS AND DISCUSSION

The performance of the DSS created for the river Lima basin was verified for past rainfall events, using a backcasting approach to four events occurred in the years 2006, 2010, and 2011. In addition, a forecasting event was also considered in order to show the applicability of this methodology in future situations demonstrating the strength of the FEWS-LIMA platform. The rainfall event considered for flood forecasting was adopted from the Portuguese official meteorological service information for the week 2013.10.14 – 2013.10.21. This rainfall event scenario was obtained from the UGrib service. Table 1 shows the rainfall event scenarios considered and the correlation coefficients resulting from comparison between simulated and observed time series.

Table 1 - Rainfall event scenarios considered in the case study.

Rainfall event		Correlation coefficients – R^2	
		Flow rate (Ponte Barca)	**Water level (Ponte Lima)**
Backcast	BC1: 2006.03.20 – 2006.03.27	0,892	0,914
	BC2: 2006.11.20 – 2006.11.27	0,792	-
	BC3: 2010.01.01 – 2010.01.07	0,844	-
	BC4: 2011.01.03 – 2011.01.10	0,790	0,705
Forecast	FC: 2013.10.14 – 2013.10.21	-	-

Figures 3 and 4 shows the results obtained for river flow rate at Ponte da Barca and river water levels at Ponte de Lima in scenario BC4, respectively.

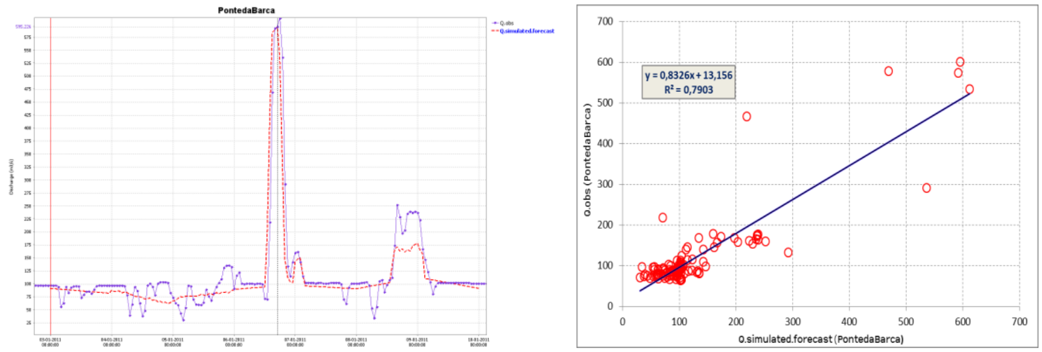

Figure 3. Scenario BC4. River rates at Ponte da Barca and its correlation coefficient.

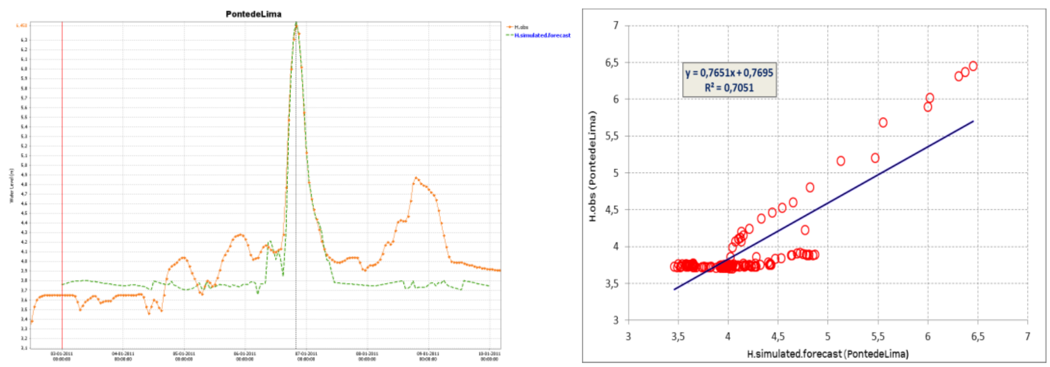

Figure 4. Scenario BC4. River water levels at Ponte de Lima and its correlation coefficient.

Results obtained for BC4 scenario allow the following considerations: (i) for the backcast scenarios a high correlation between the simulated and observed values has been achieved in the 7-days simulation time period; (ii) the correlation coefficient in the flood peak situations is apparently higher than for the periods before and after the occurrence of those events. This suggests that FEWS-LIMA has better performance in flood peak events than in other river hydrodynamics situations; and (iii) the good performances achieved with FEWS-LIMA DSS in all the backcasting scenarios allow confidence enough to trust in the results obtained for the forecasting scenarios.

7. CONCLUSIONS

We present a forecasting system for flood events for river Lima basin in Portugal. This platform integrates hydrological and hydrodynamic models that work together to predict streamflows and water levels in the river system. The predictions use observed and forecasted rainfall time series as input data originating from the gauging network and Numerical Weather Predictions.

The integration of all components in the Delft-FEWS forecasting platform creates a user friendly tool for the operational use in flood events and also serves as a powerful support in flood management studies at river basin scale. Historical rainfall data of different rainfall events were used for backcasting to demonstrate the accuracy of the modelling processes. In this practical setup, it is verified that the results obtained have good agreement with the observed data. After the finalization of the model calibration and validation, the system can be further developed to deal with precipitation ensemble forecasts and this way could be used for operational flood forecasting and decision support for mitigating flood damage within the basin.

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