Environmental Modelling & Software 24 (2009) 502–509

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

A non-linear forecasting system for the Ebro River at Zaragoza, Spain

D.J. Pedregal [a,*], R. Rivas [b], V. Feliu [a], L. Sánchez [c], A. Linares [d]

[a] *Escuela Técnica Superior de Ingenieros Industriales, Universidad de Castilla-La Mancha (UCLM), 13005 Ciudad Real, Spain*
[b] *Departamento de Automática y Computación, Universidad Politécnica de la Habana (CUJAE), Cuba*
[c] *Escuela Universitaria de Ingenieros Técnicos Industriales, Universidad de Castilla-La Mancha (UCLM), Spain*
[d] *BEFESA, Avda de la Buharia, 2, Sevilla, 41018, Spain*

A R T I C L E I N F O

Article history:
Received 10 January 2008
Received in revised form 2 September 2008
Accepted 16 September 2008
Available online 21 November 2008

Keywords:
Systems identification
Parameter estimation
Environmental systems
Water efficient use
Kalman Filter
Forecasting

A B S T R A C T

This paper addresses the problem of modelling and forecasting river flows and levels based on flood routing type models. Though this is generally considered as a non-linear problem, very often it is treated by linear models. A forecasting system is built for the level and flow measurements registered in the Ebro River at the station of Zaragoza (Spain), with the main purpose of preventing floods in an early stage of development. The model takes advantage of the wealth of data available at the Ebro Hydrographical Confederation and is non-linear in essence. The system is obtained by application of system identification tools, starting from a linear specification and relating the parameters of the model estimated to some transformation of the input in the system. Such transformation requires the application of a Kalman Filter in a particular set up and the full estimation algorithm involves an iterative procedure. The model is fully developed on a data set and is thoroughly validated on a different span of data.

1. Introduction

Water nowadays is becoming a very scarce resource in many parts of the world and is one important challenge some modern societies have to face. The water shortage represents for some countries one of the most severe limiting factors to maintain a sustainable development. This problem is also interacting with another problem as important: the damage of the environment at a global scale. Global warming may affect water quality and rainfall and runoff regimes in river catchments, originating important reductions of hydraulic resources in different parts of the world (Ortega et al., 2005).

Spain is one country where such problems are felt as most important, since it is considered as one of the European countries that suffer from hydric stress, situation that is acknowledged when the water demand in a region is greater than the water available in a given period of time (Barciela and Melgarejo, 2000).

The Ebro River represents the Spanish most important catchment of the Iberian Peninsula. It crosses the valley with the same name in the direction of the Mediterranean Sea with a length overall of 910 km and 85,000 km^2 of river basin (see Fig. 1). Floods during the cold station occur from October to March, sometimes until May, due mainly to an oceanic pluvial regime, whereas floods in spring are the result of melting snows in the Pyrenees.

The resources of the Ebro River are managed by a public institution, the Ebro Hydrographical Confederation (EHC), depending on the Spanish Ministry of Public Works. At present, the managing tasks are carried out on the basis of a complex and modern telematic system of information combined with several sophisticated deterministic hydrologic and hydraulic models. Most of the results of such a system, as well as general information on the EHC are open to the general public via the EHC webpage, http://195.55.247.237/saihebro/.

The system is fed in real time with the hydrological data provided by a set of rain and temperature sensors scattered across the whole catchment area, as well as level sensors installed at stations in dams and along all the rivers that constitute the full Ebro basin. This information along with the meteorological forecasts obtained periodically from the Meteorological National Institute (mainly rain and temperature 48 h ahead forecasts) constitutes the basic data in real time that is fed into the models.

The system has been conceived to be able to anticipate, two days in advance, the flows and levels that can take place in the river basin and throughout the different channels, allowing the technicians of the EHC to simulate the operations that should be undertaken in order to reduce to the minimum the pernicious effects of flood events.

* Corresponding author. Tel.: +34 926 295430; fax: +34 926 295361.
E-mail address: diego.pedregal@uclm.es (D.J. Pedregal).

1364-8152/$ – see front matter
doi:10.1016/j.envsoft.2008.09.010

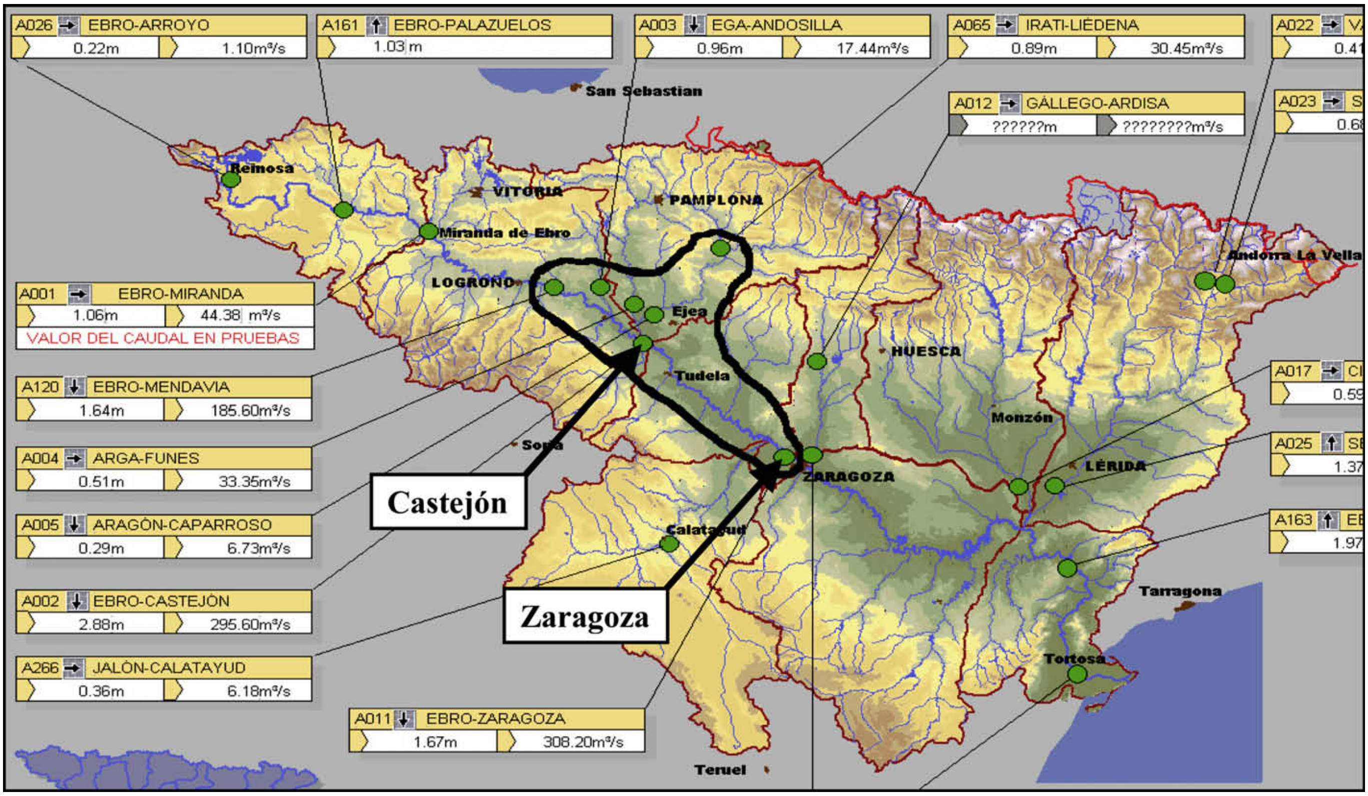

Fig. 1. The full Ebro River catchment, as shown in the EHC webpage. The river segment under study (Castejón and Zaragoza) is marked on the map.

The system incorporates a set of models working in parallel, which have been elaborated by different institutions. The main modules are:

- Hydrological module: it calculates the flows generated by a set of subriver catchments that add up the complete Ebro catchment. This module is composed of two rainfall runoff deterministic models, one developed for areas with little presence of snow and a second one for areas where the snow may take 5 or 6 months to melt down.
- Propagation module: it is in charge of transmitting hydraulically the volumes generated by the subriver basins modelled by means of the hydrological models above. Once more, the model is of a deterministic nature based on the Saint-Venant nonlinear hyperbolic partial differential equations (Saint-Venant, 1891; Chow, 1988), using a set of cross-sectional profiles for the basin.
- Dam management module: it simulates, in combination with the previous modules, different strategies of operation for the 41 dams distributed across the geography of the catchment.
- Forecasting module: in a deterministic framework it allows to distinguish between two different states, (i) simulation, where there are observed data and (ii) prediction, where the input data (rain and temperature) are fed into the system in order to foresee the future evolution of flows along the rivers in the catchment.

The hydrological module was made by a collaboration of different institutions, namely the Department of Hydrodynamics of the Technical University of Denmark, the Danish Hydraulic Institute, and the Spanish Ministry of the Environment and Ingeniería 75 (a Spanish consultancy). The rest of modules were built by adapting parts of model MIKE11 to the Ebro River, made by the Danish Hydraulic Institute (Havnø et al., 1995; DHI Water and Environment, 2003).

There are clear advantages in the system implemented. The main ones are that (i) it is rather comprehensive, since it is built for the whole catchment of the river and incorporates a wide set of meteorological and hydrological data and forecasts and (ii) it is based on solid theoretical hydraulic foundations and is built by renowned research groups.

However, the main disadvantage is that the system is in practice so demanding in computational terms that only one run per day is operative, together with usual post-processing before the information is delivered to the general public. In addition, the particular application developed for running the models at the EHC is a closed piece of software very rigid, with few degrees of freedom in order to modify the forecasts, in case they become unreliable or unstable at some point in time.

In order to overcome such disadvantages, a new complementary system, simpler to run and based on dynamic systems identification and data-based principles, is tried out. This paper represents the first small step towards a comprehensive system for the full river catchment, in the framework of a wider joint project with the University of Castilla-La Mancha. The particular aspect considered in this paper is the modelling and forecasting of one section of the river, namely the 110 km segment connecting the town of Castejón to Zaragoza (see Fig. 1). This is one of the most critical sections of the whole river, since Zaragoza is the main and biggest city in the Ebro catchment area.

The approaches used in this project are within non-deterministic techniques based directly on the data. The literature on this topic is immense, because forecasting flows or levels at certain points in a river have been done in many different ways.

Firstly, there are some attempts to forecast flows or levels on the basis of univariate models, though there are not many (Abrahart and See, 2000). Secondly, flood routing or stage routing studies are found often, by which the situation at a point in a river is forecast on the basis of measurements upward in the catchment (e.g. Nash, 1959; Tawfik, 2003; Nayak et al., 2004; Onyando et al., 2005; Tsai,