An Example of Flood Forecasting and Decision-Support System for Water Management in Spain

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ABSTRACT

The paper provides an overview of past, present and future development in the program to implement a Flood Forecasting and Decision-Support System (DSS) for the SAIH network in some Spanish basins. These tools represent a significant advance by embedding the decision-making components for management of hydraulic infrastructure into the flood forecasting and flood early warning procedures.

The DSS has been implemented based on an open-shell platform for integrating various data sources and different simulation models. So far, it covers the Segura, Jucar, Tajo, Duero and Miño-Sil basins, which represent 42% of Spanish territory. Special attention is paid to the decision-support for the operation of the 66 major reservoirs as a fundamental part of flood management.

Keywords

Flood Forecasting Systems, Flood Early Warning Systems, Decision Support Systems, Reservoir Management.

INTRODUCTION

Flood events are the natural hazard with the highest number of casualties in Spain with a total number of 268 only in the period from 1995 till 2009 (MMA, 2009). Cases like the floods in Valencia in 1957, Murcia and Almeria in 1963, Júcar basin in 1982 and Basque country in 1983 became part of the historical memory of our society. Therefore, the study of flood events and its mitigation is a relevant part of Spanish water policy.

Flood management in Spain has relied on structural measures until recently, mainly through the attenuation of peak flows by reservoirs and protection of urban areas by river training. The preponderance of this management option was mainly in short-term effectiveness of these measures and the ease of implementation, as they materialize through infrastructure projects that rely on a single administration.

Recently, the main attention is shifting to non-structural measures. Such measures are more sophisticated to implement from an organizational point of view, because they require the participation of multiple stakeholders and coordinated action of several administrations. On the other hand, they provide a relatively inexpensive alternative to the construction of new infrastructure and result in a better exploitation of the existing one. Non-structural measures for flood management include flood forecasting and warning systems with embedded decision-support components. In Spain, these are based on real-time data acquisition systems developed in the

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SAIH Program (Sistema Automático de Información Hidrológica).

The SAIH Program is active since 1983. The real-time hydro-meteorological information systems are structured on the level of the large Spanish River Basin Districts. Nowadays, the system has 2,650 telemetry sites, including rain gauges, snow gauges, channel and river gauges and reservoir monitoring. So far, investment in this program has been about 840 million €. The experience of nearly 20 years of using SAIH systems shows that although the systems have become an indispensable tool for the management and administration of water resources, society also demands tools to anticipate the response to flood events. In response to an increasing need from society real-time flood forecasting models have been developed (Parker, 2005).

From the perspective of the EU legislation, it is worth noting, that the directive 2007/60/CE of the European parliament and of the council of 23 October 2007 on the assessment and management of flood risks requires member states to draw up maps identifying all areas exposed to flooding risk and indicating the probability and the potential damage for local populations, property and the environment by the end of 2013. Moreover, it requires preparing and implementing flood risk management plans for each river basin district including management measures focusing on reducing the probability of flooding and the potential consequences of flooding by the end of 2015.

The Directorate for Hydraulic Works (DGA) has promoted the implementation of DSS for flood management in the main River Basin Districts of Spain. Flood warning systems are typically tailor-made to suit the specific requirements for specific regions (Werner et al., 2004). The system developed by the authors ia based on the idea of building a flood forecasting system with an open architecture in order to take into account the different requirements of different administrative units and, at the same time, standardize tools for flood forecasting and management. This led to the selection of the Delft-FEWS (Flood Early Warning System), an open-shell flood forecasting platform that allows an easy integration of data and models used in forecasting.

As mentioned above, the paper describes the evolution of flood forecasting systems in Spain with emphasis on the development of decision-support components. The following section gives some background on the open-shell platform Delft-FEWS. The next section specifies the River Basin Districts where the DSS have been implemented so far. The last section provides an overview about the scope of the DSS and the tools included.

DELFT-FEWS

Whilst the role of flood forecasting in the flood warning process traditionally held a modest position in the chain of detection, forecasting, warning, and response (Haggett, 1998), its potential in added effectiveness of warnings through an increase of lead time means its significance is becoming more and more relevant in state-of-the-art systems. This lead time can be effectively used to implement measures either to reduce the consequence of flooding through for example evacuation, or to reduce flooding itself through controlling dedicated hydraulic structures.

From a technical point of view, most forecasting systems in the past have been developed as an interface around a hydrological or hydraulic model, thus concentrating on the model rather than the data process (Moore and Jones, 1998). Increasing availability of observed data through online telemetry and from technologies such as weather radar and quantitative precipitation forecasting are, however, requiring attention to shift to the complete process of information and data in forecasting. This has led to the development of software packages such as Delft-FEWS (Werner et al., 2004; Werner and Whitfield, 2007) with an open systems approach for integration of arbitrary data and models in the forecasting process. The modular approach has the advantage that many of the components used, such as the underlying models can be easily adapted or exchanged, without the need to change how the forecasting system is operated by its users. This allows for a much more rapid adaptation to advances in modeling techniques, without the added effort in organizational change.

In order to improve the predictions of water systems that are influenced by human interactions such as the operation of reservoirs or reservoir systems, it is necessary to include the control dynamics of these entities by enabling interactive decision-making via graphical user interfaces (GUI) or automatic procedures based on control and optimization theory.

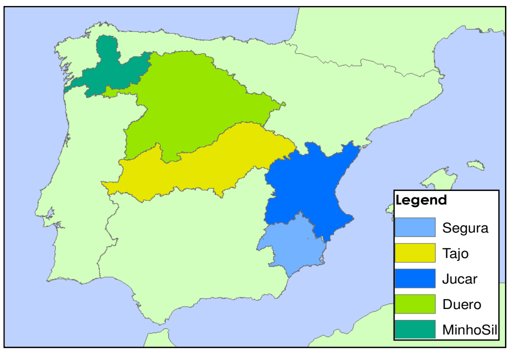
STATUS OF THE INTRODUCTION OF DSS IN THE SPANISH WATER BOARDS

Spatial coverage

Until the end of 2010, DGA promoted the implementation of DSS in the River Basin Districts of Segura, Jucar, Tajo, Duero and Miño-Sil. It represents 42% of the total area of Spain (Figure 1).

It deserves special attention, that the Spanish-Portuguese river basins (shared by Spain and Portugal) occupy 264,560 km^2 out of about 581,000 km^2 or 45.5 % of the total area of the Iberian Peninsula. This area is equivalent to 2.5 % of Europe and 18 % of the EU territory.

The shared basins occupy 207,630 km^2 in Spain and 56,930 km^2 in Portugal or 78.5 % and 21.5 %, respectively. The areas of the Miño/Minho, Limia/Lima, Duero/Douro, Tajo/Tejo and Guadiana are, respectively, 17,080 km^2, 2,480 km^2, 97,600 km^2, 80,600 km^2 and 66,800 km^2.



Name	Area (km^2)	Percentage
Duero	78,865	16%
Jucar	42,958	8%
Miño-Sil	17,594	3%
Segura	18,897	4%
Tajo	55,767	11%
Total with DSS	**214,081**	**42%**
Total Spain	**506,259**	**100%**

Figure 1 River basins with Flood Management by DSS

Data feeds

The DSS for flood management integrates observed hydro-meteorological data from telemetry systems, remote sensing data from radars or satellites as well as numerical weather predictions. The data is linked to hydrological and hydraulic models for conducting model-based forecasts including performance indicators for assessing the forecast quality mainly in terms of lead time accuracy. Furthermore, a reservoir management module has been incorporated for evaluating optimum use of the reservoirs as well as GUI-supported scenario analysis for predictions and reservoir management.

The sources of telemetry data are the SAIH systems which provide real-time telemetry data to the DSS in a standardized XML format. The data feeding the systems are discharge in rivers and channels, inflow and release of reservoirs, reservoir levels and volumes, precipitation, temperature, wind, humidity in meteorological station, snow gauges, etc. These data come from the 857 telemetry sites implemented in the DSS.

AEMet (Agencia Estatal de Meteorología) provides Radar Precipitation and a weather forecasting numerical model, HIRLAM, to the system. It owns a radar observation network comprised of 15 regional radars and a national radar system, responsible for the centralization of the regional end products and for the generation of national mosaic images. The radar data feeding the system are those corresponding to the composition of the Peninsula and the Balearic Islands and consist of generated images composing CAPPI-0.5 (cod McIDAS, Q data in mm, lambert, n = 1520 x 1520, res = 2x2 km2, 8 bits) radar network AEMet except the Canary Islands.

The HIRLAM (High Resolution Limited Modelling Area) model is a regional weather model (limited area) that is operative in the AEMet from 1995. AEMet is a partner in the international HIRLAM project which has, as its main goal, the development of a Limited Area Model for its use in operational short range weather prediction. The short range numerical prediction system is run by AEMet four times per day at 00, 06, 12 y 18 hours UTC with a resolution of about 16 km (0.16º in a latitude/longitude grid) and 40 vertical levels. It is run up to +72 hours. Boundary conditions are supplied from the ECMWF model, with 3-hourly time resolution.

Modelling components

As regards the implemented hydrologic and hydraulic models in the DSS, we focused on i) the models already available and validated in the river basins and ii) the implementation of new models adequate for the characteristics of the study areas. The hydrology models used are: ASTER, TOPKAPI, TETIS, NAM and ANN.

The hydraulic models used are: SOBEK, MIKE 11 and HEC-Ras. Furthermore, the DSS also integrates RAINMUSIC, which is a model for Bayesian averaging of precipitation information from rain gauges, radar and satellite data. The open architecture of the forecasting platform enables a similar integration of all models via a general adapter functionality, providing also a consistent GUI for all data imports and model simulations.

A key element of the DSS is the Reservoir Management Module (RMM). It provides a range of management alternative for the reservoir operation. An essential task of flood management is the determination of an effective reservoir operation strategy that minimizes downstream damage, while keeping dam safety within reasonable limits and maximizing the volume of water stored at the end of the flood event (Mediero et al., 2007)

The management of reservoirs during flood events aims at the prevention or reduction of its harmful effects and damping of the flood wave by controlling the outlet gates within a feasible range of operation. This range is found between two physical extremes in each operating point corresponded to completely closed and opened gates, or the minimum and maximum release, respectively. In some cases, the operating range can be more restricted, if we take into account some additional conditions. For instance, the operating rule may restrict the release to be lower than the inflow. Within the operating range, the most advantageous management alternative must be selected. Therefore, three basic modeling alternatives exist: the calculation of attenuation, schedule management and optimization of management.

The calculation of the attenuation consists on the definition of the raised levels and release of the reservoir during the flood events based in a strategy of operation. It is used to evaluate from a quantitative point of view the consequences of a strategy proposed. The schedule management is the application of the operation rules according to the current situation of the reservoir. And finally the optimization which is the definition of the optimal strategy based on a number of objectives and constraints.

The calculation of the attenuation is very simple. Modeling schedule management can also be programmed easily, although the process can become very complex. However, the definition of the optimal strategy is a problem with mathematical formulation more complicated and its resolution requires the development of sophisticated algorithms.

CONCLUSIONS AND OUTLOOK

Nowadays in Spain, priorities in flood management are shifting to non-structural measures. Within the SAIH program, real-time hydro-meteorological information systems have been developed for the main Spanish river basins. These systems have become an indispensable tool for water management in Spain. However, more advanced tools are required for flood management in order to achieve greater efficiency in the use of the available infrastructure. DSS for flood management are being implemented in the main river basins aiming at the integration of meteorological and hydrological data with simulation models to provide flood forecasts more in advance and enable anticipatory control of the infrastructure. The open-shell architecture of the chosen platform allows an easy integration and exchange of data and simulation models implemented in the system.

Future developments in the Spanish flood forecasting system will mainly focus on the decision-support components. This includes further refinement of available tools, and better technical integration into the platform with advanced GUI options for model calibration, data assimilation, interactive GUIs, the introduction of optimization in the reservoir management module, and more interactive options for decision-making.

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