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Research papers

Drought early warning based on optimal risk forecasts in regulated river systems: Application to the Jucar River Basin (Spain)

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ABSTRACT

Droughts are a major threat to water resources systems management. Timely anticipation results crucial to defining strategies and measures to minimise their effects. Water managers make use of monitoring systems in order to characterise and assess drought risk by means of indices and indicators. However, there are few systems currently in operation that are capable of providing early warning with regard to the occurrence of a drought episode. This paper proposes a novel methodology to support and complement drought monitoring and early warning in regulated water resources systems. It is based in the combined use of two models, a water resources optimization model and a stochastic streamflow generation model, to generate a series of results that allow evaluating the future state of the system. The results for the period 1998–2009 in the Jucar River Basin (Spain) show that accounting for scenario change risk can be beneficial for basin managers by providing them with information on the current and future drought situation at any given moment. Our results show that the combination of scenario change probabilities with the current drought monitoring system can represent a major advance towards improved drought management in the future, and add a significant value to the existing national State Index (SI) approach for early warning purposes.

1. Introduction

Droughts are a major threat to the sound operation and management of water resources systems. Developing new approaches to anticipate them will help in defining strategies and measures to minimise their effects. The use of monitoring systems to calculate drought indices and indicators can help water managers characterize droughts and define risk scenarios. The activation of a drought scenario in a system will trigger a number of measures addressed to minimise the possibilities of developing into a worse scenario and minimizing the possible effects of the current situation.

The assessment of drought severity requires the use of an index which fulfils well-known criteria (Tsakiris et al., 2013): operational usefulness, physical meaning, sensitivity to a wide range of drought conditions, applicability in all parts of the globe, quick response to changes due to drought and high availability of required data. Commonly, such an index is a prime variable for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent as defined by Yevjevich (1967) in his theory of runs. A time series of drought indices provides a framework for evaluating drought parameters of interest. Generally, drought indices are categorized as meteorological, hydrological, agricultural or remote sensing-based (Rossi and Cancelliere, 2013). Mishra and Singh (2010) and Pedro-Monzonís et al. (2015) made an extensive review of existing univariate drought indices both concluding that each index performance is region specific mostly due to the characteristics of the variables used for their calculation and the purpose of the analysis. In addition, in recent time some authors have also attempted to combine all the variables (e.g. precipitation, soil, water content) that lead to different physical forms of drought in so-called multivariate drought indices (Rajsekhar et al., 2015). In some cases, the index is built as an aggregation of variables selected according to their relation each drought type (Keyantash and Dracup, 2004; Rajsekhar et al., 2015). Inother, the index is constructed using copulas to derive the joint distribution of two or more variables (Kao and Govindaraju, 2010; Hao and AghaKouchak, 2013).

An indicator system is a drought monitoring system that allows the anticipation in the application of mitigation measures for the reduction of socio-economic and environmental impacts of droughts (Estrela and Vargas, 2012). Such systems can also be considered early warning systems for their capacity to anticipate the

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effects that drought may have on the system in order to trigger necessary mitigation measures (Rossi et al., 2008). In most cases, these systems are normally formed by basic variables selected at different points in a river basin that are capable of defining the current drought status. Their reliability will depend on their capacity to represent, using real-time data: (1) the relationship between significant reductions of water availability with deviations of meteorological and hydrological components from their average; (2) detecting early stages of drought development; (3) provide results that allow comparison between events both in time and space; and (4) assessing the severity of the ongoing situation in order to support decision making for triggering drought mitigation actions. Additionally, in the case of regulated water resources systems, it would be desirable that the indicator is capable of showing the evolution of management and how this would change the drought status of the system if new operation rules are envisaged.

Different drought early warning systems have been developed at different spatial scales, but a very small number of such systems are actually in operation (Rossi and Cancelliere, 2013). This is mainly due to the low density of meteorological and hydrological gauging networks, the sharing of the data among different agencies with different objectives, and to the lack of universal standards in computing drought indices (Rossi, 2003). In addition, the development of indicator systems based on observational frameworks cannot provide sufficient anticipation with regard to the event in progress in order to activate the necessary measures to mitigate its effects (Haro et al., 2014a,b). Efforts have been made to correlate drought indices to impacts (Stagge et al., 2015), but these relationships only provide insight after the event has finished and the impacts reported. Mishra and Singh (2011) acknowledged that to develop suitable techniques for forecasting the onset and termination of droughts is still a major research challenge due to the inability to predict drought conditions accurately for months or years in advance. Due to these inaccuracies and uncertainties, drought management relies nowadays mainly on risk assessment. Risk assessment during the operation phase of a system is often referred as conditioned risk assessment. With this procedure, the state of the system is usually evaluated for the short-term to explore alternative mitigation measures and policies for an ongoing drought episode. This same assessment approach can be adopted for early warning purposes (Cancelliere et al., 2009).

Alecci et al. (1986) considered that the risk assessment of a water supply system is a problem that is better approached through a set of several indices and analysing the probability of suffering shortages of different entities. This is due to the many complexities existing within a water resources system such as the stochastic nature of inflows, the high interconnection that exists between different components of the system, the competition for water by conflicting demands, the definition of what elements are at risk, and the uncertain character of the impacts in different drought episodes. Traditionally, reliability, resiliency and vulnerability have been the indices used to capture the different performance aspects of water supply systems (Hashimoto et al., 1982). However, these indices are normally representative of just one particular use, defining the state of the system with regard to the probability of a failure for such index. Since all drought events are unique, so too are their effects both temporally and spatially. Therefore, it is necessary to have an indicator that is capable of summarising the state of the system for any given situation. In regulated systems, it will be the volume stored in reservoirs since it provides an overview of the previous management of the system and is the basis for future resources allocation.

This paper proposes a novel methodology to support drought monitoring and scenario definition in regulated water resources systems. It is based on the results of two models, an optimisation model and a stochastic streamflow generation model, both of which have been calibrated and validated in previous research (Haro et al., 2012a, 2012b, 2014b; Ochoa-Rivera, 2002). Using storage in reservoirs as a summary indicator of the future system status, we propose a combined use of the two models to generate a series of results that can support and complement drought monitoring and early warning systems currently in place in a river basin. The methodology is applied to the Jucar River Basin in Spain to evaluate the probability of a scenario change several years in advance. The proposed method has the potential to enhance decision making under highly uncertain hydrological situations, and provide water resource planners and managers with new insights both regarding the behavior of the system and the development of drought episodes.

2. Case study description

The Jucar River Basin is located in the eastern part of the Iberian Peninsula in Spain (Fig. 1). This basin is the most important of the 9 water exploitation systems in the Jucar River Basin Demarcation (Demarcacion Hidrografica del Jucar – DHJ in Spanish). In the Valencia coastal plain, where the Jucar River has its mouth, there is a shallow lake called Albufera, with an associated wetland. Both, the lake and the wetland depend on return flows from irrigated areas in the basin, and also on groundwater flows from the coastal aquifer beneath the plain (Andreu et al., 2009). It is the largest system of the DHJ both in surface (22,261 km^2) and in volume of resources (1548 hm^3/year).

The river is an example of a typical Mediterranean river, characterized by a semi-arid climate in most of the basin territory consisting of low precipitation rates (475 mm/year) during the year combined with exceptional convective storms that can lead to flooding and seasonal summer scarcity that occurs when irrigation requirements are at their highest. Urban demand accounts for circa 143.3 hm^3/year and the water demand for irrigated agriculture reaches 1034.3 hm^3/year. Water supply to small urban areas comes mainly from wells and springs, but large metropolitan areas such as Albacete, Sagunto and Valencia rely on surface water (Andreu et al., 2009). According to the White Book of Groundwater (CEDEX, 1995), nearly three quarters (73%) of the resources in the territory of the DHJ have subterranean origin. This highlights the major importance that groundwater resources have in the management of these basins. The total amount of available groundwater resources in the basin is 1225 hm^3/year. However, this only represents the estimated volume in all the groundwater bodies without accounting for their sharing between other basins or the relationship these bodies have with the surface water system.

With regard to droughts, the Jucar River Basin can be considered to be one of the most vulnerable areas in the western Mediterranean region, due to high water exploitation indexes, and the environmental and water quality problems that arise when droughts occur. This situation has triggered increased use of nonconventional resources in recent years, such as reuse of wastewater and drought emergency wells. Also, conjunctive use of surface-ground waters has historically been a very important option in the region to provide robustness against droughts. The integrated use of these three resource options was considered a major success in adapting to the latest drought episode between 2005 and 2008 (Ortega-Reig et al., 2014).

The operation of the system is mainly multi-year. The Alarcon and Contreras reservoirs, at the headwaters of the system, are capable of storing the highly variable streamflow coming from their upstream sub-basins. The third most important reservoir in the system, the Tous, is operated on an annual basis. Before the summer season it stores incoming mid-basin streamflow and upstream reservoirs releases to supply the different demands within the