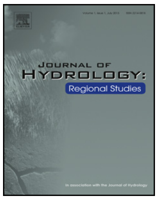
Journal of Hydrology: Regional Studies 4 (2015) 550–570

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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



Estimating climate-change effects on a Mediterranean catchment under various irrigation conditions

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ARTICLE INFO

Article history:
Received 25 May 2015
Received in revised form 31 July 2015
Accepted 3 August 2015
Available online 5 September 2015

Keywords:
Irrigation
Climate change
Integrated hydrological model
Mediterranean region
Hydrological response

ABSTRACT

Study region: The Lerma catchment, a small (7.3 km^2) sub-catchment of the Ebro Basin in northern Spain.
Study focus: The Lerma catchment underwent a monitored transition to irrigated agriculture, using water from outside the catchment, between 2006 and 2008. This transition has successfully been simulated using the partial-differential-equation-based model HydroGeoSphere, simulating coupled evapotranspiration, surface water, and groundwater flow in the catchment. We use the calibrated model to study how irrigation practices influence the response of the Lerma catchment to the climate change projected for northern Spain. We consider four different irrigation scenarios: no irrigation, present irrigation, climate-adapted irrigation with current crops, and adapted irrigation for crops requiring less water. The climate scenarios are based on four regional climate models and two downscaling methods.
New hydrological insight: The simulated catchment responses to climate change show clear differences between the irrigation scenarios. In future climate, groundwater levels and base flows decrease more when irrigation is present than without irrigation, because groundwater levels and base flow in present climate are already at low levels without irrigation. In contrast, annual peak discharges increase more in non-irrigated cases than in irrigated cases. Irrigation increases water availability and an associated rise in potential evapotranspiration results in higher actual evapotranspiration during summer. In non-irrigated scenarios, by contrast, actual evapotranspiration in summer is controlled by precipitation and thus decreases in future climate.

1. Introduction

The increase in mean global air temperature over the past 30 years, linked to the anthropogenic increase of CO_2 emissions (e.g., Meehl et al., 2007), influences the global and regional water cycle and is expected to change future precipitation patterns (e.g., Sillmann and Roeckner, 2008). Particularly strong impacts are expected in semi-arid regions, such as the Ebro basin in north-east Spain (Vargas-Amelin and Pindado, 2014). The timing and magnitude of these impacts, however, are difficult to

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http://dx.doi.org/10.1016/j.ejrh.2015.08.001

predict (Ghosh and Misra, 2010), a fact which complicates efficient mitigation. In the next century, less water will probably be available in the Ebro region (Bovolo et al., 2010; Buerger et al., 2007; Milano et al., 2013) as a result of increased potential evapotranspiration (Moratiel et al., 2010; García-Garizábal et al., 2014) and decreased precipitation in spring and summer (Blenkinsop and Fowler, 2007; Ribalaygua et al., 2013).

Various catchment-scale case-studies in north-east Spain forecast a decrease in runoff (Candela et al., 2012), streamflow (Ferrer et al., 2012; López-Moreno et al., 2014; Zambrano-Bigiarini et al., 2010), recharge (Candela et al., 2012), and water quality (Bovolo et al., 2010). Some recent observed changes, for example variations in run-off generation (Otero et al., 2011) and decrease in river flow (Milano et al., 2013), have already been linked to ongoing climate change. In addition, irrigation needs are likely to increase (e.g. Jorge and Ferreres, 2001; Rey et al., 2011; Iglesias and Minguez, 1997) because of the higher evaporative demand and possibly because of expanding irrigated areas (Scanlon et al., 2007; Bielsa and Cazcarro, 2015).

Changes in land use often interact with climate change and its impacts (e.g., Dale, 1997; Pielke, 2005). For example, predictions of stream-flow in the Pyrenean mountains indicate that reforestation and climate change together lead to a decrease stream-flow twice as much as climate change alone (López-Moreno et al., 2014). In the same region, the duration of snow cover is expected to decrease due to climate change, while reforestation influences the snow depth (Szczypta et al., 2015). Reforestation also impacts climate-change effects on erosion in semi-arid regions (Simonneaux et al., 2015) and on groundwater recharge (Montenegro and Ragab, 2012). In the semi-arid Upper Yellow River region of China, land-use changes, notably over-grazing and increased irrigation, result in a decrease of stream-flow at a similar magnitude than the one due to climate change (Cuo et al., 2013; Zhao et al., 2009; Zheng et al., 2009). In general, assessing the contribution of land-use and climate changes on streamflow changes is difficult and uncertainties are large (Cuo et al., 2013; Kling et al., 2014; Mehdi et al., 2015). In irrigated regions, the choice of irrigation techniques and cropping patterns can support the adaptation to climate change (Mehta et al., 2013; Woznicki et al., 2015). However, because of water-resources limitation and increasing irrigation needs, irrigation often worsens effects of climate change on hydrological processes in semi-arid climates (e.g., Candela et al., 2009).

Because of the interactions between climate and land-use changes, the increase in irrigation needs or in irrigated area, which might be as high as 50% of the current irrigated area in the Ebro region (Bielsa and Cazcarro, 2015), is likely to have impacts beyond the direct increase in water use. Apart from its importance for the regional water resources, irrigation management might influence the response of the catchment to climate change. An irrigated and a non-irrigated catchment might react differently to the same changes in climate. However, the extent and nature of these differences in climate sensitivity is unknown.

In this study, we analyze some of these differences to better understand the interactions between irrigation and climate change. We concentrate on a catchment-scale case study, situated in north-east Spain. The Lerma catchment experienced a monitored transition to irrigated agriculture in the years 2006–2008 allowing us to simulate the hydrological processes in this catchment, before and after the implementation of irrigation. Then, we model the studied catchment assuming different irrigation scenarios and a scenario without irrigation in present and future climate. The differences in the catchment responses to climate change can be linked to irrigation practices and used to improve the understanding of interactions between climate change and irrigation. Our comparison is centered on a specific case study. However, climate, geology, and agricultural practices in many catchments in the Ebro region are similar to those in the Lerma catchment. Hence, our results are relevant for the whole region, especially because of the planned expansion of irrigated agriculture.

The remainder of this paper is structured as follows: First, we review the study area and the hydrological model. Then, we describe the climate and the irrigation scenarios. Finally, we present our results about the impact of climate change on hydraulic heads, base flows, peak flows, and actual evapotranspiration assuming different irrigation scenarios.

2. Study area

The Lerma catchment (~42.06° N, ~1.14° W, Fig. 1) is located in the central Ebro basin. Current climate is classified as semi-arid with a mean annual precipitation of 402 mm/year (2004–2011) and a mean reference evapotranspiration (ET_0) of 1301 mm/year (2004–2011) (Merchán et al., 2013). Daily precipitation and temperature have been measured since 1989 at the meteorological station of Ejea de los Caballeros, located ~5 km to the north of the catchment. Wind speed, radiation and relative humidity have been measured there since 2003. Annual total precipitation has varied between 236 mm/year and 630 mm/year over that period of time. Most rains fall in autumn and spring, while summers are usually drier and characterized by long periods of anticyclonic conditions.

The catchment is about 7.3 km^2 large with elevation ranging between 330 meters above sea level (masl.) and 490 masl. Agriculture is currently the dominant land use (Pérez et al., 2011). However, prior to 2006, irrigated agriculture was not practiced in the catchment. Irrigation started in April 2006 and has been expanding since. Currently, the area of irrigated land is about half of the watershed. The volume of irrigation was 2.1×10^6 m^3/year in 2011 (Merchán et al., 2013) and none prior to 2006 (Table 1). Irrigation is recorded daily in 52 zones, which are generally defined based on the limits of the fields owned by each farmer. The majority of irrigation is applied from April to September and the main cultivated crops are corn, winter cereal, and sunflower (Table 2). The irrigation water is provided from the Aragon river whose flow is stored in the Yesa reservoir, situated about 70 km to the north of the catchment in the Pyrenees. After being transported using the Bardenas irrigation canal, the irrigation water is distributed in the catchment using sprinklers in 86% of the irrigated area and drip irrigation otherwise (Abrahao et al., 2011). No groundwater is used for irrigation or for water supply within the catchment.