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Dry getting drier − the future of transnational river basins in Iberia

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ABSTRACT

Study region: Main international rivers of Iberia (SW Europe): Douro, Tagus and Guadiana.
Study focus: Iberia has long suffered from water scarcity which will worsen with projected reductions in rainfall and increases in temperature. Nonetheless, there has been almost no research concerning the future discharges of these rivers. We examine an ensemble of climate model projections from CMIP5 RCP 8.5 and use two downscaling methods to produce a range of changes in discharge using a physically-based, spatially-distributed hydrological model (SHETRAN) for historical (1961–1990) and future (2040–2070) periods.
New hydrological insights for the region: There is uncertainty in the sign of change in high (winter) discharges but most model runs show decreases in monthly, seasonal and annual discharges for all basins; especially for medium and low discharges, with all but one run showing future decreases. The magnitude of these decreases varies significantly for different CMIP5 ensemble members. However, autumn shows the biggest decreases (reaching −61% for the Douro, −71% in the Tagus, and −92% for the Guadiana) and the reductions are consistently larger for the Guadiana. This is the first study to explore a wide range of possible futures for these international basins. We show that, despite uncertainties in model projections, there is common behavior with reductions in mean and especially in low discharges which will have important implications for water resources, populations, ecology and agriculture.

1. Introduction

Portugal and Spain share five river basins which cover 40% of the Iberia peninsula. Under natural conditions around 70% of the total outlet flow of the three main international Iberian rivers, the Douro, the Tagus and the Guadiana, has its origin in Spain (INAG, 2001). The main characteristic of these rivers are shown in Table 1.

The first water treaties between Portugal and Spain date back to the 19th century and several treaties were later signed in the 1920s and 1960s. The latest, from 1998, is the Albufeira Convention. This convention seeks to balance environmental protection with sustainable use of water resources within the framework of International and EU Law (UN, 2013). In 2008 a seasonal flow regime for the Douro, Tagus and Guadiana was defined (as a revision of the convention), which includes minimum flows for different times of the year.

The seasonality of flows in these basins, with high winter discharges and low summer discharges, is typical of Iberia and is mainly a result of the seasonality of the rainfall exacerbated by the high temperatures (and therefore potential evapotranspiration − PET) of the summer months. The highest mean discharges occur in the Douro but the highest maximum discharges occur in the Tagus. Iberian rivers tend to show high coefficients of variation in flow, which increases from south to north: around 100% for the Guadiana and

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Table 1
Basin area and annual discharge of the three studied basins (INAG, 1999a; INAG, 1999b; INAG, 2001).

River	Basin area (km^2)	Annual discharge (hm^3)
Douro	97 603	14 800
Spanish: Duero	(19% in Portugal, 81% in Spain)	
Portuguese: Douro		
Tagus	80 629	9 629
Spanish: Tajo	(30% in Portugal, 70% in Spain)	
Portuguese: Tejo		
Guadiana	66 800	2 680
Spanish: Guadiana	(17% in Portugal, 83% in Spain)	
Portuguese: Guadiana		

50% for the Douro (Gámiz-Fortis et al., 2008).

Along the Douro River there are numerous hydroelectric power plants and the middle Douro is extensively used for irrigation. In Portugal, the principal crop of the Douro valley is grapes, which are used to produce Port wine (UNEP, 2003). The Tagus River acts as a natural border between "wet Iberia" in the north and "dry Iberia" in the south, with its northern tributaries having considerably higher discharges than the southern tributaries (Portela et al., 2009). It is also the source of the Tagus-Segura water transfer which was built in 1978 to transfer up to 1,100hm^3/yr from the headwaters of the Tagus to the Mediterranean basins of the Jucar and the Segura, mainly to supply water to the irrigated areas in the south-east of Spain. The transfer is controversial and in the 2005/2006 drought caused several public demonstrations in both the Tagus and the Segura basins, respectively against and in favor of this water transfer system (Beguería et al., 2009).

The headwaters of the Guadiana are one of the driest places in Europe, with mean annual rainfall of 415 mm and PET above 800 mm/yr (Kilsby et al., 2007).The upper Guadiana basin consists of streams closely connected to aquifers with both stream flows and groundwater levels in decline in line with a dramatic increase of groundwater abstraction for irrigation. Degradation of protected wetlands has occurred due to declining groundwater levels, problems with water salinity and with invasive species from the Tagus basin that have resulted from occasional water transfers between the two basins (Conan et al., 2003). The Portuguese part of the Guadiana has the largest reservoir in Europe: Alqueva. It was built with the objective of being a strategic water reserve for the south of Portugal, providing water for irrigation, urban and industrial consumption, energy production and regularization of flows (INAG, 2001). It irrigates an area of around 120,000 ha (through a complex system with 69 dams, reservoirs and weirs) and is the main source of water supply for 200,000 people (EDIA, 2016).

Despite the strategic water resources of these basins, and projections of a drier future for the region (Ekström et al., 2007; Hingray et al., 2007; Kilsby et al., 2007; Guerreiro et al., 2016, 2017), climate change studies that focus on hydrological impacts on the Douro, Tagus or Guadiana basins could not be found. Some studies can only be found for small sub-basins inside these three international river basins. The exception is Kilsby et al. (2007) who looked at the hydrological impacts of climate change on the Tagus and the Guadiana rivers for 2070–2100 under the SRES A2 scenario using one Regional Climate Model − RCM (HadRM3H driven by HadCM3), two downscaling techniques (monthly bias correction and a circulation-pattern-based stochastic rainfall model) and a conceptual rainfall-runoff routing model. Reductions in flows for both basins were projected throughout the year due to increased PET and year-round rainfall decreases. The circulation-pattern-based method produced smaller reductions in flows (21% for Guadiana and 20% for Tagus) than the bias correction method (26% and 49%). Kilsby et al. (2007) pointed towards the need for major improvements of the hydrological modelling since observed and simulated flows showed large discrepancies. This improvement is a challenge due to the effect of dams and abstractions on the observed discharges and the infeasible task of accounting for these in the absence of operational data. The only other study found was Lobanova et al. (2016) that looked at the impacts of changing climate on the hydrology and hydropower production of the Tagus river using five CMIP5 GCM runs bias corrected using the WATCH ERA40 dataset. They projected that for RCP8.5, river discharge will decrease on average by 30% for 2021–2050 and 60% for 2070–2099 with model agreement being higher for the end-of-century period. However, values for individual model projections or for intermodal spread were not provided.

European and global climate change impact studies on hydrological variables can be used to infer the general behavior expected in the area but they use simplified continental or global hydrological models that are not specifically calibrated or validated for the study area. Nevertheless, these tend to identify the Iberian Peninsula or the wider Mediterranean area as one of the most problematic regions in the world in terms of future water resources. Prudhomme et al. (2014) ran 7 global impact models with climate data from 5 Global Circulation Models (GCMs) for the period 2070–2099 and found that Iberia was one of the areas where hydrological drought (defined as daily runoff below the 10th percentile of the reference period − 1976–2005) was expected to increase, with Southern Europe being identified as a "possible hotspots for future water security issues". Schneider et al. (2013), using a global hydrological model (WaterGAP3) for 2041–2070 and 3 bias corrected GCMs, found that the strongest impacts in terms of flow regime modification in Europe were in the Mediterranean and boreal regions (with the Mediterranean area encompassing the 3 basins of this paper). In the Mediterranean, they concluded that discharges will be lower throughout the year (in terms of the model ensemble mean) but the range of change in the winter half-year (October to March) was very high. Forzieri et al. (2014) used a 12 member ensemble of bias-corrected climate projections from the EU FP6 ENSEMBLES project (Linden and Mitchell, 2009) and one large-scale hydrological model − LISFLOOD (Burek et al., 2013) to conclude that in southern Europe strong reductions in low flows will be felt, with Iberia