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Evaluation of changing surface water abstraction reliability for supplemental irrigation under climate change

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ABSTRACT

In many temperate parts of the world, supplemental irrigation is crucial to assure both crop yield and quality. Climate change could increase the risks of irrigation being restricted by increasing crop water requirements and/or decreasing water availability. In England, water abstraction for irrigation is limited by maximum annual volumetric limits, as specified in the abstraction licences, and surface water abstraction restrictions imposed by the regulator during drought. This paper assesses how climate change might impact future irrigation abstraction reliability from surface water in England. Firstly, the probability of annual abstraction being close to the maximum licence limit was estimated for the baseline (1961–1990) and future (2071–2098) periods in each catchment based on observed relationships between annual weather and irrigation abstraction in three licence usage groups. Secondly, the current river discharge triggers for mandatory drought restrictions were used to assess the annual probability of surface water abstraction restrictions being imposed by the regulator in each period. Results indicate significant future increases in irrigated abstraction licence use due to an increase in aridity, particularly in the most productive agricultural areas located in eastern and southern England, assuming no adaptation. The annual probability of having less than 20% licence headroom in the highest usage group is projected to exceed 0.7 in 45% of the management units, mostly in the south and east. In contrast, irrigators in central and western England face an increased risk of drought restrictions due to the lower buffering capacity of groundwater on river flows, with the annual probability of mandatory drought restrictions reaching up to 0.3 in the future. Our results highlight the increasing abstraction reliability risks for irrigators due to climate change, and the need for the farming community and the regulator to adapt and collaborate to mitigate the associated impacts.

1. Introduction

Irrigation is crucial for sustaining the world's population, as 40% of crop production is concentrated in the 18% of total arable land that is irrigated (Fischer et al., 2007). Climate change is projected to alter temperatures, as well as the magnitude and seasonal distribution of precipitation (Arnell, 2003; Charlton and Arnell, 2011). In humid climates, a reduction of summer precipitation and an increase in the probability of extreme events such as heatwaves and droughts (Falloon and Betts, 2010; Bindi and Olesen, 2011; Weatherhead et al., 2015) are likely to increase irrigation water demand. Consequently, whilst irrigation needs are expected to increase in the future, water availability may decline in many regions due to climate change and competing demands for water (FAO, 2002; De Silva et al., 2007; Rodriguez Diaz et al., 2007; Charlton and Arnell, 2011; Gerten et al., 2011).

This tri-lemma of reduced water resource availability, increased irrigation demand and increasing competition between water users will require regulatory bodies to actively manage abstraction to ensure water resources sustainability and environmental protection (Henriques et al., 2008; Weatherhead and Howden, 2009). In Europe, governments have their own national legislation and abstraction management rules, described by Mills and Dwyer (2009), in addition to European regulations. For example, financial charges are payable in Germany according to the volume of water abstracted; France also applies volumetric charges and water users require a permit to abstract more than 8 m^3/h; similarly, Denmark uses a time-limited permit system for ground and surface water

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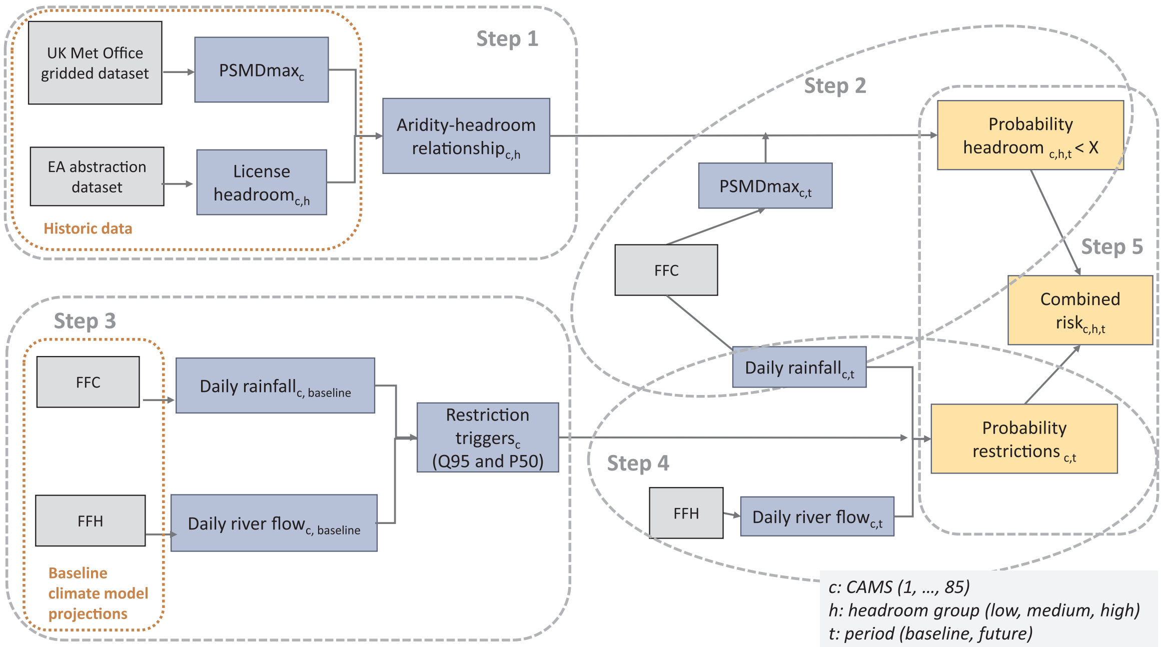

Fig. 1. Methodological diagram.

abstraction; and Belgium, Netherlands and the United Kingdom have compulsory registration and licensing systems, in which abstraction can be restricted during severe droughts.

In England, an abstraction licence is required from the Environment Agency (EA) to abstract more than 20 m^3/day from surface or groundwater (Environment Agency, 2013). However, having an irrigation abstraction licence does not entitle the licence holder to always be able to abstract, as the EA can impose partial or total bans on irrigation abstraction from surface water sources during droughts to protect public water supplies and the aquatic environment (Environment Agency, 2015). Such restrictions on supplemental irrigation can have severe impacts on crop yield and quality leading to considerable financial losses – Rey et al. (2016) assessed the net financial benefits of supplemental agricultural irrigation at the farm level in a dry year at over £660 million in England and Wales, using current irrigated cropping and market data. Irrigation is mainly concentrated in central and eastern England, where many catchments are already assessed by the EA as "over-abstracted" or "over-licensed" (Hess et al., 2011) and therefore vulnerable to future pressures on water resources.

In this global context of climate change, increasing irrigation needs and increasing likelihood of water management constraints, this paper provides the first national scale assessment of how climate change will impact the future reliability of supplemental irrigation from surface water. Focusing on England as a case study, it assesses the changing annual risk of individual farmers being unable to meet future irrigation demand due to having an insufficient annual licensed volume and/or being subject to mandatory restrictions on surface water abstraction during droughts. The paper has broader relevance as the analysis can be replicated in other countries to understand how climate change could affect water availability for irrigators.

2. Material and methods

There are five main stages to the analysis (Fig. 1). Firstly, explanatory relationships between actual annual licence usage by irrigators in the period 1999–2011 and an annual agroclimatic indicator of aridity (annual maximum Potential Soil Moisture Deficit, PSMD) are derived from observed data for each of the 85 Catchment Abstraction Management Strategy (CAMS) units in England (Step 1). Secondly, the relationships obtained in Step 1 are applied to baseline (1961–1990) and future (2071–2100) annual PSMDmax calculated from the Future Flows Climate dataset (FFC) (Step 2), assuming stationarity in crop spatial distribution and irrigation efficiency, to estimate the annual probability of irrigators in each CAMS being constrained by the volumetric abstraction licence limit for each period. Thirdly, the drought management rules currently used by the Environment Agency are applied to the simulated timeseries of daily river flow and rainfall data for the baseline period (1961–90) from the Future Flows Climate (FFC) and Future Flows Hydrology (FFH) datasets, respectively, to calculate the daily river flow and rainfall triggers for mandatory restrictions on irrigation abstraction (Step 3). Fourthly, the restriction triggers in Step 3 are applied to simulated baseline and future daily river flows (FFH) and rainfall (FFC) to estimate the annual probability of irrigators in each CAMS being under mandatory drought restrictions (Step 4). Finally, a combined risk metric was calculated based on the results from Steps 2 and 4, representing the annual probability for irrigators being close to their volumetric licence limit and being under mandatory drought abstraction restriction (Step 5). Results from the baseline and future periods were then compared to assess the direct and indirect climate change impact on surface water reliability for irrigation in every catchment across England.

2.1. Data

2.1.1. Climate data

Two sets of climate data are used: i) a 5 km × 5 km UK Meteorological Office gridded dataset of observed monthly precipitation and derived reference evapotranspiration estimated using the FAO Penman-Monteith equation (Allen et al., 1998) from 1961 to 2011; ii) the Future Flows Climate (FFC) dataset (Prudhomme et al., 2012b), a national-scale set of high resolution transient climate change projections of precipitation and reference evapotranspiration for 1950–2098 based on 11 different variants of a regional climate model, that captures climate modelling uncertainty. This 11-member ensemble is based on HadRM3-PPE (Met Office Hadley Centre's Regional Climate Model Perturbed Physics Ensemble) under the SRES A1 B emissions scenario (Special Report on Emissions Scenarios; IPCC, 2000), which was used as part of the derivation of the current (UKCP09) scenarios[1] (Murphy et al., 2009).

[1] AlB is broadly similar to the Representative Concentration Profile (RCP) 6.0 (Melillo et al., 2014).