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# The drying up of Britain? A national estimate of changes in seasonal river flows from 11 Regional Climate Model simulations

**Short title**: A national estimate of changes in seasonal river flows from 11 RCMs

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**Authors**: Christel Prudhomme, Andy Young, Glenn Watts, Tracey Haxton, Sue Crooks, Jennifer Williamson, Helen Davies, Simon Dadson and Stuart Allen

**Address**:

Centre for Ecology and Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire, OX10 8BB, United Kingdom

Email: chrp@ceh.ac.uk

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**Abstract**

As climate change may modify the hydrological cycle significantly, understanding the impact on river flow is important because it affects long term water resources planning. Here we describe a high-resolution British assessment of changes in river flows in the 2050s under eleven different realisations of HadRM3. In winter, river flows may either increase or decrease, with a wide range of possible decreases in summer flow. These results should encourage adaptation that copes with a broad range of future hydrological conditions.

(80 words)

**Keywords**

hydrological impact assessment, river flows, climate change, adaptation, change factor method, 2050s.

**Word count**: 1869

## Introduction

Adapting to changes in the terrestrial hydrological cycle is an increasingly pressing problem (Bates et al., 2008; Milly et al., 2008; Stern, 2007) as rivers provide water supply and contribute to ecosystem services (Costanza et al., 1997). As changes to water infrastructure and governance take tens of years to implement and have an expected lifespan from decades (eg legislation) to a century or more (eg reservoirs), water planning and policy must consider changes in river flows over at least the next 25 years (Watts, 2010).

Methods for calculating the impact of climate change on river flows are well established (Fowler et al., 2007) and have been implemented at the catchment scale to explore climate model uncertainty (eg Lopez et al., 2009) and model parameter uncertainty (eg Wilby, 2005). Results from specific catchments are valuable but difficult to generalise and do not on their own provide a sound basis for water policy. River flow studies at the river basin to country scale usually consider a few climate scenarios (Environment Agency, 2008a; Kay and Jones, 2010) or use a spatial or temporal resolution not readily applied to water policy questions (eg Arnell, 2003) and only provide a limited range of possible changes. The latest UK climate projections, UKCP09, explicitly consider climate model parameter uncertainty (Murphy et al, 2007; Jenkins et al., 2009; Murphy et al, 2009), and are likely to form the basis for future climate impact assessment and adaptation planning in the UK. This paper provides, for the first time, a national assessment of seasonal changes in river flows for the 2050s from the eleven climate scenarios that underpin UKCP09.

## Data and methods

Changes for Britain were estimated following the change factors method (Hay et al., 2000) where mean seasonal flow simulated by the semi-distributed hydrological model CERF (Young 2006; Environment Agency, 2008b) for a 30-year baseline (1961-1990) and future (2040-2069) were compared. The CERF rainfall run-off model has regionalised parameters that have been related to catchment characteristics by simultaneous parameter optimisation at 260 undisturbed catchments across the UK. This allows CERF to be applied consistently without the need for site-specific calibration, making it a powerful tool for evaluating changes in hydrological response across the UK. Gridded daily precipitation P (Environment Agency, 2008c), temperature T (Perry et al., 2009) and monthly potential evapotranspiration PE (Thompson et al., 1982) time series derived from observations were used to calculate baseline catchment averages as input to CERF. For PE, monthly totals were equally distributed within each month. CERF was run with a daily timestep from 1961 to 1990 to provide the baseline flows.

Climate change factors of P and PE, spatially coherent over the UK at a 25 km resolution, were derived from the UK Met Office Regional Climate Model perturbed physics ensemble HadRM3-PPE, which, in the development of UKCP09, was nested within a perturbed physics ensemble of the HadCM3 coupled atmosphere-ocean global climate model (see Murphy et al. 2007 for more details). The ensemble of RCMs contains 11 physically plausible simulations of detailed climate variability and change run under the A1B SRES emission scenario (IPCC, 2000), referred to as the "medium" emissions scenario in UKCP09 (Jenkins et al., 2009). For P, the monthly change factors were derived from time series bias-corrected using a gamma function (Piani et al., 2010), using 1961-90 as the baseline for bias correction. PE estimates follow the FAO56 method (Allen et al., 1998); investigation showed that this energy balance Penman-Monteith method (Monteith 1965) was the most effective way to close the water balance in the baseline period (this will be the subject of a future paper). The PE estimates use HadRM3-PPE time series for radiation, vapour pressure and wind speed. Temperature was bias-corrected and spatially disaggregated at 5 km using a linear (Lenderink et al., 2007) method, using 1961-05 as a baseline. Ideally, other components of the energy balance would also be bias-corrected, but this is limited by the paucity of appropriate observed data. However, it should be noted that the separate bias correction of temperature and rainfall may lead to rainfall and PE series that are not physically coherent, though this is less likely to be a problem where change factor approaches are used to represent future climate, as in this work. Bias correction will be the subject of a future paper. The monthly change factors for P and PE were applied to the 1961-90 data to make series representing the 2050s; these were used in the CERF model and the resulting flows were compared to the baseline series to calculate changes in seasonal flow. This approach means that any changes in flow are a direct response to the climate signal from the 11 RCMs.

**Results**

The percentage changes in mean flow between the baseline and 2050s are shown in Figure 1 for four seasons for each of the 11 RCMs. Increases in flow are indicated with shades of blue, decreases with shades of yellow/red whilst no change (-5% to +5%) is shown in beige. The overall pattern for the different RCM scenarios is varied. In winter (December, January, February) there is a mixed pattern in England and Wales with drier, similar or wetter signals, within - 20% to +40% change (one scenario with up to 60% in a small region). In contrast, flows in Scotland show a small increase or decrease, although this is still mainly within ± 20% with changes in the west reaching up to 40%. In spring (March, April, May) more of the RCM scenarios are drier for most of the UK, with decreases of up to 40%. However, for 3 scenarios central England has increased flows (up to 60%). In summer (June, July, August) scenarios predominantly show decreases in runoff through the UK, but range from +20% to -80%. The largest percentage decreases are mainly in the north and west of the UK although the range in these areas between scenarios can be large (0 to -80%). In autumn (September, October, November) there is a mixed pattern with a full range of percentage changes (+60 to -80%) across the UK. Most scenarios indicate decreases in flows, especially in the south and east (up to -80%) whilst in the west and north changes can be small. One scenario shows no change or an increase in runoff across the UK.

In summary, the results indicate marked variations between the RCM scenarios. While mixed patterns exist, for autumn and winter especially, all scenarios indicate a decrease in flow in the summer almost everywhere. Some of the summer flow decreases are large even compared to natural variability. For example, in the River Thames Teddington flow series that starts in 1883, only four summers (1976, 1934, 1921 and 1944) had flows that were more than 80% below the 1961-90 average. However, the differences between the scenarios at any location can be large.

## Discussion

Using HadRM3-PPE climate data in a national hydrological model results in eleven spatially coherent scenarios of river flow that help to explain how climate model uncertainty and climatic variability are manifested as a hydrological response. Considered together, the scenarios present a more complex picture of possible change than that from the earlier UK climate projections UKCIP02 (Hulme et al., 2002). Almost all scenarios suggest lower summer (JJA) flows across Britain, though the magnitude of the change is variable. In winter, spring and autumn there is much more variability both between scenarios and between different parts of Britain.

As this study uses the change factor method that scales historic weather sequences to represent the future climate, the resulting flows may not capture the full range of change. This may be a lesser issue for long-term average change assessments. Note also that no change in the catchment behaviour (e.g. due to vegetation change) was considered, and that these results show hydrological response to only one climate model ensemble; other models would give different results. Despite these assumptions, the range of results demonstrates that “predict and provide” approaches to adaptation are unlikely to be successful, as climate change adaptation measures and actions are more effective if they are robust to a range of possible futures.

Future work will consider other time horizons and exploit fully the transient HadRM3-PPE time series to create transient flow scenarios, so that rates of change of river flow can be explored, answering important questions about when different management actions should be taken.

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the UK Climate Impacts Programme (http://ukcip.org.uk/) and HadRM3-PPE time series from the British Atmospheric Data Centre (www.badc.nerc.ac.uk). Other data were obtained from the National River Flow Archive (http://www.ceh.ac.uk/data/nrfa/).

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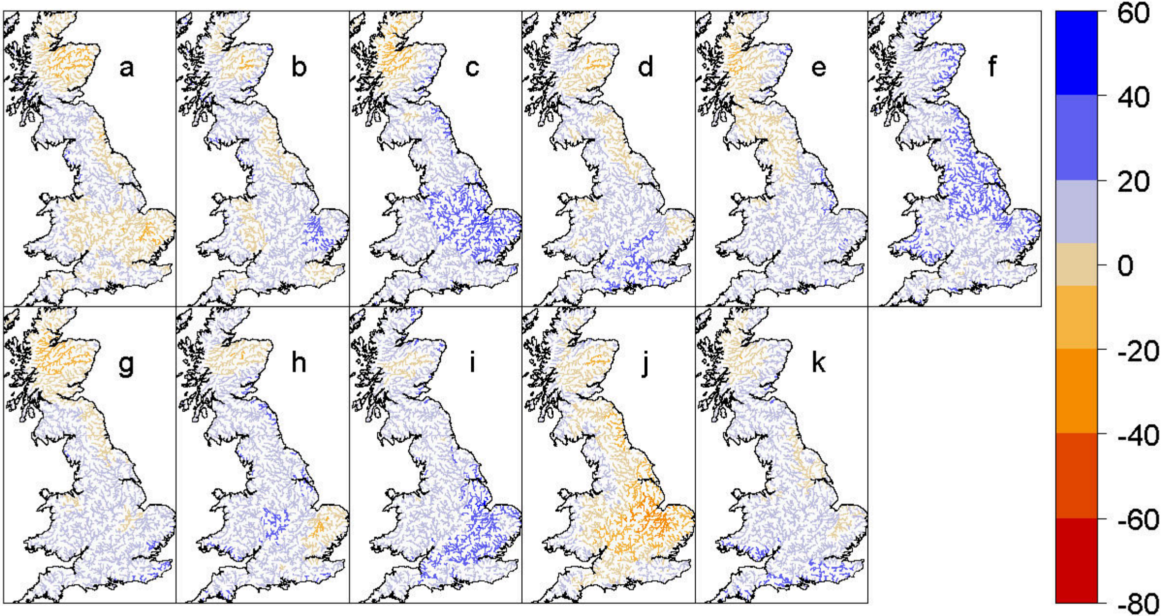
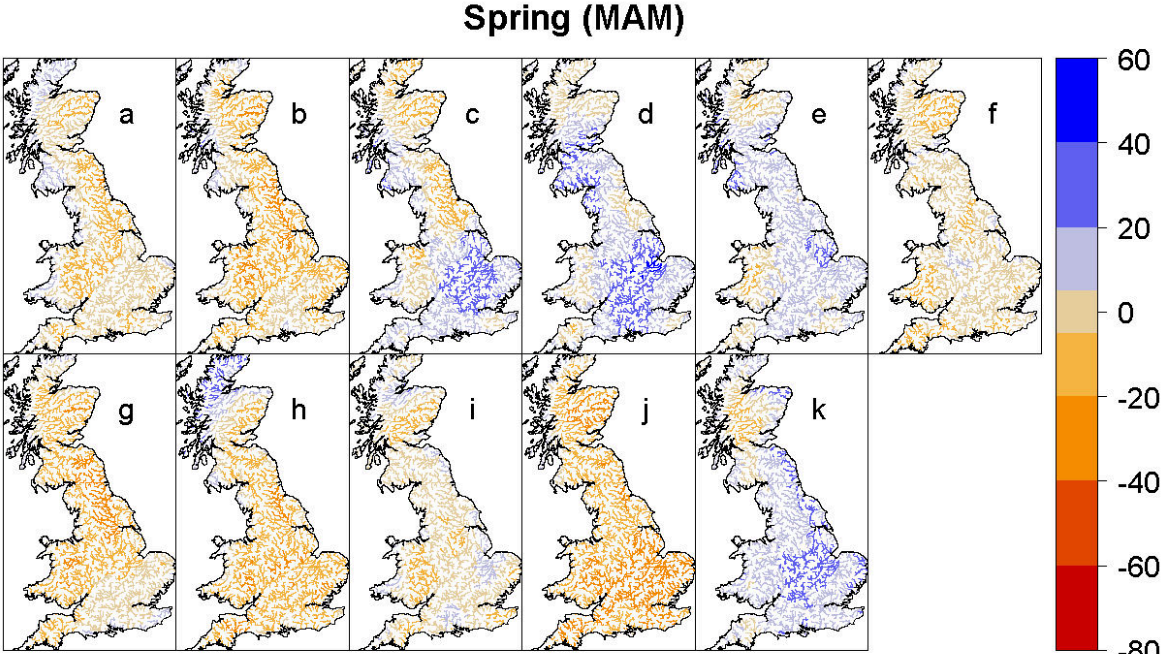
**Figure caption:**

Figure 1: Percentage change in seasonal mean flow for the 2050s as simulated by CERF with each of the HadRM3-PPE members. a HadRM3Q0 (unperturbed, run afgcx); b HadRM3Q3 (run afixa); c HadRM3Q4 (run afixc); d HadRM3Q6 (run afixh); e HadRM3Q9 (run afixi); f HadRM3Q8 (run afixj); g HadRM3Q10 (run afixk); h HadRM3Q14 (run afixl); i HadRM3Q11 (run afixm); j HadRM3Q13 (run afixo); k HadRM3Q16 (run afixq)

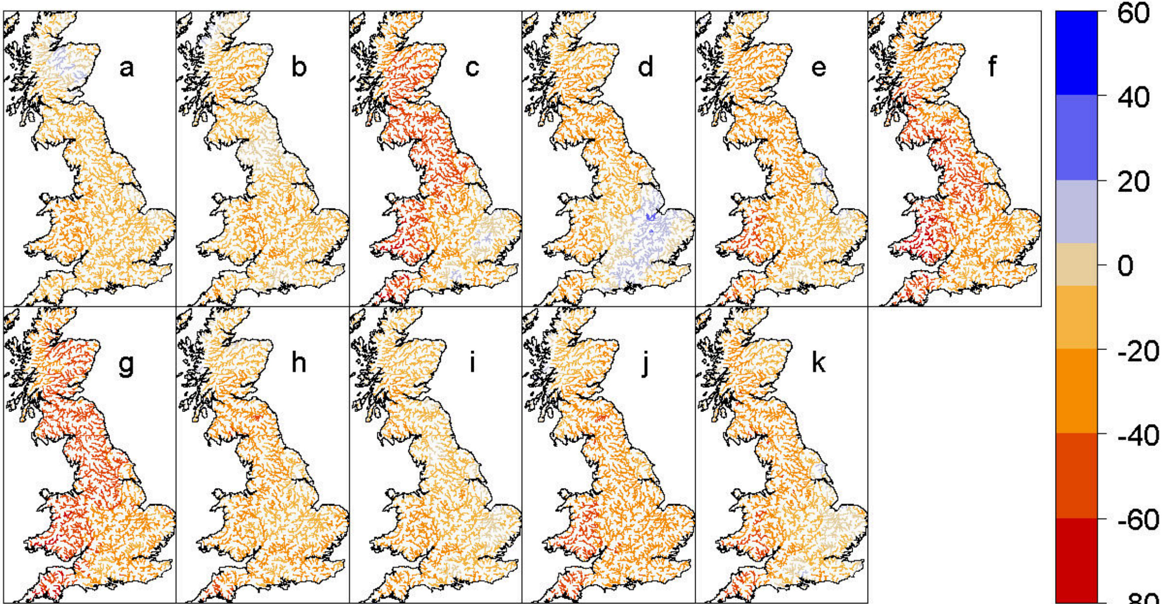
## Winter (DJF)





Spring (MAM)
a
b
c
d
e
f
g
h
i
j
k
60
40
20
0
-20
-40
-60
-80

# Summer (JJA)



# Autumn (SON)