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Simulation of river flow in the Thames over 120 years: Evidence of change in rainfall-runoff response?

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ABSTRACT

Study region: The Thames catchment in southern England, UK.
Study focus: Modelling with 124 years of rainfall, potential evaporation (PE), temperature and naturalised flow data. Daily rainfall-runoff flow simulation using current and three historic land cover scenarios to determine the stationarity of catchment response examined through three time-frames of analysis – annual, seasonal and flow extremes. The criterion of response stationarity is often assumed in climate change impact studies.
New hydrological insights: The generally close correspondence between observed and simulated flows using the same model parameter values for the whole period is indicative of the temporal stability of hydrological processes and catchment response, and the quality of the hydrometric data. Changes that have occurred are a decrease in flood peak response times, typically two to three days pre and post the early 1940s, from change in agricultural practices and channel conveyance, and an increase of about 15% in summer flow from increase in urban land cover between the first decade of the 20th and 21st centuries. The water balance was found to be sensitive to the PE data used, with care needed to avoid discontinuity between two parts of the data record using different methods for calculation. Long-term mean annual rainfall shows little change but contrasting patterns of variation in seasonal rainfall demonstrate a variable climate for which simulated flow is similar to observed flow.

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1. Introduction

The Thames is a highly studied catchment partly due to the length of the flow record at its lowest gauging station which, beginning in 1883, is the longest continuous flow series in the UK (Marsh and Harvey, 2012). The value of the observed record is substantially enhanced by having a companion naturalised series which takes account of major abstractions in the lower reaches of the river. This series provides a record of catchment runoff for over 100 years, through many variations in climate, land-use and channel hydraulics which have occurred within the time-span.

Hydrological models for simulating river flow from rainfall are widely available with a broad range of structures and representation of hydrological processes and similarly broad range of purposes (Todini, 2007). One purpose has been simulating impacts of change, for example, climate and land cover, on the flow regime but models are often run with the assumption that rainfall-runoff processes in the current or baseline time period are applicable under the changed conditions (e.g. Quilbé et al., 2008; Prudhomme et al., 2013). Many models require catchment-specific calibration of model parameters through optimising fit between observed and simulated flow over a particular period of data, but increasingly research has allowed models to be set-up through development of generalised relationships between physical catchment properties and model parameter values which can be applied over national or larger areas (e.g. Bell et al., 2007; Hrachowitz et al., 2013; Skaugen and Onof, 2014). This generalised approach has advantages through parameter values being not so specifically related to a calibration time period with possibly a limited range of hydrological events, or biased to wet or dry conditions, with consequent implications for use of the model under different conditions (Wilby, 2005; Merz et al., 2011). While measures of model performance using parameter values determined through generalised relationships may be slightly lower than can be achieved with catchment-specific calibration, advantages are gained in terms of temporal and spatial stability of parameter values.

Lack of pre-1961 digitised climate data (in the UK) has up to now limited historic applications of hydrological models requiring continuous daily data but with this situation beginning to change simulation of river flow over long time periods (∼100 years) has become possible. A European monthly data-set from 1887 (HISTALP; Auer et al., 2007) was used by Kling et al. (2012) to evaluate historic modelling of the upper Danube before applying climate change scenarios. Monthly rainfall and evaporation data were used by Jones et al. (2006) in a regression-based reconstruction of flow records for 15 catchments in England and Wales from 1865 including the upper Thames. The availability of long daily data series for the Thames provides the opportunity for a much fuller examination of temporal variability of catchment rainfall-runoff response, over a range of time scales, than has been possible up to now. By definition, extremes of the flow regime are likely to have occurred only once, or not at all, in a 30- or 40-year record so use of a much longer data period may well allow examination of more extreme events than those with which a model was calibrated, or set-up, for a catchment. However, methods of data measurement and resulting data quality have changed over time and need to be considered in interpretation of comparison between observed and simulated flow series.

An existing generalised model, CLASSIC (Crooks and Naden, 2007), has been used for continuous simulation of flows in the Thames from 1890 to 2013, previously only run from 1961. The model is used to provide a ‘benchmark’ flow series with which the observed series is compared. Time series of differences between the two series are analysed, over a range of time scales, to examine the following questions. Are the same model parameter values, mostly determined from physical catchment properties, appropriate for the whole period including flow extremes; do patterns in the difference time series relate to changes in the catchment; is data quality an issue in interpretation of these differences? The use of a model allows investigation of temporal variation in the relationship between rainfall and river flow, questions about which cannot be easily answered by separate analysis of each observed data series because of the non-linearity between them.

One hydrological model has been used for this initial investigation into rainfall-runoff response for the Thames using a long daily rainfall set, to identify the main differences between observed and simulated river flow and their possible causes. Potential drivers of differences considered (after Harrigan et al., 2014) are consistency of the rainfall, PE and flow datasets, historic land cover scenarios and change in agricultural practices and river management. Uncertainty from hydrological model