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Combined impacts of future land-use and climate stressors on water resources and quality in groundwater and surface waterbodies of the upper Thames river basin, UK

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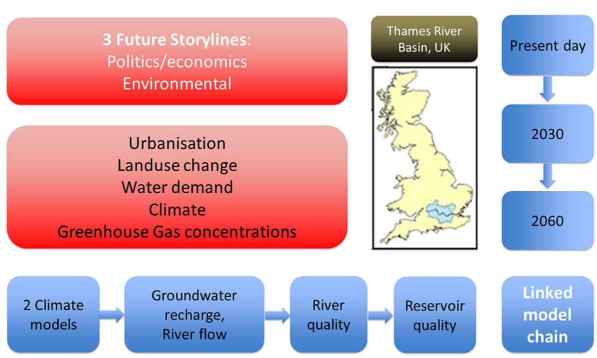
HIGHLIGHTS

- Future climate and human activity threaten water resources in the Thames Basin UK.
- A linked model approach was used and included groundwater, river and lake domains.
- Flow and quality modelled for three future policy and management scenarios.
- Continuation of current economic development reduces flow and impairs river quality.
- Water imports needed in less sustainable futures partly preserve freshwater status.

GRAPHICAL ABSTRACT



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ABSTRACT

It is widely acknowledged that waterbodies are becoming increasingly affected by a wide range of drivers of change arising from human activity. To illustrate how this can be quantified a linked modelling approach was applied in the Thames river basin in southern UK. Changes to river flows, water temperature, river and reservoir quality were predicted under three contrasting future "storylines"; one an extension of present day rates of economic development, the others representing more extreme and less sustainable visions. Modelling revealed that lower baseflow conditions will arise under all storylines. For the less extreme storyline river water quality is likely to deteriorate but reservoir quality will improve slightly. The two more extreme futures could not be supported by current management strategies to meet water demand. To satisfy these scenarios, transfer of river water from outside the Thames river basin would be necessary. Consequently, some improvement over present day water quality in the river may be seen, and for most indicators conditions would be better than in the less extreme storyline. However, because phosphorus concentrations will rise, the invoked changes in water demand management would not be of a form suitable to prevent a marked deterioration in reservoir water quality.

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1. Introduction

1.1. Background

With the global population continuing to increase, water resources are becoming ever more threatened by drivers of change, such as urbanisation, agricultural intensification or climate change, that can be directly or indirectly attributed to human activity (Vörösmarty et al., 2010; Wen et al., 2017). The impacts of these drivers of change in freshwater bodies, e.g. on flows, water storage and water chemistry, are here defined as stressors. Due to the increasingly complex nature of the drivers of change and their nonlinear interactions, freshwater bodies are exhibiting an increasingly diverse assemblage of multi-stressors rather than single stressors, (Schinegger et al., 2012; Hering et al., 2015). Consequently, there is a fundamental need to provide regulators, catchment managers and other stakeholders with an understanding of the links between drivers of change, multi-stressor waterbody responses to such changes, and the impacts of those multi-stressor combinations, i.e. effects on ecosystem services, which can be incorporated into programmes of measures to improve the status of water resources.

Whilst there is much well-founded evidence of effects on water resources of single stressors such as nutrient and sediment loads (e.g. Wagenhoff et al., 2012), in particular from monitoring programmes and controlled experiments, effects of stressors in combination are less tractable (Harris and Heathwaite, 2012). Multiple stressors can be hard to distinguish particularly in monitoring studies as they are often manifested in terms of the same indicator variable (Dafforn et al., 2016), they often act simultaneously (Floury et al., 2013) and their effects may be seen at different spatial scales (Hipsey et al., 2015; Villeneuve et al., 2015). To summarise by way of example, nutrient concentrations depend upon pollutant loads from a variety of sources (e.g. sewage, agriculture, industry) and are mediated by climatic factors (e.g. Neal et al., 2010). Nevertheless, at local scale insights on the interplay between pairs of stressors and their impacts on water resources have been gained, primarily through experimental work (e.g. Townsend et al., 2008). Syntheses of monitoring evidence on whether or not multiple-stressor effects are synergistic or merely additive have been compiled, for example in the case of biotic (phytoplankton, macroinvertebrate) responses (Jackson et al., 2016). Often however, due to circumstances and practicalities, the definition of these stressors and the mechanisms of their impacts are specific and restricted both in concept and in spatial scale. For example, impacts of the intensification of agricultural activity or the mitigation of its polluting effects in specific localities may be apparent in waterbodies only for short distances downstream. Detection of changes in downstream water quality in response to land management is likely to be moderated by other sources to river flow and by in-stream processes (Kirchner et al., 2000; Lloyd et al., 2014; Rode et al., 2016). River systems are often significant sinks of nutrient nitrogen and phosphorus (e.g. Mulholland et al., 2008 and Jarvie et al., 2012 respectively). Moreover, the nature of these impacts may be highly dependent on local conditions and be time-variant, for example bed sediments potentially act as sources as well as sinks of phosphorus (Withers and Jarvie, 2008). For these reasons, to evaluate impacts on river basin-wide water resources a statistical or deterministic modelling approach that incorporates the effect of climate drivers is essential. Moreover, the combined impacts of more than two stressors are much harder to identify without the application of modelling techniques (Hipsey et al., 2015).

1.2. Objectives

The objectives of the present paper are to evaluate how water resources in the Thames river basin will be affected by each of three future climate and planning scenarios. The Thames, (described in Section 2.1) is subject to a wide variety of stressors and the magnitude and interactions of these will inevitably change in the future.

A process-based modelling approach is used. Whilst integrated catchment models are well-suited to quantifying water resource impacts in different domains (soils, groundwater, flowing and standing water bodies) and in terms of hydrological, chemical and biological metrics (Abbaspour et al., 2015), an approach linking separate deterministic model applications is often favoured (Hipsey et al., 2015). A linked approach retains flexibility to choose model structures of a level of complexity sufficient to cover the issues being addressed and appropriate for the availability of data. Adopting a relatively simple approach where possible is appealing as it helps prevent model uncertainty from escalating (Lindenschmidt, 2006), for example when representing soil hydrology and chemistry. Conversely, the known complexity in the dynamic inter-relationships between aquifers can be captured more realistically using river basin-specific configurations of recharge and groundwater models. Therefore to achieve study objectives, a linked modelling approach using three tools was adopted here, comprising (i) catchment hydrology encompassing river flows and groundwater levels, (ii) river flow routing and water quality, and (iii) reservoir quality. The chosen modelling approaches and their performance under calibration and testing is described in Section 2.2.

The future climate and planning scenarios (termed "storylines") are outlined in detail in Section 2.3. In Section 2.4 the technical process of linking the models together and applying the storylines is described. The results of the storylines are reported systematically in Section 3 for each of the three modelling tools in turn. These results are brought together in Section 4 and discussed in terms of the relative vulnerability of future water resources to the different storylines and to climate. Later in Section 4 the utility of the approach as a means for stakeholders to identify dominant stressors is reviewed. Overall in terms of the wider nature of the storylines themselves, the analysis comprises two elements. Firstly, the impact on water resources of future climate and socio-economics under an extension of present day rates of economic development is assessed and compared to present conditions. Secondly, the results from this assessment are further compared with two more extreme and less sustainable visions of future development.

2. Method

2.1. Water resources in the Thames river basin

The Thames river basin (Fig. 1) is situated in the south east of the United Kingdom and covers an area of ~16,000 km^2 (Environment Agency, 2016). It consists of a mixture of rural areas, primarily grassland, arable, and woodland in the east and south of the region, and urban areas, dominated by Greater London but also including numerous other towns and cities, with a total population of ~15 million. The river basin is underlain by two major aquifers, the Chalk and the Oolitic Limestones which provide the majority of public water supply in the river basin (Bloomfield et al., 2011). The River Thames, the principal water course, has a mean flow of ~78 m^3 s^{-1} at the lowest gauge in the river basin, and the mean annual rainfall is ~750 mm (Marsh and Hannaford, 2008).

As is common in regions of intensive agriculture and large urban populations, the Thames river basin is subject to a variety of drivers of change and of resulting stresses, many linked to land-use, to which water body failures may be attributed (Environment Agency, 2009). These include:

- abstraction and artificial flow regulation;
- physical modification of water bodies, for example for flood defence purposes;