



Projecting impacts of climate change on hydrological conditions and biotic responses in a chalk valley riparian wetland



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SUMMARY

Projected changes in climate are likely to substantially impact wetland hydrological conditions that will in turn have implications for wetland ecology. Assessing ecohydrological impacts of climate change requires models that can accurately simulate water levels at the fine-scale resolution to which species and communities respond. Hydrological conditions within the Lambourn Observatory at Boxford, Berkshire, UK were simulated using the physically based, distributed model MIKE SHE, calibrated to contemporary surface and groundwater levels. The site is a 10 ha lowland riparian wetland where complex geological conditions and channel management exert strong influences on the hydrological regime. Projected changes in precipitation, potential evapotranspiration, channel discharge and groundwater level were derived from the UK Climate Projections 2009 ensemble of climate models for the 2080s under different scenarios. Hydrological impacts of climate change differ through the wetland over short distances depending on the degree of groundwater/surface-water interaction. Discrete areas of groundwater upwelling are associated with an exaggerated response of water levels to climate change compared to non-upwelling areas. These are coincident with regions where a weathered chalk layer, which otherwise separates two main aquifers, is absent. Simulated water levels were linked to requirements of the MG8 plant community and Desmoulin's whorl snail (*Vertigo moulinsiana*) for which the site is designated. Impacts on each are shown to differ spatially and in line with hydrological impacts. Differences in water level requirements for this vegetation community and single species highlight the need for separate management strategies in distinct areas of the wetland.

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1. Introduction

Wetlands are highly vulnerable to climate change due to the primary importance of the hydrological regime in controlling their ecological characteristics (e.g. Baker et al., 2009). Unequivocal warming of the climate (IPCC, 2014) will alter precipitation and evapotranspiration rates, and result in changes to runoff and groundwater levels. The key roles of these processes in controlling wetland vegetation (Baldwin et al., 2001; Wheeler et al., 2009), animals (Ausden et al., 2001; McMenamin et al., 2008) and biogeochemical cycling (McClain et al., 2003; Lischeid et al., 2007) means that climate change is likely to have major impacts on the world's wetlands, their flora and fauna as well as delivery of the many ecosystem services which they provide.

Groundwater may contribute a significant proportion of the water balance in riparian wetlands (Bravo et al., 2002; Krause and Bronstert, 2005; House et al., 2015b), which can strongly influence the hydrological regime, nutrient status and species composition (Wheeler et al., 2009; House et al., 2015a). Groundwater/surface-water interactions are inherently complex, being time dependent (Hunt et al., 1999), spatially heterogeneous (Hunt et al., 1996; Lowry et al., 2007; House et al., 2015a), and sensitive to topographical, geological and climatic controls (Winter, 1999; Sophocleous, 2002). The effects of climate change on regional aquifers and catchment runoff may cause intricate and significantly detrimental impacts to wetlands underlain by permeable geology, such as the chalk lowlands of southeast UK (Herrera-Pantoja et al., 2012). The impacts of climate change upon such wetlands should ideally therefore be assessed on an individual basis in relation to their water supply mechanisms and position within the catchment (Acreman et al., 2007).

Hydrological changes due to climate change may be linked to water level requirements of different species and communities to

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infer ecological impacts (Wheeler et al., 2004; Acreman et al., 2009). For instance, water table level regime is a dominant control on wetland plant communities (Silvertown et al., 1999). In the UK, the preferred water levels and depths to groundwater for wetland plants and communities have been well documented (Elkington et al., 1991; Newbold and Mountford, 1997; Gowing et al., 2002; Wheeler et al., 2004, 2009). Modifications to a wetland's hydrological regime may also be linked to changes in animal species distribution. Focus has centred on the indirect impacts to wading birds through the habitat requirements of macroinvertebrates that serve as their prey and the penetrability of soils by their beaks. Waterlogged areas sustain a higher biomass of surface-active and aerial invertebrates (Plum, 2005; Eglington et al., 2010). For example, the distribution of the near threatened Desmoulin's whorl snail (*Vertigo moulinsiana*) (Killeen et al., 2012) has been directly linked to water levels (Tattersfield and McInnes, 2003). Indirectly, softer ground allows snipe (*Gallinago gallinago*) to forage for food more easily (Ausden et al., 2001; Smart et al., 2008), while drains and wet rills provide favoured feeding grounds for lapwing (*Vanellus vanellus*) and redshank (*Tringa totanus*). Alterations to a wetland's water balance, and in turn its water level regime, due to climate change could therefore lead to shifts in habitat availability (Johnson et al., 2005), and affect the capacity of a wetland to support populations of conservation importance (Sorenson et al., 1998; Herron et al., 2002; Thompson et al., 2009).

There are few hydrological modelling studies at a suitable resolution which link water table predictions directly to plant and animal requirements for individual wetlands (Thompson et al., 2009; Carroll et al., 2015). To our knowledge, none do so for individual wetlands with groundwater contributions. However, an ability to accurately predict the impacts of climate change is vital for wetland management where species conservation and ecosystem service provision relies on managing hydrological functions (Acreman et al., 2009). Models able to accurately represent wetland hydrology will enable the assessment of possible degradation to wetland ecosystems through climate change (Acreman and Jose, 2000). In turn, such models will permit assessment of the likely success of modifications to wetland management designed to mitigate the impacts of climate change. Models are required that can accurately simulate groundwater levels at the fine-scale resolution associated with water level requirements of different species and communities (Thompson et al., 2009). Changes in water table level of less than 0.1 m may have profound effects on species composition, and provide conditions which favour distinct species or communities over those currently dominant at a given site (Wheeler et al., 2004). Whilst, as shown in Table 1, hydrological modelling has been used to assess some ecological impacts of climate change, in many cases this has not been undertaken at a resolution sufficient to directly infer impacts for particular species and communities; instead surmising effects through changes in habitat availability (Johnson et al., 2005; Candela et al., 2009; Barron et al., 2012). Other studies have postulated impacts generalised over regional scales (Acreman et al., 2009; Herrera-Pantoja et al., 2012).

The aim of this study is to assess the impacts of climate change on a riparian wetland in the chalk lowlands of the UK. The objectives are to: (1) Project changes in hydrometeorological inputs to a distributed hydrological/hydraulic model of the wetland under scenarios of different climate sensitivities to incorporate the uncertainty associated with climate change, (2) use the hydrological model to investigate how climate change scenarios affect wetland hydrology, and (3) compare simulated water levels under each climate change scenario to the requirements of conservation species/communities for which the site is designated. In this way the study provides an assessment of the potential ecohydrological effects of climate change upon the wetland and resulting management implications of these changes.

2. Study area

The Centre for Ecology & Hydrology (CEH) River Lambourn Observatory located in Berkshire, UK (51.445°N 1.384°W) comprises c. 10 ha of riparian wetland which is bordered to the east by a 600 m stretch of the River Lambourn (Fig. 1). The Westbrook Channel divides the wetland into northern and southern meadows. The site is located 13 km downstream from the ephemeral source of the River Lambourn at Lynch Wood, Lambourn (51.512°N, 1.529°W), the perennial head of which is situated 6–7 km downstream of the source at Maidencourt Farm (51.481°N, 1.464°E). The river drains the Chalk of the Berkshire Downs and is characterised by a large baseflow component. The baseflow index and mean discharge of the Lambourn at Shaw, the nearest gauging station 5 km downstream of the observatory, are 0.96 and $1.73 \text{ m}^3 \text{ s}^{-1}$, respectively (Marsh and Hannaford, 2008).

The wetland owes its designation as a Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) to the presence of Desmoulin's whorl snail (*V. moulinsiana*) and the MG8 vegetation community (*Cynosurus cristatus* – *Caltha palustris* grassland) of the UK National Vegetation Classification (NVC) (Rodwell, 1991). The site was managed as flood pastures and water meadows until the middle to late 20th century (Everard, 2005). Maps dating to the 1880s show a characteristic network of predominantly linear conduits. Most of these channels have since infilled naturally and are absent from current maps although the relic drainage network is still evident in the topography. Current management efforts concentrate on the river, where periodic cutting of instream macrophyte growth is carried out to maintain flood conveyance and lower water levels (Old et al., 2014).

A previous field campaign using three-dimensional (3D) electrical resistivity tomography (ERT) (Chambers et al., 2014) revealed a complex subsurface architecture. This comprises bedrock Chalk, overlain by a discontinuous layer of highly weathered 'putty' chalk (Younger, 1989), then gravels and peat. The peat and gravels are considered to have good hydraulic connectivity, with head boundaries in the River Lambourn and Westbrook broadly controlling water levels across the wetland (Chambers et al., 2014; Old et al., 2014; House et al., 2015a, 2015b). The putty chalk acts as a low permeability confining layer to the Chalk aquifer. Leakage occurs between the Chalk and gravels where the putty chalk is absent causing localised increases in water levels, which occur mainly in the north meadow (House et al., 2015a, 2015b). The relationship between the river and underlying gravels involves components of groundwater flow both parallel and transverse to the river, and with both influent and effluent behaviour (Lapworth et al., 2009; Allen et al., 2010).

The site instrumentation network and monitoring schedule are detailed in House et al. (2015b). Briefly, the network contains piezometers installed in the peat (P), gravel (G), and chalk (C) (Fig. 1). Stage boards are located along the River Lambourn (L1, L3–L7) and Westbrook (W1–W3), with a stilling well at L2. An automatic weather station (AWS) is installed in the south meadow.

3. Methodology

3.1. Simulation of baseline conditions

A hydrological model of the CEH Lambourn Observatory was produced using the integrated MIKE SHE/MIKE 11 modelling system, which simulates the major components of the land-based phase of the hydrological cycle (Graham and Butts, 2005). A detailed description of the MIKE SHE model of the site is provided by House et al. (2015b). For this study, the model area was discretised using a $5 \text{ m} \times 5 \text{ m}$ grid, producing 4261 computational cells.

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