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Assessing the impacts of climate change and dams on floodplain inundation and wetland connectivity in the wet–dry tropics of northern Australia

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SUMMARY

Floodplain wetlands and their hydrological connectivity with main river channels in the Australian wet–dry tropics are under increasing pressure from global climate change and water resource development, and there is a need for modelling tools to estimate the time dynamics of connectivity. This paper describes an integrated modelling framework combining conceptual rainfall–runoff modelling, river system modelling and hydrodynamic (HD) modelling to estimate hydrological connectivity between wetlands and rivers in the Flinders and Gilbert river catchments in northern Australia. Three historical flood events ranging from a mean annual flood to a 35-year return period flood were investigated using a two dimensional HD model (MIKE 21). Inflows from upstream catchments were estimated using a river network model. Local runoff within the HD modelling domain was simulated using the Sacramento rainfall–runoff model. The Shuttle Radar Topography Mission (SRTM) derived 30 m DEM was used to reproduce floodplain topography, stream networks and wetlands in the HD model. The HD model was calibrated using stream gauge data and inundation maps derived from satellite (MODIS: MODerate resolution Imaging Spectroradiometer) imagery. An algorithm was developed to combine the simulated water heights with the DEM to quantify inundation and flow connection between wetlands and rivers. The connectivity of 18 ecologically important wetlands on the Flinders floodplain and 7 on the Gilbert floodplain were quantified. The impacts of climate change and water resource development on connectivity to individual wetlands were assessed under a projected dry climate (2nd driest of 15 GCMs), wet climate (2nd wettest of 15 GCMs) and dam conditions. The results indicate that changes in rainfall under a wetter and drier future climate could have large impacts on area, duration and frequency of inundation and connectivity. Topographic relief, river bank elevation and flood magnitude were found to be the key factors contributing to the level of connectivity. Under a wetter future climate the average duration of connection of wetlands to the main river channel increased by 7% and under a drier climate it decreased by 18%. Construction of a 248 GL dam in the Flinders catchment and two (498 and 271 GL capacity) in the Gilbert catchment could reduce the average duration of connectivity by 1% and 2% in the Flinders and Gilbert catchments respectively. This information is potentially useful to future studies on the flood-dependent ecology in this region.

1. Introduction

The floodplain wetlands of northern Australia are important ecosystems that provide not only clean water, food and recreation but have important intrinsic ecological and cultural value (Kennard, 2011). Floodplain wetlands perform vital ecosystem functions and provide important habitats that support biodiversity (Richardson, 1994; Lasne et al., 2007; Mitsch and Gosselink, 2007). Habitat quality and the ecological integrity of a floodplain wetland depend on many factors, but a key determinant is how the wetland is hydrologically connected to the main river channel over time (Junk et al., 1989; Bunn and Arthington, 2002; Leigh and Sheldon, 2009). Whilst river flows often provide continuous connectivity to in-stream wetlands, off-stream wetlands may be

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isolated from main river channels for significant periods of time. Flood flows provide connectivity to off-stream wetlands and these 'flood pulses' are thought to be the driving force for the high biodiversity of floodplains by creating heterogeneity of habitats (Bayley, 1995; Gallardo et al., 2009). During floods, exchanges of water, sediments, nutrients and biota occur between the main channels and off-stream wetlands (Junk et al., 1989; Thoms, 2003; Tockner et al., 2010). The importance of overbank flow connection for these exchanges and the productivity of diverse aquatic biota in river-floodplain systems have been emphasized in many studies (e.g. Bayley, 1991; Heiler et al., 1995; Arthington and Balcombe, 2011).

In recent years there has been renewed interest in developing the water resources of northern Australia, predominantly for irrigated agriculture. However, water resource and agricultural development has invariably been accompanied by loss of floodplain wetland habitat and value, with floodplain wetlands diminishing at increasing rates around the world as a result of land-use change and water resource development for agricultural, urban and industrial expansion and climate change (Tockner et al., 2008; Vorosmarty et al., 2010). In northern Australia, however, the majority of rivers have very low levels of regulation (i.e., water use for human consumption is less than 1% of the median annual flow) and there is a globally unique opportunity to proactively plan for future water resource developments.

To understand and maintain critical connectivity pathways of wetland habitats, accurate information on extent, timing and duration of hydrological connectivity is crucial (Tockner et al., 2010; Ward et al., 2013). This information is scarce for the majority of river floodplains across the world since field-based monitoring of river-wetland connectivity for numerous individual wetlands is technically difficult, time consuming and expensive. Past studies have explored the use of remote sensing methods to predict how inundated area may change as a result of perturbations to streamflow (Overton, 2005; Penton and Overton, 2009; Peake et al., 2011; Dzubakova et al., 2014). Similar approaches have also been used to quantify how the number of inundated wetlands changes with variations in streamflow (Shaikh et al., 2001; Frazier et al., 2003; Ganf et al., 2010). Recently, Trigg et al. (2013) and Ward et al. (2013) have used MODIS imagery to investigate the dynamic nature of surface water connectivity during extreme floods. However, these approaches are based on static image processing with no underlying dynamic model and only provide information on potential wetland inundation when the rate of rise/fall of stage height is relatively small. Due to the poor temporal resolution of cloud free imagery during flood events, it is not possible for these approaches to properly define the duration of connectivity, which can have an important influence on wetland ecology. With recent progress in computing power, HD modelling has become a more widespread approach for understanding floodplain hydraulics and quantifying flood inundation (Nicholas and Mitchell, 2003; Stelling and Verwey, 2005). While a floodplain HD model can produce inundation dynamics with fine spatial and temporal resolution, it requires accurate information on inflows from upstream catchments and locally generated runoff to configure and calibrate the model. In this study, we seek to overcome these limitations by integrating HD modelling with rainfall–runoff and river system modelling.

The objectives of this paper are to:

- use an integrated modelling approach to simulate floodplain inundation for different hydrological and land development conditions;
- use the modelling results to estimate wetland connectivity for two large and remotely located river catchments, namely the Flinders and Gilbert, in northern Australia;
- assess the relative impacts of potential water resource developments and projected future climates on floodplain inundation and wetland connectivity.

In doing so the paper seeks to inform the debate about the development of water resources in northern Australia. The key innovation of this study was the integrated modelling approach designed to overcome the limitation of current approaches in simulating floodplain inundation on large scale floodplains under different hydro-climatic conditions, and in a data limited environment.

In the next section, we provide a brief description of the study area including climate, hydrology and floodplain wetlands. This is followed by details of the methods used to simulate flood inundation and wetland connectivity under current and future climates, and future development scenarios. Sections 4 and 5 provide the results and discussion, respectively. Major conclusions from this study are summarised in Section 6.

2. Study area

The Flinders and Gilbert catchments are located in the Gulf region of northern Australia, which is part of the Australian wet–dry tropics (Fig. 1). A notable feature of the Gulf region is that it has an extensive coastal floodplain that supports a large number of ecologically and culturally important wetlands. The Flinders catchment includes several large rivers (e.g. Flinders, Cloncurry and Corella), two small storages (less than 20 GL capacity) and more than 80 listed wetlands. The Gilbert catchment includes two major rivers, the Gilbert and the Einasleigh, a small dam in its headwaters (20 GL capacity) and several nationally and internationally recognised wetlands in the lower part of the catchment. The Flinders catchment is predominantly flat and the Gilbert catchment is undulating in its mid to upper reaches. A major proportion of these catchments is occupied by open savanna and grassland with less foliage protective cover. The land use in both Flinders and Gilbert catchments is dominated by cattle grazing. Only a small proportion is used for agriculture, and the major anthropogenic disturbances are associated with cattle grazing and erosion (Pusey and Kennard, 2009).

The Flinders and Gilbert catchments have a semi-arid tropical climate. The mean annual rainfall is in the range of 500 mm in the Flinders and 800 mm in the Gilbert catchment. However, the historical annual rainfall series for both catchments shows considerable intra- and inter-annual variations. A defining characteristic of the Flinders and Gilbert catchments is the seasonality of rainfall with more than 85% of rainfall occurring during the wet season (November to April inclusive). Seasonal floods are common in parts of the Flinders and Gilbert catchments. In the Flinders catchment, floods normally develop in the headwaters of the Flinders, Cloncurry and Corella rivers. Heavy rainfall can develop from cyclonic influences in the Gulf of Carpentaria which can cause widespread flooding, particularly in the lower reaches below Canobie. In the Gilbert catchment, floods normally develop in the headwaters of the Gilbert and Einasleigh rivers, however, heavy rainfall due to tropical cyclones also causes widespread flooding, particularly in the lower reaches below Strathmore, where the Gilbert and Einasleigh rivers converge before flowing across the Gilbert river fan and entering the Gulf of Carpentaria (BoM, 2011). More information on hydro-climatic characteristics of the study area is given in Table 1.

The Flinders and Gilbert catchments consist of a series of ecologically important wetlands that provide important habitat for a broad range of aquatic species. The wetlands are mostly Palustrine type in the Flinders catchment and Lacustrine type in the Gilbert catchment (Finlayson et al., 2005; Pusey and Kennard, 2009).