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Original Research Article

A simple model to quantify the potential trade-off between water level management for ecological benefit and flood risk

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ABSTRACT

Throughout the world, historic drainage of wetlands has resulted in a reduction in the area of wet habitat and corresponding loss of wetland plant and animal species. In an attempt to reverse this trend, water level management in some drained areas is trying to replicate a more natural 'undrained' state. The resulting hydrological regime is likely to be more suitable to native wetland species; however the raised water levels also represent a potential reduction in flood water storage capacity. Quantifying this reduction is critical if the arguments for and against wetland restoration are to be discussed in a meaningful way. We present a simple model to quantify the hydrological storage capacity of a drainage ditch network under different water level management scenarios. The model was applied to the Somerset Levels and Moors, UK, comparing areas with and without raised water level management. The raised water level areas occupy 11% of the maximum theoretical storage but when put in the context of the recent severe flooding of winter 2013/2014 occupy only 0.6% of the total flood volume and represent an average increase in flood level of 7 mm. These results indicate that although the raised water level scheme does occupy an appreciable volume of the maximum possible ditch storage, in relation to a large flood event the volume is very small. It therefore seems unlikely that the severity of such large flood events would be significantly reduced if the current water level management for ecological benefit ceased.

1. Introduction

Grazing marshes have assumed a significant role in the conservation of British wetlands representing a stage in the conversion of 'virgin' land into farmland (Mountford, 1994). As such they support vegetation that is neither typical of primaeval wetland nor of intensive cultivation (Moss, 1907; Williams, 1970). In the ancient undrained wetland wild grazing animals (*e.g.* horses, deer) would have helped maintain the herbaceous vegetation (arresting scrub invasion), but their place was taken by livestock as the wetlands were ditched and converted to grazing marsh. Since the Roman occupation, freshwater grazing marshes have been created both by the enclosure of high coastal saltmarsh and the drainage of inland mires, and now such areas are typically permanent pasture, intersected by a network of drainage channels (Williams and Hall, 1987). Drainage and land use change have modified or destroyed large areas of wetland in England and the loss of wetland species has been observed over many years (Mountford, 1994). Drainage, leading to subsidence and

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peat decomposition, can also significantly alter soil hydraulic properties, including water retention, hydraulic conductivity and specific yield, and in turn reduce the wetland's capacity to regulate the hydrological cycle (Price and Schlotzhauer, 1999; Kellner and Halldin, 2002; Kennedy and Price, 2005; Acreman and Holden, 2013).

To address the negative impacts of drainage, encouragement has been given to land owners to maintain water levels in ditches typical of a natural annual cycle (*i.e.* high water levels in winter and low water levels in summer) with the hope that a more 'natural' regime will support increased numbers of wetland species. Raised water levels in ditches can produce a high soil water table and as such are effective for promoting the desired wet conditions. This management practice was especially promoted by agri-environment schemes such as the Somerset Levels and Moors Environmentally Sensitive Area (ESA) and there is evidence that this initiative has at least arrested the decline of some wetland species (Swetnam et al., 2004). Whilst raising water levels may support delivery of some ecosystem services, others may be lost or reduced. Acreman et al. (2011) looked at the effect of various management practices on the extensively drained Somerset Levels and Moors and found that raised water levels increased delivery of services, such as carbon sequestration, climatic regulation, biodiversity (in the long term) and recreation and education. They also found that food production, freshwater availability, biodiversity (in the short term) and flood storage were reduced. It is flood storage that is the particular focus of this paper.

Effective management of hydrological systems requires a quantified understanding of the impact of management on the service(s) in question, and a combination of monitoring and modelling is likely to underpin that understanding. A conceptual model is the first step in identifying which elements should be included in the study and an iterative process then takes place whereby the model is tested numerically and altered and/or refined as necessary in order to improve the representation of reality (Acreman and Miller, 2007). Depending on the nature of the study area, model development can be highly complex and time consuming. Various models for predicting in-field water tables exist ranging in complexity from empirical ditch-drainage equations (*e.g.* Youngs, 1985) which relate water table height to rainfall, drain spacing and hydraulic conductivity (Eq. (1)) to complex groundwater/surface water models such as MIKE-SHE (DHI, Hørsholm, Denmark), which provide numerical solutions to both unsaturated and saturated processes.

$$\text{Steady-state drainage equation}: \quad \frac{H_m}{D} = \left(\frac{q}{K}\right)^{1/a} \tag{1}$$

where H_m is the mid-drain water-table height, D is the drain spacing, q is the steady-state rainfall rate, K is the hydraulic conductivity and a is a factor dependent upon the position of an impermeable barrier (Youngs, 1985).

However for a catchment containing many thousands of separate fields and hundreds of km of ditches, a catchment-wide fully distributed application of either of these modelling approaches model is likely to take considerable time and require detailed input data, and may therefore be unsuitable for many applications. A rapid yet robust approach is desirable in situations that require management questions to be answered quickly and with confidence.

In this study, we developed a simple model of ditch and soil water storage. The model was applied to the winter 2013/2014 floods in the Somerset Levels and Moors to quantify the reduction in flood storage volume resulting from the maintenance of raised water levels. The volumes calculated using the model were assessed in relation to direct rainfall, instantaneous flood volume and inflow volume. In relation to the 2013/2014 floods, our initial hypothesis to be tested was that the impact of the raised water level areas was minimal and that the main driver of flooding was unusually high rainfall.

2. Methods

2.1. The model

A simple hydrological storage model has been developed to provide rapid quantitative assessment of hydrological storage volume in a landscape dominated by drainage channels and permeable soils. Storage is available in both the ditches themselves and in the soil adjacent to the ditches. The conceptual basis for this model comes from observations of water table elevation from Tadham Moor (on the Somerset Levels and Moors). When rainfall consistently exceeds evapotranspiration a dome-shaped water table forms sloping downward from field centre to bounding ditch. When evaporation consistently exceeds rainfall a bowl-shaped water table forms sloping from bounding ditch to field centre. The model is developed specifically for application to wet winter conditions when evaporation is small in comparison to rainfall and the hydrological gradient is towards the ditch. It does not account for any topographic variation and assumes that parameters are uniform across the study area.

Rather than attempting to produce a dynamic model that computes the volumes of water moving through the study site and how those volumes change with time, a steady-state approach is taken. The model consists of two elements, within channel storage and soil storage. The total storage per unit length of ditch is calculated as the sum of the two elements.

2.1.1. Storage component 1: the available volume in the surface water body ($m^3\,m^{-3}$)

Calculated by multiplying the width of surface feature by the vertical distance from ditch water level to the adjacent land surface (*i.e.* the depth of water required to fill the ditch).

2.1.2. Storage component 2: the available volume in the soil profile ($m^3\,m^{-3}$)

Instead of using hydraulic conductivity to calculate the flux into and out of the soil, the parameter 'Extent of influence' is used to describe the width of soil away from the ditch that is likely to receive water from the ditch during a flood event. The storage is then calculated by