Journal of Hydrology 517 (2014) 378–389

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

# Detecting land use and land management influences on catchment hydrology by modelling and wavelets

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ARTICLE INFO

*Article history:*
Received 8 January 2013
Received in revised form 9 April 2014
Accepted 20 May 2014
Available online 29 May 2014
This manuscript was handled by Andras Bardossy, Editor-in-Chief, with the assistance of Axel Bronstert, Associate Editor

*Keywords:*
Flood risk management
Land use change
Catchment modelling
HySim
Discrete wavelet transform

SUMMARY

There exists a widespread recognition that land use and management change should affect catchment response to precipitation (and therefore stream flow characteristics). Previous studies have shown that this affect exists at a local scale, but there is a paucity of evidence that local scale effects aggregate to detectable impacts within downstream catchments. This paper describes a novel wavelet-based analysis of hydrological model residuals to examine the effect of land-use change on the catchment hydrology across four UK catchments (the Kird, Lod, Coalburn and Wye), of which all but the Wye experienced significant changes in their land use. The HySim rainfall–runoff model was calibrated against observed long term flow series assuming a static land hydrology to allow for the effects of climatic variability. Deviations of model fit were assessed in relation to changes to catchment land hydrology. The wavelet transform was used to decompose both simulated and observed flows into different scale components and to assess changes in catchment hydrology across different temporal scales; model residuals and model performance were tested for significant changes in wavelet variance and wavelet correlation respectively. Significant changes in wavelet variance and wavelet correlation corresponded with changes in catchment land use for two of the three catchments that experience land use change, in the third there were significant changes in wavelet variation that may have resulted from land-use change, but no changes in wavelet correlation. The control catchment showed no significant features of variances and no significant change in wavelet correlation across the scales. This new approach holds great potential for separating the influences of land use and management change on catchment stream flow based on frequency scale.


## 1. Introduction

Significant changes in land use and land management within a catchment have consequences to river stages further downstream in the catchment. For instance, changes in land use will affect the overall amount of evapotranspiration, water infiltration and water runoff in the catchments, impacting on the amount of water in a river at any given time. There is a general recognition (Archer et al., 2010; O'Connell et al., 2004) that changes in catchment land use and land management affect the short term catchment response to precipitation as well as the longer term or annual stream flow (Oudin et al., 2008), with important implications for flood risk and water resource management. This has been clearly demonstrated in smaller catchments (Robinson et al., 1998; Kirby et al., 1991). However, studies of flow records of larger, rural catchments have not been able to detect any significant features that can be attributed to land use or land management (O'Connell et al., 2007).

There are a number of contributing factors which may confound the effects of land use or land management in catchment response such as climatic or weather variability dominating the character of the of catchment stream flow (Newson, 1994; O'Connell et al., 2004), as well as the spatially and temporally heterogeneous nature of changes in catchment land use which can suppress individual features within flow time series. Generally, it has been noted (Kokkonen and Jakeman, 2001; O'Connell et al., 2007) that there is an almost complete lack of evidence that local scale effects aggregate causing impacts at larger scales downstream as a result.

In the above studies and generally in many hydrological studies, statistical or quantitative methods of varying complexity have been used to detect changes in time series data. These range from simple threshold analysis to more complex autoregressive time series models. Beven et al. (2008), for instance, used Dynamic Harmonic Regression (Young et al., 1999) methods and Data Based

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http://dx.doi.org/10.1016/j.jhydrol.2014.05.052
0022-1694/

Mechanistic (Young, 2001) models to detect land use or land management induced changes to flood dynamics in long term historical river flow records in rural catchments. They concluded that uncertainties in the data and the piecemeal effect of different catchment land uses confounded any singular response from an individual land use change to be detected through models. Data analyses do suggest evidence for land use change signals within time series of flow and rate of change of flow 'pulses' (Archer et al., 2010). These methods rely on a stochastic or probabilistic basis, in which different autocorrelated variance components are allocated to a set of factors. Although generally effective at identifying and describing changes in the hydrological time series, this approach is less effective at ascribing causality to these changes.

Causality in hydrology is often described using mechanistic or semi-empirical models, in which known processes are described and the model predictions compared to the observed hydrological time series. The processes that drive water retention, transport and loss from the watershed are well known and there are many models which describe these. Given such a model, it should be feasible to assess how much of the variation in the river stage measurements can be accounted for by the modelled processes, or more importantly, the extent to which processes not described by the model influence variation. In effect, the hydrological process model functions as a filter to remove influence of climatic and weather variability. The changes imposed by land use and land management should be reflected in how the model simulations diverge from the stage observations.

Land use or land management influences upon catchment hydrology occur at different temporal scales (from the rapid, hourly to weekly, for instance, in response to soil compaction, to the longer, monthly to annual effects of afforestation on interception and actual evapotranspiration, AET), and any significant changes in the catchment hydrology resulting from land use and land management changes should manifest at the appropriate scales. Scale-dependent changes in variation are often obscured within a time series, however, and it can be more informative to separate the variation into scale dependent components. Wavelet transforms provide a means to decompose time-series into various components of scale, whilst still retaining information on the location of features in time. Wavelet transforms are integral transforms. They have been used to analyse time-series on variables whose variance, at multiple scales, cannot plausibly be treated as stationary (Percival and Walden, 2000; Lark and Webster, 1999). Unlike other integral transforms, such as Fourier transform, the wavelet basis comprises a set of localised functions which are non-zero for only a narrow window (they have, what is known as, compact support). Transforming the time series with a given basis function results in a wavelet coefficient. Any given wavelet coefficient describes the local variation of the time series within some scale interval (both the location and scale depend on the basis function use), whereas any Fourier coefficient for the same time series describes the variation within a frequency interval across the whole time series. Changes in the variance of the time series at a particular scale are reflected in the wavelet coefficients, and methods have been proposed to detect changes that are significant (Percival and Walden, 2000; Lark and Webster, 2001). Similarly, wavelets can be used to detected scale dependent changes in the correlation between two variables.

Within this paper, we describe the novel application of the discrete wavelet transform (DWT) to hydrological time series (both observed and simulated by rainfall-runoff modelling) across four UK catchments. The DWT is used to discern whether the changes in catchment land use and land management manifest as distinct features in the hydrological response at certain scales. A rainfall-runoff model was calibrated assuming unchanged land use. This simulated data was assumed to account for weather and climate variability, and so the residuals between the observed and simulated flow comprised the hydrological effects of changes in land use and management within the recorded flow and errors from model simulation and input data (Ewen et al., 2006; O'Connell et al., 2007). Wavelet methods were then used to detect significant changes in both the wavelet variance of the model residuals, and the correlation between observed and simulated flows across different scales. The following questions were considered; (i) In comparing the wavelet variances in observed flow, what can be surmised about the individual catchment hydrology? (ii) Have the models successfully simulated hydrological response to variability within the precipitation and evapotranspiration (ET) across the scales? (iii) Can the influence of land-use change be detected in the time-series and if so at what scales? In answering these questions and understanding how wavelets can represent catchment hydrology, assessment of changes in that hydrology should become clearer.

## 2. Material and methods

### 2.1. Study catchments

Four small to medium sized headwater catchments were selected from across the UK. Their locations are shown on Fig. 1. Three (the Kird, Lod and Coalburn) experienced notable land use changes over recent history of which the Coalburn is well documented and analysed (Robinson et al., 1998), whilst the final catchment (Wye) was chosen as a control catchment in which no significant land use change has occurred. All are classed as 'Natural' to within 10% of the 95th percentile flow (Centre of Ecology and Hydrology, 2011).

#### 2.1.1. Kird and Lod catchments

The Kird at Tanyards (67 $km^2$) and Lod at Halfway Bridge (52 $km^2$) are sibling headwaters of the lowland Western Weald River in Hampshire and West Sussex, southern England. Their

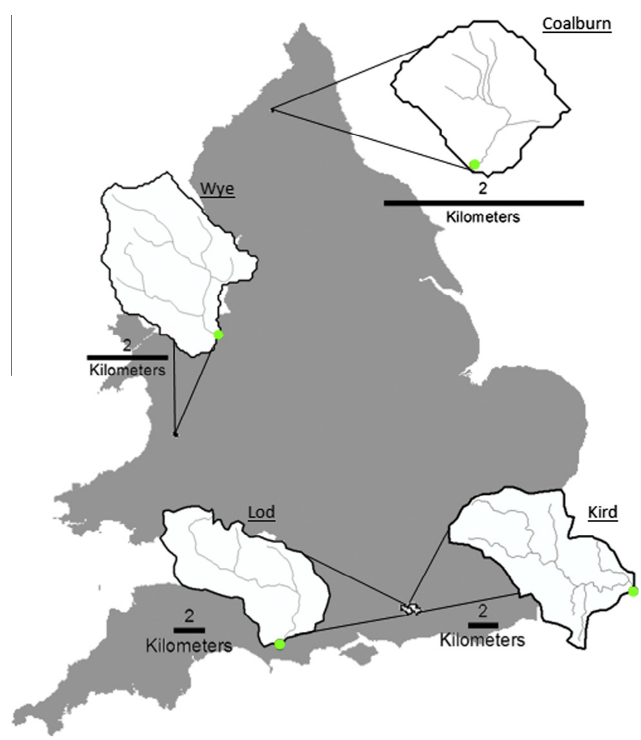


**Fig. 1.** Locations of four study catchments within England and Wales. Green circles indicate the gauging stations, length of scale bars indicate a length of 2 km's. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)