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Development and application of a soil classification-based conceptual catchment-scale hydrological model

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Abstract

A conceptual, continuous, daily, semi distributed catchment-scale rainfall-runoff model that has the potential to be ultimately used in ungauged catchments is described. The Catchment Resources and Soil Hydrology (CRASH) model is developed from the basis that the transformation of rainfall into simulated river discharge can be parameterised using pre-existing national datasets of soil, land use and weather; and that the spatial variability in soil properties and land use are important to the hydrological response of a catchment and should be incorporated into the catchment representation. Both infiltration-excess and saturation-excess runoff mechanisms are simulated, with water movement through each soil layer simulated using a capacitance approach limited according to layer physical properties. The hydrological linkage between the response unit and catchment is parameterised using the existing national Hydrology of Soil Types (HOST) classification. The HOST classification groups all UK soil types into one of 29 hydrological classes for which nationally calibrated values of Base Flow Index and Standard Percentage Runoff are provided. CRASH has been calibrated and validated for three catchments in England with contrasting soil characteristics and meteorological conditions. The model was successful at simulating time series and flow duration curves in all catchments during the calibration and validation periods. The next development stage will be to test CRASH for a large number of catchments covering a wider range of soils, land uses and meteorological conditions, in order to derive a set of regionalised model parameters based upon the HOST classification. The successful cross-scale linkage between water movement through the response unit and the catchment-scale hydrological response using the HOST classification, which incorporates the scale effects between plot and catchment, suggests that such national soil hydrological classifications may provide a sound and consistent framework for hydrological modelling in both gauged and ungauged catchments which should be extended to other regions.

Keywords: Rainfall-runoff model; Conceptual model; Classification; Ungauged catchment; Semi-distributed model; Soil hydrology

1. Introduction

Rainfall-runoff models can be used to investigate various hydrological issues relevant to environmental managers and decision-makers. Their use can, however, be restricted by the availability and quality

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of input and parameterisation data. One approach to tackle the challenge of modelling river flows in ungauged catchments appeared with the blue-print for a physically-based, distributed catchment model by Freeze and Harlan (1969). The Système Hydrologique Européen (SHE) system was developed following such a blue-print (Abbott et al., 1986) and was presented in opposition to lumped parameter models that 'depend essentially on the availability of sufficiently long meteorological and hydrological records for their calibration' (Abbott et al., 1986). However, the use of physically-based, distributed models has since been questioned because of the actual significance of the parameters and the great amount of physical characteristics they require (Beven, 1989).

It is generally agreed that the level of complexity of physically-based models is excessive for many practical problems. Jakeman and Hornberger (1993) stated that a simpler structure based on a slow-flow component and a quick-flow component is sufficient for many purposes. Such conceptual models use simplified representations of the component processes which they do not try to fully represent with physically-based equations, but are generally optimised using observed streamflow data.

However, because they incorporate many fewer parameters, approaches have been developed to apply conceptual models in ungauged catchments. The most widely used method relates the model parameters to physical descriptors of the catchments (e.g. Sefton and Howarth, 1998; Seibert, 1999). The procedure of calibration has two stages. Firstly the parameters values are determined for a number of gauged catchments. Then a relationship between the model parameters and physical descriptors of those gauged catchments is derived. This relationship can use simple (e.g. multivariate regression, Sefton and Howarth, 1998) or more sophisticated techniques (such as kriging or clustering, Vandewiele and Elias, 1995) to find similarities among the catchments.

An alternative approach to regionalisation is to assume that areas of a catchment with the same physical characteristics have similar hydrological response. Each homogeneous unit is calibrated to build a library of parameters for all units that can then be used in ungauged catchments. This type of approach is suited to semi-distributed models that use the principle of hydrological response units or to fully distributed models. Dunn and Lilly (2001) managed to determine parameters of the distributed DIY model according to a soil hydrological classification for two catchments in Scotland but failed to adequately calibrate the fast response. Beldring et al. (2003) calibrated a distributed version of the HBV model in 141 catchments in Norway and estimated the model parameter values for 5 land use classes. They successfully used this library of parameter values in 43 independent catchments.

Unlike many other studies where the objective has been to relate the parameters of existing models to catchment descriptors, the objective of this study is to tackle the problem in reverse. A conceptual, continuous, daily, catchment-scale rainfall-runoff model has been developed to solely utilise nationally available data with the ultimate purpose of being applied in ungauged catchments throughout the United Kingdom using the latter homogenous unit regionalisation approach. This paper presents the development and validation of the Catchment Resources and Soil Hydrology (CRASH) model, which has been based on two underpinning principals:

- Firstly, that the transformation of rainfall into simulated river discharge can be parameterised using pre-existing nationally available datasets of soil, land use and weather; and
- Secondly, that the spatial variability in soil properties and land use is important to the hydrological response of a catchment and should be incorporated into the catchment representation.

2. Model description

The Hydrology of Soil Type (HOST) system (Boorman et al., 1995) has been used to classify the soils of each catchment according to their hydrological behaviour. HOST is a conceptual representation of the hydrological processes in the soil zone. All soil types (soil series) in the United Kingdom have been grouped into one of the 29 hydrological response models (or HOST classes) based on soil attributes