Environmental Modelling & Software 81 (2016) 56–71

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Applicability of Hydrologic Response Units in low topographic relief catchments and evaluation using high resolution aerial photograph analysis

Urooj Khan [a, b], Narendra Kumar Tuteja [b], Ashish Sharma [a, *], Stuart Lucas [c], Brian Murphy [c], Brian Jenkins [c]

[a] School of Civil and Environmental Engineering, University of New South Wales, Sydney, New South Wales, Australia
[b] Environment and Research Division, Bureau of Meteorology, Canberra, Australian Capital Territory, Australia
[c] New South Wales Office of Environment and Heritage, New South Wales, Australia

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form
27 February 2016
Accepted 14 March 2016
Available online 25 March 2016

Keywords:
Hydrologic Response Units (HRUs)
Landform
Aerial photograph
Channel head
Slope

ABSTRACT

Topography and geomorphology of a catchment are major drivers of runoff generation. In an earlier publication by the authors, a novel approach of delineating Hydrologic Response Units (HRUs) was investigated with reference to high topographic relief catchments. In the present study, this approach is evaluated for low topographic relief catchment and found to be applicable. To verify the proposed HRUs delineation logic, the thresholds derived from the DEM analysis are evaluated here at catchment scale using high resolution aerial photograph analysis and associated site visits. The thresholds derived from the DEM analysis are found in the same range as obtained from the aerial photographs analysis. The adequacy of the HRUs delineation approach is further verified by soil moisture movement modelling across four cross-sections and sensitivity analysis test for one cross-section in the Little River catchment which further supports the application of HRUs delineation approach in low topographic relief catchment.

1. Introduction

The point where the hillslope ends and the channel begins is called the channel head. Understanding the channel head location is useful in understanding the associated geomorphology as well as the various components of catchments hydrological response (Hancock and Evans, 2006a). The location of channel heads is also crucial in differentiating between diffusive (e.g. Creep, rain splash or biogenic activity) and fluvial process dominated regions, which can be both depositional and erosional (i.e. incised channels) (Montgomery and Dietrich, 1988, 1989; Willgoose et al., 1991; Tarboton et al., 1992; Willgoose, 1994; Hancock and Evans, 2006a; McNamara et al., 2006). Incised stream networks generally occur below active channel heads. In the last few years, several researchers have ascertained the exact location of channel heads using field observations linked with area-slope and Cumulative Area Distribution (CAD) curves (Hancock and Evans, 2006b, a; McNamara et al., 2006; Henkle et al., 2011). The area-slope curve shows the relationship between the upslope area at particular point in the catchment and the local slope at the same point, whereas CAD curve is the function defining the proportion of the catchment which has upslope area greater than or equal to specified upslope area. The area-slope and CAD curve enabled diffusive and fluvial process dominated regions to be distinguished from each other (Hancock and Evans, 2006b, a; McNamara et al., 2006; Tarolli and Dalla Fontana, 2009; Henkle et al., 2011; Orlandini et al., 2011).

Hancock and Evans (2006a) identified the positions of channel heads in the Tin Camp Creek, Arnhem Land, Northern Territory, Australia using a field survey. They mapped the channel heads on CAD and area-slope curve and concluded that a majority of channel heads have relatively small source area and that CAD and area-slope curve can provide reliable information about the location of channel heads. McNamara et al. (2006) identified channel heads by field survey in the Pang Khum Experimental Watershed in Northern Thailand. They also mapped the channel heads on area-slope and CAD curve and found that most of the channel heads are

* Corresponding author.
E-mail address: a.sharma@unsw.edu.au (A. Sharma).

http://dx.doi.org/10.1016/j.envsoft.2016.03.010

located in convergent (concave) topography regions or fluvial process dominated regions of area-slope and CAD curve. The area-slope and CAD curve without the channel head observations were also widely used to differentiate the diffusive and fluvial process dominated regions in earlier studies (Willgoose et al., 1991; Ijjasz-Vasquez and Bras, 1995; Perera and Willgoose, 1998; Hancock, 2005), indicating the continued importance this specification holds to the geomorphological and catchment hydrology research community. Although, the area-slope and CAD curve both are useful to differentiate diffusive and fluvial process dominated regions in a catchment, for large catchments, the raw area-slope curve shows considerable scatter. As a result, CAD curve was preferred to differentiate diffusive and fluvial process dominated regions (Khan et al., 2013). Besides area-slope and CAD curves, the hypsometric curve and width function are also useful geomorphologic descriptors which are used to understand the geomorphologic characteristics of the catchment. The hypsometric curve is a non-dimensional area and elevation curve which gives an idea of steepness of catchment in different range of areas (Langbein, 1947) and has been used to understand geomorphic maturity of catchment, age, erosion processes, catchment geometry and network form (Strahler, 1952; Willgoose and Hancock, 1998; Hancock, 2005). The width function is a plot between the distance from the catchment outlet and number of channels at that distance (Surkan, 1968; Naden, 1992) and has been used to analyse catchment shape (Hancock, 2005). The width function and hypsometric curve cannot be used to differentiate the diffusive and fluvial process dominated regions therefore not used in this study.

Besides geomorphologic attributes, topographic attributes like slope and curvature are also useful to understand the hydrological functioning of a catchment (Beven et al., 1988; Wood et al., 1988; Frei and Fleckenstein, 2014). In the last three decades, several attempts have been made to capture the heterogeneity in topographic features and to disaggregate the catchment into smaller spatial entities (Beven and Kirkby, 1979; Wood et al., 1988; Flugel, 1995; Singh and Woolhiser, 2002; Summerell et al., 2005; Argent et al., 2007; Golden et al., 2014; Guzman et al., 2015). These spatial entities are known by various terms, the common references used being Hydrologic Response Units (HRUs), Representative Elementary Area (REA), and Functional Units (FUs). The most commonly used term and the one referred in the present study is HRUs, with the focus here being a methodology for delineating such HRUs for catchments of different topography, and an assessment of how this delineation performs when verified against high resolution aerial photograph and ground field survey data. The slope is an important topographic variable to control the runoff generation and therefore most of the existing HRUs delineation approaches consider slope as an important control in the approach formulated (Wood et al., 1988; Flugel, 1995; Lacroix et al., 2002; Argent et al., 2007; Dehotin and Braud, 2008; Li and Sivapalan, 2011). The majority of existing approaches for HRUs delineation lack topological connectivity across the units, which is important for understanding catchment scale hydrologic processes. The verification of the existence of these HRUs on ground is seldom carried out. A new method for delineation of contiguous, topologically connected HRUs was developed by Khan et al. (2013) for high topographic relief catchments. This HRUs delineation method was verified by soil moisture movement modelling of hillslope cross sections by Khan et al. (2013).

The HRUs delineation method developed by Khan et al. (2013) is evaluated here for the first time in a large, low topographic relief catchment using high resolution aerial photograph data and found to be applicable. To delineate the HRUs, Khan et al. (2013) divided the entire catchments into four contiguous landform elements, i.e. landform-upslope, -midslope, -footslope and –alluvial flats, and first order sub-basins. For ease of use and reference, these landform elements are simply referred to as ‘landforms’ in the rest of the paper. The landforms are delineated on the basis of similarities in geomorphologic and topographic attributes, i.e., the CAD curve and slope, to disaggregate the catchment into homogeneous spatial entities.

Khan et al. (2013) delineated the HRUs to reduce the computational units/time in physically based distributed hydrological modelling and to increase the application of these models in large catchments. But the verification of these HRUs has not been carried in the field earlier, which is the main aim of this research. There are three interrelated aims for this study. Firstly, to extend the HRUs delineation framework in low topographic relief catchments. Secondly, to evaluate the thresholds used to delineate the four landforms using high resolution aerial photograph analysis. Thirdly, to validate HRUs delineation approach by hydrologic modelling on hillslope cross-sections including sensitivity analysis test. Furthermore, the upslope areas of channel head in the different rock types are also analysed.

The paper is organized as follows: Section 2, study regions, geology and data; Section 3, brief description of the HRUs delineation approach; Section 4, evaluation of the HRUs delineation by aerial photograph analysis and in-situ observations; Section 5, results and discussion; and, Section 6, conclusions. The hydrologic modelling on hillslope cross-sections is presented in Supplementary material.

2. Study area and data

2.1. Catchments

The McLaughlin catchment, which is a part of the greater Snowy River catchment and located in the Snowy-Monaro region, west of the town of Bombala in South-Eastern New South Wales (NSW) has been selected as the high topographic relief catchment to evaluate the HRUs delineation methodology from high resolution aerial photograph analysis. The McLaughlin catchment has an elevation range of 533–1231 m and a catchment area of 459 km^2 (Fig. 1).

The HRUs delineation method is extended for Little River catchment and evaluated using high resolution aerial photographs and soil moisture movement modelling on hillslope cross-sections. Little River catchment is a sub-basin of the Macquarie River basin and located in the Central West region of NSW, Australia. The Little River catchment has low topographic relief (elevation range 266–803 m) and a catchment area of 2183 km^2 (Fig. 2).

The McLaughlin and Little River catchments are located in sub-alpine and semi-arid climates respectively (http://www.bom.gov.au/climate/change/hqsites/). The average annual runoff of McLaughlin catchment at gauging station “The Hut” (catchment area 314 km^2) is 136 mm/yr, calculated on the basis of daily stream flow record for the period 1961–78 (Tuteja et al., 2007). The average annual runoff of Little River at “Yeoval” (catchment area 734 km^2) is 26 mm/yr, calculated on the basis of daily stream flow record 1967–81. The runoff per km^2 for McLaughlin and Little River catchments are 0.433 and 0.035 mm/yr/km^2 respectively, which indicates that the Little River catchment is comparatively drier than the McLaughlin catchment.

2.2. Data

Hard copy aerial photo contact print coverage was used in conjunction with a stereoscope to allow for 3D viewing of all areas within both the McLaughlin and Little River catchments. Prints were on a scale of 1:25,000 for the McLaughlin catchment and 1:50,000 for the Little River catchment. The McLaughlin catchment photographs were taken in 1998. The aerial photographs for the