Journal of Hydrology (2007) **347**, 474–486

available at www.sciencedirect.com

ScienceDirect

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

Representation of stores along drainage networks in heterogenous landscapes for runoff modelling

C. Spence *, **J. Hosler**

Environment Canada, 11 Innovation Boulevard, Saskatoon, SK, Canada S7N 3H5

Received 30 March 2007; received in revised form 8 August 2007; accepted 18 September 2007

KEYWORDS
Runoff;
Storage;
Canadian Shield;
Hydrological modeling;
Scaling

Summary Recent field research of runoff generation processes has revealed that hydrological connectivity is crucial for runoff generation in many landscapes. The runoff generation process in these studies has been conceptualized as a series of independently cascading reservoirs. How to efficiently represent a patchy landscape as a sequence of reservoirs in a runoff model is not necessarily obvious. The present study considers the pattern of hydrological elements over which a drainage network passes in an attempt to understand how the landscape heterogeneity should be sampled in order to best represent it for the purposes of runoff modeling. The present study addresses how drainage density and sampling frequency influence the nature of the probability density function of hydrological elements along a drainage network in a typical heterogeneous Canadian Shield catchment. Upon generating 55 sequences, the results imply that these two factors do influence sequence representation, and that the typical or representative sequence is one dominated by lakes. The gross variation in this sequence can be characterized into three phases. These phases were a function of the rate of change in drainage density with defined minimum contributing area. Since drainage density can be representative of the moisture state of a catchment, the results imply that parameterization of patchy landscapes for hydrological modelling needs to be dynamic and may need to be a function of the moisture state of the catchment.

Crown Copyright © 2007 Published by Elsevier B.V. All rights reserved.

Introduction

Recent advances in research on runoff generation processes (Carey and Woo, 2001; Hutchinson and Moore, 2000; Spence and Woo, 2003; Tromp van Meerveld and McDonnell, 2006) are creating a paradigm shift in hydrology as the importance of basin heterogeneity, geometry, topology and dynamic hydrological connectivity among physiographic types and flow paths are beginning to be recognized in hydrological theories and concepts (Western et al., 2001; Sidle et al., 2000; Beven and Freer, 2001). These ideas are fueling a debate over how best to represent a specific landscape and the influence of its inherent process and structural

---

* Corresponding author. Fax: +1 306 975 5143.
E-mail address: chris.spence@ec.gc.ca (C. Spence).

0022-1694/$ - see front matter Crown Copyright © 2007 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.jhydrol.2007.09.035

heterogeneity on catchment response (Shaman et al., 2004; Uchida et al., 2006; Buttle, 2006).

After studying hydrological and energy budget processes in the northern Canadian Shield physiographic region where connectivity has a profound influence on the runoff signal, Spence and Woo (2006) proposed an element threshold concept of runoff generation that perceives heterogeneous catchments as comprised of ''hydrological elements''. Hydrological elements are areas within a catchment that function hydrologically in a homogenous manner over time at a given scale of interest. Spence and Woo conceptualize the runoff generation interaction of hydrological elements as a series of independently cascading reservoirs with variable storage capacities. The cascading reservoir model structure has been in existence for a half-century (Nash, 1957; Wooding, 1965; Kibler and Woolhiser, 1970). Rodriguez-Iturbe and Valdes (1979) and Gupta et al. (1980) derived models using this structure with assumptions of connectivity and effective precipitation. This permitted implicit representation of the reservoirs based upon drainage network geometry. As the element threshold concept is free of those assumptions, the topology and geometry of the reservoirs may need to be explicitly represented in models of those catchments where the concept is applicable. These tend to be watersheds with disorganized or disconnected drainage networks; where topography is not necessarily a first-order control of runoff generation. For example, the sequence and relative sizes of water bodies in lake dominated catchments in sub-arid Western Canada is crucial to basin runoff response and residence time (Gibson et al., 2002; Spence, 2006). Furthermore, some catchments experience processes that change storage thresholds over time, such as those associated with seasonal field crops or frozen conditions, so explicit representation of the reservoirs, their thresholds and their sequence along the drainage network may be necessary to correctly simulate when they contribute to downstream runoff. However, no methodology exists to derive a representative sequence of elements (or similar areal catchment components such as the hydrological response unit of Leavesley and Stannard (1990)) in a heterogeneous catchment.

Some direction can be provided by previous research that has interpreted the hydrologic response of a watershed as a function of the probability density function, *pdf*, of travel times to the outlet along the drainage network. These *pdf's* have been equated to Strahler (1952) stream order (Wang et al., 1981), basin width function (Mesa and Mifflin, 1986), basin magnitude (Boyd, 1978) and basin area function (Robinson et al., 1995). The drainage networks in these applications are often represented as simple plane true patterns and are assumed to be a function of the landscape. By using topographic indices to derive a *pdf* of travel times, Beven et al. (1996) is one of the few works directly relating the landscape to the runoff response. The present study attempts a similar probabilistic methodology that could be used to derive a representative pattern of hydrological elements (Spence and Woo, 2006) or response units over which a drainage network passes.

Similar questions about resolution effects on element *pdf's* would apply to this activity as much as deriving the *pdf* of a component of a drainage network (Becker and Braun, 1999). Melville and Martz (2004) and Helmlinger et al. (1993) show that changes in assigned minimum contributing areas (that is the minimum area required to produce surface runoff) do not necessarily change scaling properties. The effect of decreasing observation resolution on basin and drainage network delineation, and derived topographic variables has been found to be non-linear (Armstrong and Martz, 2003), but the persistence of symmetries is often observed (Marani et al., 1991). The present study addresses the following questions in the context of a probabilistic approach to defining representative element sequences along a drainage network for hydrological modeling:

1. Does (a) drainage density or (b) sampling resolution influence the nature of the cumulative density function of hydrological elements along a drainage network?
2. Do changes in these two factors influence the eventual element sequence representation?
3. Is there a typical or representative sequence?

Research basin

Baker Creek is a water course characterized by lakes connected by short channels that drains $\sim$150 km^2 into Great Slave Lake in Canada's Northwest Territories (Fig. 1). The portion of the watershed that was investigated is upstream of the Baker Creek at the outlet of Lower Martin Lake Water Survey of Canada (WSC) hydrometric gauge (07SB013), draining a $\sim$137 km^2 basin area.

In most years, the largest input of water to the basin is during the spring freshet (Spence, 2006) and the hydrological regime of Baker Creek is described best as subarctic nival (Church, 1974) as this melt dominates the annual hydrograph of Baker Creek (Fig. 2). The average annual streamflow at the outlet of Lower Martin Lake is 0.29 m^3/s, providing an annual runoff ratio of 0.24 using the precipitation record from the nearby Meteorological Service of Canada climate station Yellowknife A. The runoff regime exhibits remarkable variation for a basin with almost 350 lakes as the standard deviation of annual streamflow is 0.2 m^3/s. Annual runoff ratios range from 0.03 (1995) to 0.39 (2001). A maximum daily streamflow of 8.7 m^3/s has been observed, but common prolonged dry periods result in Baker Creek's intermittent discharge at the outlet of Lower Martin Lake (Fig. 2).

Baker Creek's drainage network is very dynamic with storage thresholds throughout the basin significantly controlling its extent. The extent is generally at its maximum during the spring freshet as snowmelt inputs easily overcome soil storage thresholds kept low by frozen conditions. Relatively high runoff from the uplands brings headwater lake levels above their outlet elevations, permitting flow to proceed to the main channel (Mielko and Woo, 2006). As spring gives way to summer, low intermittent rainfall-runoff from uplands and intermediate wetlands in the basin becomes disconnected from the main channel as evaporative and outflow losses drop levels in intervening lakes below their outlet elevations. By mid-summer in a dry year only the three lowest lakes in the system can be hydrologically

Download English Version:

https://daneshyari.com/en/article/4579584

Download Persian Version:

https://daneshyari.com/article/4579584

Daneshyari.com