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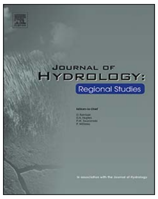

Combining observations of channel network contraction and spatial discharge variation to inform spatial controls on baseflow in Birch Creek, Catskill Mountains, USA

Stephen B. Shaw[a,*], Donald B. Bonville[a], David G. Chandler[b]

[a] *SUNY College of Environmental Science and Forestry, Dept. of Environmental Resources Engineering, Syracuse, NY 13210, United States*
[b] *Syracuse University, Dept. of Civil and Environmental Engineering, Syracuse, NY 13244, United States*

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ABSTRACT

Study region: This study was carried out in the 32 km^2 Birch Creek watershed in the Catskill Mountains of New York State. Birch Creek is situated within the Hudson River Basin.
Study focus: Very few studies have paired measurements of changes in the extent of the actively flowing channel network with measurements of small scale flow variations. In this study, we map changes in a 23.5 km active channel network and concurrently take periodic measurements of discharge at 31 sub-channels (with drainage areas ranging from 0.04 to 11.5 km^2) in order to better understand the spatial distribution of baseflow generation over time within the catchment.
New hydrological insights: For the 31 different sub-channels, baseflow discharge per unit drainage area and per unit stream length were highly variable, even during periods of higher moisture storage when all channels were active. Simple mapping of the active channels would not have recognized these sizable spatial differences in discharge contribution. Previous studies of hydrologic scaling in the Catskills have noted the likelihood of heterogeneity in discharge below a threshold of approximately 3–8 km^2. This study provides direct documentation of such heterogeneity at smaller spatial scales. When considering perennial and ephemeral streams, such heterogeneity was not well explained by standard topographic, geologic, or meteorological factors. We suggest the heterogeneity may arise from difficult to map fine-scale variations in subsurface properties.

1. Introduction

Hydrologists have long recognized that different spatial locations within even a small watershed can contribute different amounts of discharge per unit area, even when controlling for differences in land use or weather variables (e.g. Dunne and Black 1970). These spatial variations in discharge have most always been considered during periods of “runoff” during and soon after precipitation ends. This spatial variability in runoff generation has its own terminology with the use of phrases such as “partial” (Engmun 1974) or “variable” source areas (e.g. Creed and Band 1998) and is often quantified with the use of models such as TopModel (Beven and Kirkby 1979) that identify areas of saturation excess runoff generation. Much less frequently has baseflow been considered in the context of spatially distributed contributing areas. Instead, baseflow has most often been generalized as a regional process with less thought as to a specific location of its origin. A more direct consideration of spatial variations in baseflow contribution can help understand variations in biogeochemical hotspots, infer the sensitivity of certain ecological habitats to rain-free periods, and provide

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[*] Corresponding author.
E-mail address: sbshaw@esf.edu (S.B. Shaw).

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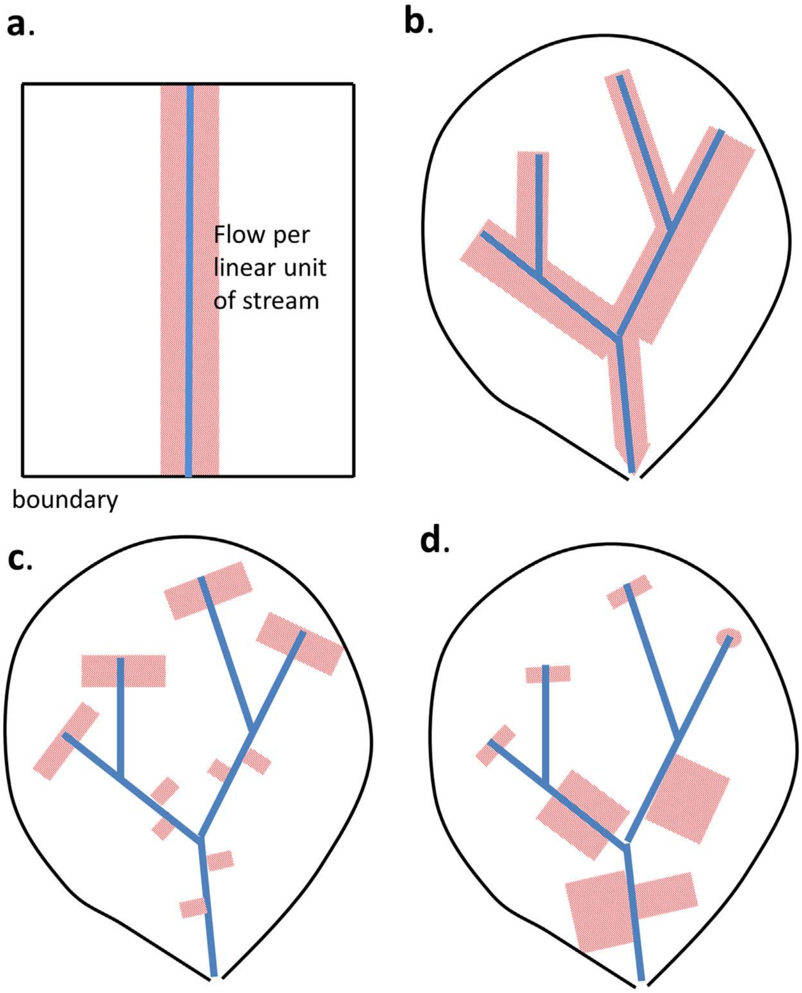

Fig. 1. Schematics of different possible spatial arrangements of baseflow generation in streams. Shading indicates the magnitude of inflow per unit length of stream. Discharge generation could be uniform per unit length, as depicted in a single stream (a) or it could vary with hillslope area (b). Alternately, at one extreme, discharge generation could be dominant at the channel heads with minimal contributions downstream (c). At the other extreme, discharge generation could be dominant in second and third order streams (d).

some physical explanation for variations in water travel times. However, there remain numerous competing conceptualizations of the spatial origin of baseflow (Fig. 1).

The traditional paradigm for baseflow contribution, in accord with hydraulic aquifer theory (e.g. Troch et al., 2013), has been to assume that a uniform, curving water table extends underneath a watershed and that baseflow originates in near equal proportion from all parts of the watershed. In a watershed with equal distance between stream and watershed boundary,traditional hydraulic aquifer theory would imply that baseflow discharge is effectively proportional to active channel length. Even when not in a watershed with uniform distance from stream to boundary, others have also adopted this assumption that discharge contribution is directly proportional to active channel length (e.g. Biswal and Marani, 2010; Biswal and Nagesh Kumar, 2014). As an alternative – which accounts for variation in distance between stream and channel boundary – many have assumed discharge is proportional to upslope contributing area (Archfield and Vogel 2010; Payn et al., 2012; Gianfagna et al., 2015).

Field observations have suggested additional ways of conceiving of baseflow generation that take into account the possibility of greater spatial heterogeneity. Recent work mapping changes in the active channel length of headwater stream networks has noted the presence of channel head seeps that “anchor” first order channels (Hunter et al., 2005; Whiting and Godsey 2016; Shaw 2016). Other work has noted seeps in high-order channels, often at the valley bottom (e.g. Payn et al., 2012; Briggs et al., 2012; Binley et al., 2013; Williams et al., 2015). This conceptualization of valley bottom seeps is more in line with traditional graphics illustrating the interaction between groundwater and surface water (Winter et al., 1998; Shaman et al., 2004) in which the groundwater table is shown intersecting the land surface near the valley bottom, not at the channel head. While seeps are not entirely incompatible with traditional hydraulic theory, the presence of seeps implies greater heterogeneity in subsurface processes than a uniform water table could explain.

Fig. 1 graphically summarizes the four different conceptualizations of spatial variation in baseflow generation: uniform per unit of