Progress in Physical Geography 33(2) (2009) pp. 288–293

Classics in physical geography revisited

Hewlett, J.D. and Hibbert, A.R. 1967: Factors affecting the response of small watersheds to precipitation in humid areas. In Sopper, W.E. and Lull, H.W., editors, *Forest hydrology*, New York: Pergamon Press, 275–90.

Hewlett and Hibbert's (1967) 'Factors affecting the response of small watersheds to precipitation in humid areas' (hereafter referred to as 'Factors') is one of the most important papers published in the field of catchment hydrology. Despite its grey literature appearance as a proceedings paper from the first International Symposium on Forest Hydrology at Penn State University, the work outlined a manifesto for change in catchment hydrology and the basis for modern rainfall-runoff concepts in upland humid areas. The paper was transformative in that it presented a compelling alternative – the Variable Source Area (VSA) concept – to the then status quo concept of infiltration excess overland flow. It also ushered in a perception of catchment runoff behaviour that would be codified in many topographically based rainfall-runoff models used today. The paper also introduced a new quickflow hydrograph separation approach that has been used to classify and organize watersheds with diverse sets of hydrological behaviour from different parts of the globe. This short review of the classic paper attempts to set the work in the context of the field, then and now, and to explore how the variable source area concept links to modern catchment hydrology.

Hewlett and Hibbert were field-based, forest hydrologists working at U.S. Department of Agriculture Forest Service Coweeta Hydrologic Laboratory in the southern Appalachian mountains near Asheville, North Carolina. John Hewlett (Figure 1) was then an Associate Professor of Forest Hydrology at the University of Georgia and Alden Hibbert was a Research Forester for the Forest Service based in Ashville. Through their field studies at Coweeta they were struck by the fact that headwater streams responded quickly to rainfall inputs – but with seemingly no overland flow (except for areas around the stream margin). The prevailing assumption in catchment hydrology at the time of 'Factors' was that direct runoff was a 'product of overland flow and that other types of flow were mere exceptions to that general rule' (p. 277). Their philosophy, based on basic observations at Coweeta during storm rainfall events, was that 'the opposite approach is more logical in the case of forest land; that is, to begin with the assumption that all flow is subsurface flow until there is evidence otherwise' (p. 277). Clearly, Hewlett and Hibbert's ideas on these issues were very much influenced by their predecessors at Coweeta, especially C.R. Hursh (Hursh and Brater, 1941; Hoover and

DOI: 10.1177/0309133309338118

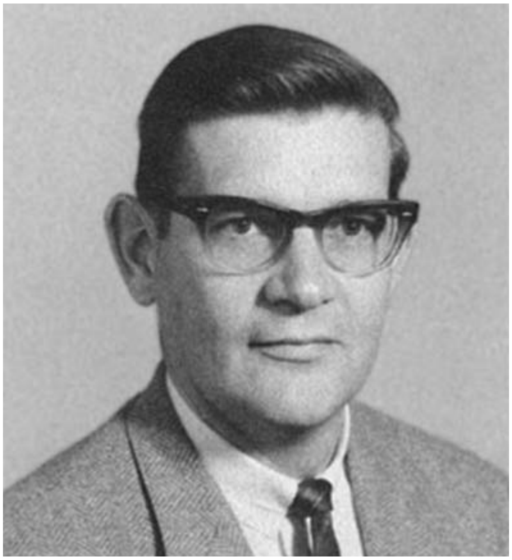

Figure 1 John Hewlett. The date of this photograph is unknown but probably coincides with his tenure as professor at the University of Georgia at Athens, USA

Source: Jackson *et al*. (2005), used with permission.

Hursh, 1943). Their concepts were also heavily influenced by Horton and Hawkins (1964; 1965) and their one-dimensional soil-core work from the nearby Savannah River Site. Hewlett and Hibbert took these 1D core experiments and, for the first time, considered how they might operate writ large across the landscape. The clarity with which Hewlett and Hibbert perceived and then described the processes of infiltration, lateral movement of water in the subsurface and resulting channel stormflow was greater than that of any who came before them.

'Factors' was one of the first papers to treat explicitly how pressure and particles propagate through a catchment during a rainfall event. Indeed, how hillslopes store water for months to years and then release it in minutes to hours in the stream remains the source of considerable debate even today (Kirchner, 2003). Hewlett and Hibbert were exceptionally clear-thinking on this topic and their paper presented a thoroughgoing analysis of the passage of rainfall to the stream (Figure 2). They described (p. 279) that 'each unit of rainfall contributes more to temporary storage and less to direct runoff. However, of the parts contributed to direct runoff, a fraction will be some of the actual raindrops that fell during the storm – that is, some new rain – and the other fraction will be flow produced by a process of displacement'. They go on to say (also p. 279) that the effusion of stored water will be 'released in large quantifies only when the soil is within the field capacity range or wetter'. These words portend work that was to follow 30 years later (Montgomery *et al*., 1997) where these mechanisms would be clarified in perhaps one of the greatest hillslope hydrology experiments of all – and with a similar finding of flow sensitivity to the soil moisture release curve (Torres *et al*., 1998). Hewlett and Hibbert's translatory flow lacked any explicit treatment of preferential flowpaths or enhanced flow and transport at the soil-bedrock interface (key elements of many subsequent papers that have described the controls on rapid transmission of pre-event water to the channel during an event (McDonnell, 1990). Nevertheless, 'Factors' helped the hydrologic community begin to understand differences in source areas and timing of water delivery in a radically new way – one that continues to guide many management strategies to protect water quality.

Hewlett and Hibbert (1967) also spoke to themes that only decades later would emerge in the mainline hydrological literature. They described how the catchment as 'a topographic pattern of soil water storage and availability is already well established in soil survey, site and vegetation studies, and there will be some advantage in bringing hydrologic theory in line with these views' (p. 280). These words could almost be read now in calls for the new Critical Zone Observatories in the USA or the words accompanying the creation of the new Wiley journal *Ecohydrology*! They also spoke of

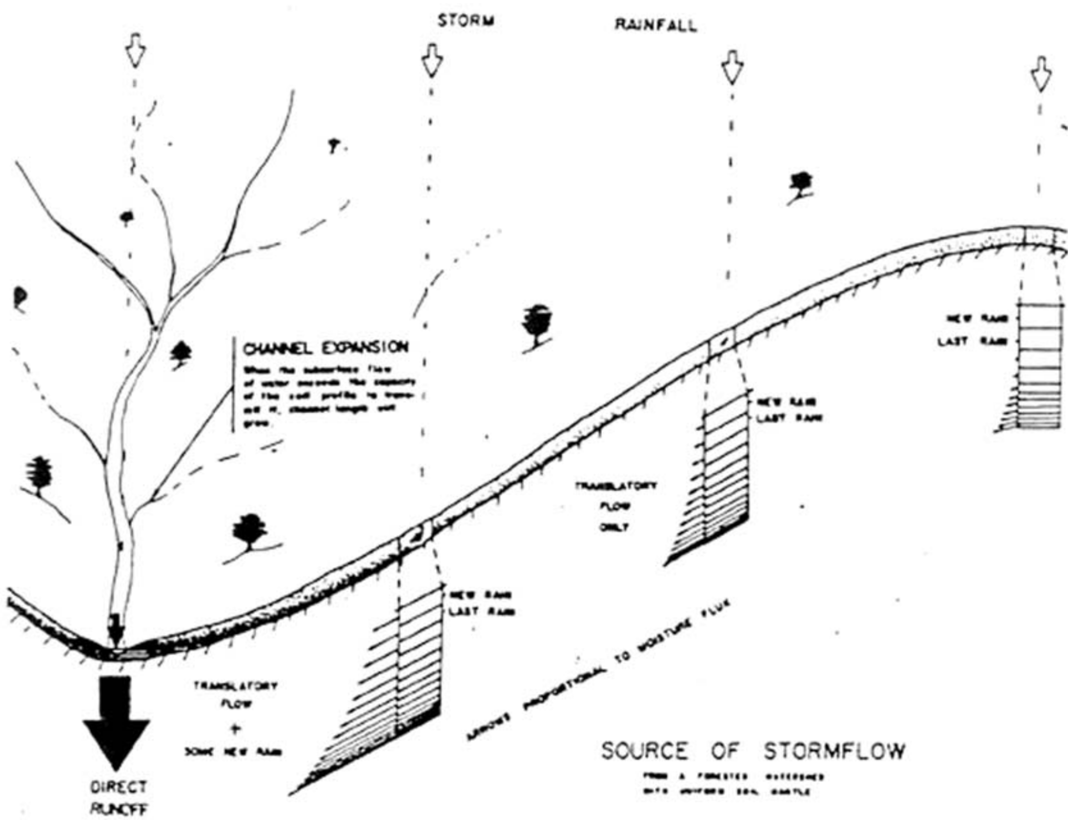

Figure 2 The variable source area concept from 'Factors'. Hewlett and Hibbert expressed the translatory flow concept with arrows denoting displacement. While channel expansion is shown in the diagram, little description is given in the paper on near-stream saturation excess overland flow processes where rain-fall may fall onto areas of groundwater exfiltration

scale issues in their work at Coweeta where 'both Coweeta [watersheds] 2 and 36 are contained within the larger watershed Coweeta 8, demonstrating the fact that subwatersheds may have response factors both larger and smaller than the main basin'. Hewlett and Hibbert were already thinking about representative elementary areas, long before Wood *et al*. (1988) and before the first explicit tests of whether large watersheds are simply the sum of their component parts (Shaman *et al*., 2004). One of the hallmarks of their paper was the intent to classify watersheds. Hewlett and Hibbert (p. 289) noted that 'there are about 50,000 small watersheds of 20 square miles in the humid eastern parts of the United States; each of these has a characteristic response factor' and that 'experimental results and prediction methods might be grouped and extended partly by response classes, as well as on the basis of geological formations, soil types, vegetal cover and climate'. It would be 40 years before these ideas were taken up by the community and classification appreciated as a laudable goal in catchment hydrology (Wagener *et al*., 2007).

The other scientific contribution of 'Factors' was the development of a standard hydrograph separation tool for partitioning

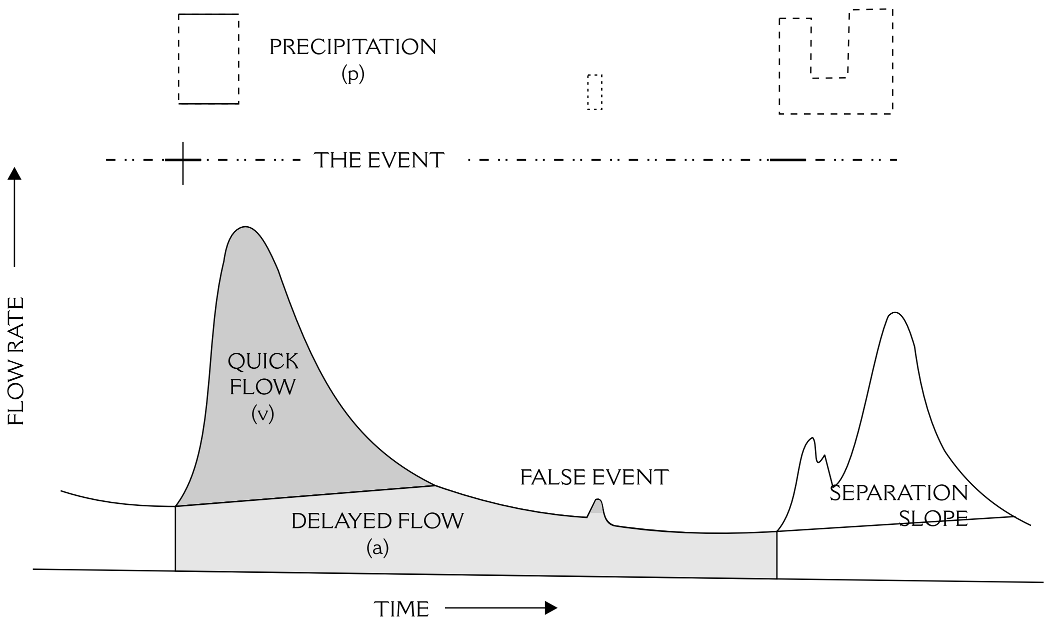

Figure 3 The quickflow/delayed flow hydrograph separation procedure from 'Factors'. Hewlett and Hibbert applied this to 200 water-years of record for 15 small forested catchments in the Appalachian-Piedmont region of the USA. This intercomparison work was instrumental in helping to illustrate the main factors influencing the production of storm runoff

the storm hydrograph into quickflow and delayed flow (Figure 3). While hydrograph separation is no longer *de rigueur* (something we now realize is akin to trying to unscramble an omelette!), the power of Hewlett and Hibbert's approach was in the intercomparison of 15 small watersheds in the Appalachian-Piedmont region. Hewlett and Hibbert showed that for their forested watershed site at Coweeta direct runoff as a percentage of storm rainfall could be as high as 50% (with virtually no overland flow involved as per the translatory flow mechanism). The question then became: if we assume that subsurface flows predominate on most wildland soils, how do direct runoff and baseflow get to the channel? Since an arbitrary separation of hydrographs must be made in any case, Hewlett and Hibbert argued then why not base the classification on a single arbitrary decision, such as a fixed, universal method for separating all hydrographs on all small watersheds? They examined 200 water-years of record for the 15 small forested catchments and decided that a line projected from the beginning of any stream rise at a slope of 0.05 cubic feet per second per square mile per hour (!) until it intersected the falling limb side of the hydrograph would be a simple and satisfactory method for separating streamflow into quick and delayed flow.

Hewlett and Hibbert (1967) found that none of the forested catchments yielded more than one-third of their total yield as quick flow. They began assembling features that might explain these variations and groupings of watersheds in terms of their quickflow production, noting that things like topography, soil depth, climate and landuse all played a role. In one of the clearest expositions of runoff generation ever written, Hewlett and Hibbert listed the order of importance of these factors based on the process-based findings at Coweeta and comparison with these other study sites. Foremost among the four factors was 'the average soil mantle depth or depth to a relatively impermeable layer (p. 288). Second was the 'average land slope and its effect on the average length of slope from the channel to the water divide' (p. 288). Third was 'the average size and number of the larger storms or the average annual storm (p. 288). They noted that 'these influence response by their obvious effect on rates of infiltration' and stated that 'average annual precipitation and its distribution may be included here, as it influences response through control of antecedent wetness conditions and variable source areas contributing subsurface flow' (p. 288). Finally, land use was listed last 'not because it is minor, but because its effects on the time distribution of flow are superimposed on the effects of the other factors' (p. 288).

So how do we view this concept today? Curiously, Hewlett and Hibbert (1967) said little about rain falling onto the stream or onto an expanding saturated area adjacent to the channel. Hewlett and Hibbert's view on saturated area development was that 'this phase of runoff occurs when the subsurface flow of water from upslope exceeds the capacity of the soil profile to transmit it and the water comes to the surface and the channel length will grow'. Given the highly incised slopes at Coweeta, we can assume that they observed little near-stream saturation and regarded stormflow production as purely subsurface stormflow driven. But perhaps there was more at work in avoiding explicit treatment of near-stream saturation dynamics – driven by the intent to counter the engineering hydrology beliefs of the role of overland flow (due to infiltration excess) as chief runoff-producing mechanism. An interesting postscript to this paper was Hewlett's reaction to Tom Dunne's PhD and the Dunne and Black (1970) paper – another benchmark in the field and one aimed at better detailing of the near-stream saturation overland flow portion of the variable source concept dynamics. Hewlett is quoted as saying to Tom Dunne that he was 'throwing the field back to Horton' (T. Dunne, personal communication, 29 January 2009)! This also speaks to how elements of the VSA concept may dominate in different environments – with little saturation excess overland flow in the highly incised hillslopes of Coweeta (VSA as channel network extension) versus rather significant saturation excess produced in the till-mantled, gently undulating slopes of the Sleepers River watershed in northern Vermont, USA (where Dunne performed his work). Since then, other geographical differences have been noted – from the dominance of soil pipes in Plynlimon, Wales, and Maimai, New Zealand, to the influence of porous or permeable bedrock at Coos Bay, Oregon, and Fudoji, Japan, to widespread saturation excess in the humid tropics of Babinda, Australia (just to name a few). The VSA concept lives on, albeit with recent calls for modification to explicitly consider watershed control volume (Sidle *et al*., 2000; McDonnell, 2003).

New theory is uncommon in the hydrological sciences. Hewlett had an uncanny knack for compact organization of empirical data and observations of catchment responses that facilitated prediction of watershed behaviour in different places. The variable source area concept remains one of the most important and enduring concepts in watershed hydrology. In an age where field work is often relegated to minimal efforts necessary for model parameterization, the body of work of Hewlett and Hibbert at Coweta leading to the VSA concept and other important discoveries (eg, Hewlett and Hibbert, 1963), remains a benchmark for scientific inquiry in the hydrological sciences. Hewlett and Hibbert sought to address fundamental challenges in the field, to forge new frontiers of hydrological science and strike at a deep intellectual level the key hydrological puzzles. Their 1967 paper is an exemplar of this approach.

Acknowledgements
I would like to thank the PhD students and Post Docs in my lab (currently Taka Sayama, Chris Graham, Luisa Hopp, Lyssette Villers, Cody Hale Rosemary Fanelli, Holly Barnard, Jurriaan Spaaks and Daniela Biondi) whose work has helped continue to shape my view of the Hewlett and Hibbert's variable source area concept. Thanks also to Tom Dunne, Pete Black, Dave DeWalle, Mike Bonell and the late George Hart for their useful historical overview of Hewlett and his work over the years. Thanks also to George Ice and Cody Hale for their critical reviews of an earlier version of this manuscript.

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