Stormflow-hydrograph separation based on isotopes: the thrill is gone—what’s next?

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Beginning in the 1970s, the promise of a new method for separating stormflow hydrographs using $^{18}$O, $^2$H, and $^3$H proved an irresistible temptation, and was a vast improvement over graphical separation and solute tracer methods that were prevalent at the time. Eventually, hydrologists realized that this new method entailed a plethora of assumptions about temporal and spatial homogeneity of isotopic composition (many of which were commonly violated). Nevertheless, hydrologists forged ahead with dozens of isotope-based hydrograph-separation studies that were published in the 1970s and 1980s. Hortonian overland flow was presumed dead. By the late 1980s, the new isotope-based hydrograph separation technique had moved into adolescence, accompanied by typical adolescent problems such as confusion and a search for identity. As experienced hydrologists continued to use the isotope technique to study stormflow hydrology in forested catchments in humid climates, their younger peers followed obligingly—again and again. Was Hortonian overland flow really dead and forgotten, though? What about catchments in which people live and work? And what about catchments in dry climates and the tropics? How useful were study results when several of the assumptions about the homogeneity of source waters were commonly violated? What if two components could not explain the variation of isotopic composition measured in the stream during stormflow? And what about uncertainty? As with many new tools, once the initial shine wore off, the limitations of the method became a concern—one of which was that isotope-based hydrograph separations alone could not reveal much about the flow paths by which water arrives at a stream channel during storms.

During the late 1980s and early 1990s, isotope-based hydrograph separation techniques matured into young adulthood. Unlike the early studies that separated hydrographs into two components based only on time, increasingly complex approaches emerged that allowed stormflow-hydrograph separation into three-components that reflected the geographic source areas of runoff. Hydrologists also began to incorporate error into their studies, and, most importantly, began to combine isotope-based hydrograph separations with physical measurements such as groundwater levels and soil water content to learn more about hydrologic flow paths. As the science matured further in the 1990s, a point was reached at which isotope-based hydrograph separations alone were insufficient to guarantee...
publication of study results in the leading water resources journals. Many studies seemed only to reconfirm that stormflow in small forested catchments is dominated by ‘pre-event’ or ‘old’ water, and hydrologists did not need to be told so over and over again. Thus, isotope-based hydrograph separation had become simply another tool—one that could not lead to a more profound understanding of catchment runoff processes unless combined with many other tools.

Now, at the dawn of the 21st century, we, as hydrologists, need to ask what new directions to take in studies that use isotope-based hydrograph separation in order to understand catchment runoff processes better. First, we can combine forces with another group of studies that began in the 1980s. These studies use annual distributions of isotope data in precipitation (or recharge) and streamflow to infer the mean residence time of baseflow in a catchment. In a few recent studies, researchers have combined this approach for determining mean baseflow residence time with hydrograph separation to calculate how ‘instantaneous’ residence time is affected by storms, snowmelt, and climatic change (Harris et al., 1995; Rose, 1996). Future studies that follow a combined approach need to consider the recent evidence of the fractal nature of mixing in catchments that refutes earlier assumptions about a simple exponential distribution of water residence time in catchments (Kirchner et al., 2001).

Second, we can strive to expand and organize our database better. Despite recent attempts to classify hydrograph-separation study results according to hydrogeomorphic setting, catchment drainage area, or degree of human development (Buttle, 1994; Genereux and Hooper, 1998), we lack the data to systematize the manner in which climate, drainage area, and percent impermeable surface alter the separated runoff components. Such a systematic categorization of hydrograph separation results could provide new insights about how landscape characteristics and human activities together affect runoff and storage in catchments across a variety of scales and disturbance regimes. A few recent studies that have used isotope-based hydrograph separation in disturbed settings have found that the death of Hortonian overland flow was announced prematurely (Buttle et al., 1995; Gremillion et al., 2000).

Third, we can explore solute and water mixing and evolution simultaneously. Recently developed techniques for measuring the $^{18}$O content of ions such as NO$_3^-$, SO$_4^{2-}$, and PO$_4^{3-}$ in water allow comparison of the mixing and transport of $^{18}$O in water with that of $^{18}$O in these ions. The oxygen in these inorganic anions is derived from both water and O$_2$ gas in the subsurface during microbial mineralization. New studies that combine solute-source separations with water mixing rates during runoff, as provided through hydrograph separation, may provide insight into the relative rates of advection, dispersion, and mixing compared with the rates of biogeochemical processes such as mineralization and adsorption/desorption (Burns and Kendall, 2002).

To return to the title of this commentary, the thrill of doing isotope-based hydrograph separations in forested, humid catchments is definitely gone, but new studies in catchments with different climatic and human disturbance regimes, and studies that combine water-isotope and solute-isotope measurements should provide hydrologists with abundant thrills and even surprises in coming years. We have entered an era in hydrology in which hydrograph separation techniques will be viewed as just one more tool among many that can help quantify runoff components and processes in a catchment. Isotope-based hydrograph separation, when combined with new cutting-edge tools, such as sophisticated residence-time models based on the fractal distribution of water mixing and the in situ rates of biogeochemical processes, can continue to contribute to the advance of hydrologic science in coming decades.

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References


