Commentary

An Ecologist's Perspective of Ecohydrology

When my hydrological colleagues first brought up the term "ecohydrology" several years ago, I was simultaneously enthused, wary, and territorial. I still am. Enthused because the interface between ecology and hydrology still seems largely unmined, despite its key importance in ecosystems ecology—particularly in the water-limited systems that have been the focus of most of my work. Wary because although this interface does seem simultaneously unmined and important, the first response tends to be, "Well it's not news to ecologists that water is important in driving ecological processes and dynamics, and it is certainly not news to hydrologists that vegetation influences the water budget." And territorial because after feeling awash and striving to get my groundings in the ever-growing field of ecology, I was uneasy labeling any new collaborative endeavor—and particularly labeling myself—with a term ending in something other than "-ecology" or "-ecologist." A few years later, these points merit reflection and updating given the rapid growth in this area, which has affected me personally, as well as, I believe, a growing number of ecologists and hydrologists.

Most researchers have been cautious about labeling ecohydrology as a new field (Baird 1999, Bond 2002, Van Dijk 2004, Wilcox and Newman 2005). Rather, it is often referred to with respect to an increase in the interaction between ecology and hydrology. The terms "ecohydrology" and "hydroecology" have both been tossed around and have not been used consistently (Hannah et al. 2004). In general, "hydroecology" seems to be used more in association with aquatic ecology and riparian systems, whereas ecohydrology seems to be used more in association with terrestrial ecology, particularly for drylands. Most generally, there seems to be agreement that ecohydrology focuses on the interactions and interrelationships between hydrological processes and the pattern and dynamics of vegetation.

Debate remains about the relative newness and importance of ecohydrology (Hannah et al. 2004). Most colleagues I have spoken with who come from a hydrological background are particularly enthused about this growing area (see also Rodríguez-Iturbe 2000). Ecohydrology seems to have captured the interest of a subset of ecologists as well, although I have the sense there is not as much widespread enthusiasm as there appears to be in hydrology (see also Bond 2003). Many ecologists see it as just the next step in developing a new interface in ecology, similar to previous advances in plant ecophysiology or biogeochemistry. Some in natural resources believe that a wheel is being reinvented that is ignoring previous interdisciplinary contributions of watershed science and management. Although the latter perspective merits weight, I do believe that recent efforts in ecohydrology indeed represent a new level of interdisciplinary integration between current ecology and hydrology. Both fields have had substantial intellectual and membership growth over the past several decades since watershed resource management became established in an academic context. Some of the difference in perspective and level of enthusiasm for ecohydrology between the ecological and hydrological communities may reflect differences in their roots. Hydrologists have more direct roots in engineering relative to ecologists (see also Baird 1999), who like to view ourselves as being fundamentally rooted in multidisciplinary science. (It should be noted, however, that hydrologists often seem to be able to run circles around ecologists when it come to predicting relevant properties from the two respective disciplines.) Hence, ecologists and hydrologists may be viewing ecohydrology from different perspectives along the engineering–science continuum. I personally see the most evidence of the importance of greater integration between ecology and hydrology in a recent set of papers published in *Ecology* that resulted from an American Geophysical Union Chapman Conference on “Ecohydrology of Semi-arid Landscapes” (Wilcox and Newman 2005). This was one of the most exciting and stimulating workshops I have participated in, and the resulting papers (disclosure no. 1: I am a coauthor on two of the resulting papers) represent what I believe are novel syntheses that would be extremely unlikely to have been developed from either the ecological or hydrological communities alone.

Disclosure no. 2: I am still a bit uneasy with labeling myself as an “ecohydrologist,” because it sounds like a specialty or “sub”-discipline in hydrology. But a close ecology colleague and friend pointed out, “Hey, Dave, you are an ecohydrologist—almost everything you study is related very tightly to the water budget, plant water use, and vegetation patterns and dynamics.” I now use the term when it seems appropriate, but I also try to clarify that I am an ecologist, not a hydrologist, and I often refer to the area as “ecohydrology and vegetation dynamics.” My active involvement at this interface was a major factor associated with my recent move to the University of Arizona, where I am working to build strong ties among related programs spread across three colleges: Hydrology and Water Resources in the College of Engineering; Ecology and Evolutionary Biology in the College of Science; and the Watershed Program within the School of Natural Resources in the College of Agriculture and Life Sciences. These academic units comprise a representative microcosm of much of the ecohydrology community at large. We now have a training grant in ecohydrology from the USDA and this fall I will teach a new course on “Dryland Ecohydrology and Vegetation Dynamics,” so my near-future fate is somewhat coupled with upcoming development in ecohydrology. Developing this ecohydrology interface remains challenging, as does any interdisciplinary endeavor, but there currently is a great deal of interest and enthusiasm about it.

So what are these important, unmined areas in ecohydrology? Most generally, there is an important shift in emphasis between ecohydrology and the traditional focus of either ecology or hydrology. Ecohydrology, as noted above, focuses on the interactions and interrelationships between hydrological processes and vegetation pattern and dynamics. Traditionally, hydrology has focused in large part on issues of water yield and, as I perceive it (as a perhaps somewhat ignorant outsider), has invested much less effort in processes that are of particular interest in understanding ecological dynamics and the associated feedbacks between hydrology and vegetation dynamics. Most notably, I believe that a major challenge in ecohydrology is to develop much more predictive and well-tested relationships for the partitioning among the subcomponents of evapotranspiration (Loik et al. 2004, Huxman et al. 2005). Evapotranspiration represents the vast majority of the water budget—more than 95% of the total in most arid and semiarid ecosystems (Wilcox et al. 2003*b*). There is great ecological relevance in how this vast majority of the water budget is partitioned among major components, which include at least three: intercepted water that is assumed to evaporate back to the atmosphere, soil evaporation, and plant transpiration. Many models generate predictions about the partitioning among these three components, yet few field studies have rigorously estimated the various components, at least for arid and semiarid ecosystems (Reynolds et al. 2000, Huxman et al. 2005). Those few studies vary in ecosystem type, methods applied, and in time scale of measurements. Hence, we need to improve our ability to predict these components of the water budget and how they vary with vegetation patterns and dynamics. Indeed, some of the most important differences between nondegraded and degraded dryland ecosystems may be evident in the ratio of transpiration to total evapotranspiration (Huxman et al. 2005).

Ecologists have not done much better than hydrologists in tackling the evapotranspiration partitioning (but see Yepa et al. 2003 as an example exception). But perhaps the most important shift for ecologists in moving toward an ecohydrological emphasis is moving away from use of precipitation alone and toward a more comprehensive understanding of the water budget (Loik et al. 2004). In particular, we would like to have a more comprehensive understanding and quantitative ability to predict the amount of "plant-available water" at a site. (This is, of course, interrelated with partitioning components of evapotranspiration.) Precipitation has served as a powerful predictor of plant productivity and other ecological attributes in many systems. When coupled with other climatic variables, it also serves as the underlying driver for biogeography and biogeochemistry models. Yet vegetation dynamics might arguably be much more tightly related to soil moisture, and soil moisture dynamics can differ markedly from patterns of precipitation alone. There are many data sets that have one, two, or even three years of soil moisture data (the old familiar correlation with grant length), and there are several emerging data sets that are five-or-so years in length, thanks to advances in automated data collection for soil moisture and longer term studies such as those associated with the Long Term Ecological Research Network, but there remain few data sets spanning up to a decade or more (e.g., Scott et al. 2000). Arid and semiarid systems characteristically exhibit great interannual variability in precipitation input. We are learning more about how longer climate patterns can persist, and this insight highlights how critical it is to obtain longer-term soil moisture time series. Soil moisture may be much more heterogeneous than we have previously appreciated, varying substantially under trees and shrubs vs. between them, or at a smaller scale, with respect to the presence or absence of biological soil crusts (Loik et al. 2004). Similarly, soil water potential gradients may be affected by vegetation type, and can, surprisingly, draw upward as well as downward (Seyfried et al. 2005). Recent insights about hydraulic lift of water by plants add whole new levels of complexity to understanding ecohydrological processes (e.g., Zou et al. 2005). These factors all require a more detailed and ecologically relevant reassessment of the water budget at a site. As one colleague frequently reminds me, data collection is usually a humbling process.

Unraveling the feedbacks between ecology and hydrology remains challenging and will surely require both modeling and field-based approaches. Continued integration is needed between these two general approaches to avoid the "Do they ever even go out in the field?" vs. "Could they even model their way out of a paper bag?" schism, which is an ongoing challenge in most areas of environmental science. Progress in modeling feedbacks is highlighted in two recent books on ecohydrology: Eagelson's (2002) *Ecohydrology* and Rodríguez-Iturbe and Poporato's (2004) *Ecohydrology of Water-controlled Ecosystems* (2004). These texts both articulate the importance of vegetation in hydrology and the role of feedbacks, with the latter particularly emphasizing the importance of soil moisture. Their strength lies in their attempts to build toward generality, an approach that I applaud. Modeling approaches such as these will be critical to improving our understanding of feedbacks between components of the water budget and vegetation dynamics. It remains critical, however, for such approaches to remain well grounded in ecological processes. Eagelson's seminal papers of the 1970s and 1980s (see Eagelson 2002 and references therein), which laid the groundwork for his recent book, intrigued me when I first read them and continue to stimulate my thinking. Yet Kerkhoff et al. (2004), in a recent publication stemming from the senior author's dissertation (disclosure no. 3: I served on his graduate committee) documents how three fundamental assumptions in the proposed framework are all ecologically flawed. (The three are related to canopy stress minimization, successional stress minimization, and maximum soil productivity.) This example simply highlights one of many areas where further collaboration among ecology and hydrology and further integration of modeling and field-based approaches seems warranted.

Perhaps the clearest success story to date for ecohydrology is the unraveling of the dynamics of ecosystems with banded vegetation, in which the redistribution of runoff alters the spatial distribution of soil moisture and drives vegetation change, which in turn feeds back to runoff patterns (Ludwig et al. 1997, Tongway et al. 2001). In this case, the effects of vegetation on runoff have been clearly documented, as has been the response of vegetation to soil water inputs from runon. Hence the feedback mechanism in this case is nicely demonstrated. Importantly, a clear plan for improving land management has been developed as a result of the new insights for these systems (Ludwig et al. 1997). Similar processes appear to be relevant not only for systems with banded vegetation, but also to some degree for a diverse set of arid and semiarid ecosystems (Wilcox et al. 2003*a*, Ludwig et al. 2005). We need to tackle other areas of ecohydrology with a similar approach, capturing the vegetation effect on hydrological processes, the hydrological effect on vegetation, the resultant feedback dynamics, and the implications and applications for management.

Where is ecohydrology headed? Well, certainly there is a need to fully partition the water budget and to better quantify feedbacks, as discussed above. Other recent interdisciplinary endeavors in ecology such as plant physiological ecology have helped dramatically to reveal underlying mechanisms and to increase predictive capability. Recent progress in ecohydrology offers similar promise. In addition, ecologists are making great progress in explicitly clarifying the ways in which ecosystems provide goods and services to society, something that the hydrologists have had down since the inception of hydrology as a discipline. (You've got to have water.) This is perhaps most clearly highlighted in the new Millenium Ecosystem Assessment (2005). There are many ecohydrological challenges imbedded within the issues raised by the Millenium Ecosystem Assessment, with desertification being among the prominent issues raised. So in addition to improving our ability to partition the water budget and quantify feedbacks, another major issue for ecohydrology is to improve our understanding and ability to predict and manage how ecosystem dynamics affect ecosystem goods and services. I look forward to the challenges ahead with both my ecology and hydrology colleagues, and will enthusiastically embrace the emerging "ecohydrology" emphasis in the hope that we will be able to improve science and serve society through this framework.

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Literature cited

Baird, A. J. 1999. Introduction. Pages 1–10 *in* A. J. Baird and R. L. Wilby, editors. Eco-hydrology: plants and water in terrestrial and aquatic environments. Routledge, New York, New York, USA.

Bond, B. 2003. Hydrology and ecology meet—and the meeting is good. Hydrological Processes **17**:2087–2089.

Eagelson, P. S. 2002. Ecohydrology: Darwinian expression of vegetation form and function. Cambridge University Press, New York, New York, USA.

Hannah, D. W., P. J. Wood, and J. P. Sadler. 2004. Ecohydrology and hydroecology: a "new paradigm"? Hydrological Processes **18**:3439–3445.

Huxman, T. E., B. P. Wilcox, D. D. Breshears, R. Scott, K. Snyder, E. A. Small, K. Hultine, W. Pockman, and R. B. Jackson. 2005. Woody plant encroachment and the water cycle: an ecohydrological framework. Special Feature on Ecohydrology. Ecology **86**:308–319.

Kerkhoff, A. J., S. N. Martens, and B. T. Milne. 2004. An ecological evaluation of Eagelson's optimality hypothesis. Functional Ecology **18**:404–413.

Loik, M. E., D. D. Breshears, W. K. Lauenroth, and J. Belnap. 2004. A multi-scale perspective of water pulses in dryland ecosystems: climatology and ecohydrology of the western USA. Special section on Precipitation Pulses in Arid Ecosystems. Oecologia **141**:269–281.

Ludwig, J., D. Tongway, D. Freudenberger, J. Noble, and K. Hodgkinson, editors. 1997. Landscape ecology: function and management. Principles from Australia's rangelands. CSIRO, Collingwood, Australia.

Ludwig, J. A., B. P. Wilcox, D. D. Breshears, D. J. Tongway, and A. C. Imeson. 2005. Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. Special

Feature on Ecohydrology. Ecology **86**:308–319.
Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, D.C., USA.
Reynolds, J. F., P. R. Kemp, and J. D. Tenhunen. 2000. Effects of long-term rainfall variability on evapotranspiration and soil water distribution in the Chihuahuan Desert: a modeling analysis. Plant Ecology **150**:145–159.
Rodriguez-Iturbe, I.. 2000. Ecohydrology: a hydrologic perspective of climate–soil–vegetation dynamics. Water Resources Research **23**:349–357.
Scott, R. L., W. J. Shuttleworth, T. O. Keefer, and A. W. Warrick. 2000. Modeling multi-year observations of soil moisture recharge in the semiarid American Southwest. Water Resources Research **36**:2233–2247.
Seyfried, M. S., S. Schwinning, M. A. Walvoord, W. T. Pockman, B. D. Newman, R. B. Jackson, and F. M. Phillips. 2005. Ecohydrological control of deep drainage in arid and semiarid regions. Ecology **86**:277–287.
Tongway, D. L., C. Valentin, and J. Seghieri, edtors. 2001. Banded vegetation patterning in arid and semiarid environments: ecological processes and consequences for management. Springer, New York, New York, USA.
Van Dijk, A. 2004. Ecohydrology: it's all in the game? Hydrological Processes **18**:3683–3686.
Wilcox, B. P., D. D. Breshears, and C. D. Allen. 2003*a*. Ecohydrology of a resource-conserving semiarid woodland: effects of scale and disturbance. Ecological Monographs **73**:223–239.
Wilcox, B. P., D. D. Breshears, and M. S. Seyfried. 2003*b*. Water balance on rangelands. Pages 791–794 *in* B. A. Stewart and T. Howell, editors. Encyclopedia of water science. Marcel Dekker, New York, New York, USA.
Wilcox, B. P., and B. D. Newman. 2005. Ecohydrology of semiarid landscapes. Ecology **86**:275–276.
Yepez, E. A., D. G. Williams, R. L. Scott, and G. H. Lin. 2003. Partitioning overstory and understory evapotranspiration in a semiarid savanna woodland from the isotopic composition of water vapor. Agriculture and Forest Meteorology **119**:53–68.
Zou, C. B., P. W. Barnes, S. Archer, and C. R. McMurtry. 2005. Soil moisture redistribution as a mechanism of facilitation in savanna tree–shrub clusters. Oecologia, *in press.* (DOI: 10.1007/s00442-005-0110-8).

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