

## Eco-hydrology's Past and Future in Focus

Lately, something called eco-hydrology has blazed forth as the next big thing in hydrologic science. A series of four papers on the topic appeared in *Advances in Water Resources* last year [Rodriguez-Iturbe *et al.*, 2001]. Before that, in 1996, the International Hydrology Programme (IHP) initiated a new project under the title of eco-hydrology [Zalewski *et al.*, 1997], and the AGU Spring Meeting, also in 1996, included a special session on eco-hydrology. Since then, a book of edited contributions has appeared [Baird and Wilby, 1999], and eco-hydrology was the topic of both a "vision for the future" in *Water Resources Research* [Rodriguez-Iturbe, 2000] and the Langbein Lecture at AGU's 2000 Spring Meeting. Another session on the topic will be featured at this year's Spring Meeting and a Chapman Conference on Eco-hydrology of Semiarid Landscapes will be held in September 2002.

What is this all about? Perusing the Web will confirm all of the above, but it will also raise some questions. Is eco-hydrology an entirely new field of study? What topics fall under this heading? We can answer these questions through a survey of recent usage of the term and a brief exploration of its historical roots. Eco-hydrology emerges as an engaging topic of study with multiple facets and deep roots in the history of hydrologic science.

A plausible definition would describe eco-hydrology as the sub-discipline shared by the ecological and hydrologic sciences that is concerned with the effects of hydrological processes on the distribution, structure, and function of ecosystems, and on the effects of biotic processes on elements of the water cycle.

This combines Rodriguez-Iturbe's [2000] definition of eco-hydrology as "the science which seeks to describe the hydrologic mechanisms that underlie ecologic pattern and processes" with his subsequent observation that "the connection between the role of plants in the water balance" is central to ecohydrology" [Rodriguez-Iturbe *et al.*, 2001]. The offered definition also emphasizes the focus on ecosystems implied by Rodriguez-Iturbe's definition and the research that he describes. Baird and Wilby [1999] define eco-hydrology more narrowly as the study of plant-water relations and the hydrological processes related to plant growth. This is not as restrictive as it might seem. Plant communities

influence the structure and function of many ecosystems, so the shift to an ecosystem focus is only a small step from the study of plant-water relations.

Eco-hydrology occupies the interface between the disciplines of ecology and hydrology. It falls clearly within the scope established for hydrologic science by the *National Research Council* [1991]. Hydrologic science encompasses "those biological processes that interact significantly with the water cycle... [including] those that are an active part of the water cycle, such as vegetal transpiration and many human activities, but [excluding] those that merely respond to water, such as the life cycle of aquatic organisms." Baird and Wilby [1999] review eco-hydrology's connection to ecology. Possibly the first published instance of the term "eco-hydrology" appeared in reference to bogs and mires [Ingram, 1987].

Why is this field called eco-hydrology rather than hydro-ecology? Is it that eco-hydrology is concerned more with the ecologically-related aspects of hydrologic science, and hydro-ecology with the hydrologic aspects of ecology? These two terms are sometimes used interchangeably. In both disciplines, eco-hydrology is used generally to refer to topics at their interface. Hydro-ecology is used more restrictive fashion, in reference either to the study of hydrologic and hydraulic characteristics of river and stream ecosystems, or sometimes, to the area known as aquatic ecology in the United States.

### Scope of Eco-hydrology

Until recently, the term eco-hydrology had been applied to a few distinct areas of interdisciplinary study. No one has yet attempted a comprehensive description of the sub-discipline, which potentially encompasses the entire biosphere. The IHP identifies eco-hydrology with a new paradigm for sustainable management of water resources [Zalewski *et al.*, 1997]. Even so, it seems unlikely that a single unifying paradigm could cover the range of water-mediated interactions between biotic components of all ecosystems and their abiotic environments. It is more likely that eco-hydrology, the science, will embrace the formulation, testing, and application of conceptual models to describe these interactions within specific constraints of scale and geomorphic setting. Some of these are described below.

Readers of *Eos* may be familiar with Peter Eagleson's work on the eco-hydrology of water-limited ecosystems [Eagleson, 1978, 1982], which Rodriguez-Iturbe *et al.* [2001] have recently taken up and extended. Eagleson's approach represents dynamics of the terrestrial water balance at a point in terms of a spatially aggregated reservoir of soil moisture responding to a stochastic climate. Soil properties and the varying moisture content of the soil control the partitioning of rainfall between infiltration and runoff. Vegetation controls the loss of soil moisture by evapo-transpiration, but evaporation and drainage by percolation also occur. Eagleson's model explicitly excluded the effects of lateral flows and interactions between soil moisture and a shallow water table. In spite of this underlying simplicity, Eagleson's investigations generated fundamental insights into the relationship among the dynamic and interdependent properties of soil, vegetation, and climate [Hatton *et al.*, 1997].

Research on wetlands has played a central role in the development of eco-hydrology in Europe and the United Kingdom [Baird and Wilby, 1999]. Hydrologic and ecological processes are intimately connected in wetlands, and their interaction has consequences not only for these ecosystems, but also for the functions they serve on larger scales. For example, water, ice, and permafrost constitute an important component of the organic soil formed in the extensive wetland regions found at high latitudes in the Northern Hemisphere. The interaction of hydrology and ecological processes involved in soil diagenesis influences stream flow, water quality, and geomorphology in the local drainage basin and the carbon cycle and climate on a global scale. Under a warming climate, these soils will thaw, dry, and oxidize, releasing stored carbon back into the atmosphere [Gorham, 1991].

Groundwater, surface water, and sediment transport interact to influence the structure and functioning of river and stream ecosystems. These ecosystems comprise distinctive channel and flood plain geomorphic components that are physically shaped by stream flow and sediment transport [Petts and Bradley, 1997]. Cycles of flood and recession modulate ecological interactions between the channel and the adjacent margin, as well as maintain their characteristic morphology. Groundwater exchange with the channel establishes base flow and influences temperature of the surface water. As well, groundwater mediates the exchanges of solutes laterally between channel and flood plain and vertical exchanges between water flowing in the channel and subsurface water in the hyporheic zone. At the scale

of the entire basin, the equilibrium structure of river and stream ecosystems varies predictably from headwaters to mouth, as described by the river continuum concept of Vannote *et al.* [1980]. This hypothesis and its corollaries have proven useful in understanding the natural, undisturbed state of river ecosystems and the response of these systems to human activities that affect stream flow and sediment movement.

As a final example, consider the influence that river flow and its variation exert on estuarine and near shore ecosystems. Although the mechanisms involved are not yet fully known, empirical evidence links the rate of fresh water discharge to the productivity of estuarine and coastal fisheries. Certainly, the supply of nutrients carried in the discharge is part of the story [National Research Council, 2000]. But, just as flow and sediment discharge interact to determine the geomorphology of river and stream ecosystems, freshwater discharge and internal mixing processes interact to determine the salinity regime, stratification of the water column, and circulation characteristic of each estuary. Changes in hydrology derived from climate and human activities on the watershed have both long- and short-term effects on coastal ecosystems. Long-term effects include changes to the rate of sediment accretion that is necessary to maintain the stability of the coastline in low-lying areas [Working Group on Sea Level Rise and Wetland Systems, 1997]. Short-term effects include changes in fishery yields [Loneragan and Bunn, 1999] and overall structure and productivity of the food web [Livingston *et al.*, 1997].

### **Eco-Hydrology's Past**

The recent flurry of interest in eco-hydrology signals its emergence as an area of focused study, but eco-hydrology is rooted firmly in the history of the hydrologic and ecological sciences. Eagleson's work on the equilibrium relationship among climate, vegetation, soil properties, and the water balance builds on concepts established in much earlier investigations of water flow in soil and plants [Honert, 1948] and the relationship between climate and soil moisture [Thorntwaite, 1948]. Petts and Bradley [1997] and Gurnell *et al.* [2000] trace the roots for eco-hydrology of river and stream ecosystems to work on the form and evolution of channels, stream networks, and catchments performed in the 1950s and 1960s. Investigations into hydrologic constraints on ecosystem structure in wetlands date back at least 50 years to Wickman's [1951] work on the equilibrium morphology of raised bogs. The pervasive influence of hydrology on

estuarine and coastal ecosystems perhaps first came to light through studies in the 1960s that demonstrated a correlation between fish abundance and river runoff (that is, papers cited in *Skreslet* [1985]).

Along each of these roots, the integration of concepts and measurements from different disciplines has served a valuable synthetic function that has advanced the disciplines of hydrology and ecology. Some mechanism for synthesis is required in the study of complex, natural systems as a counterweight to the reductionist approach predominant in the hydrologic and ecological sciences [*Hatton et al.*, 1997; *Dunne*, 1998]. The ecological optimality hypothesis, for which Eagleson was recognized with award of the Stockholm Water Prize in 1997, serves this function by providing testable theory for the interdependence of soil properties, vegetation, and partitioning of water budget components. Similarly, river continuum concept provides a testable theory for the spatial variation in the structure and functioning of river ecosystems. Eagleson achieved synthesis directly through the formal analytical framework of statistical mechanics. The river continuum concept provides a hypothesis around which synthesis has occurred through observations and analysis across a number of systems. In both cases, an intuitive insight into the behavior of the whole system has been tested and validated through the integration and analysis of concepts and observations from both hydrology and ecology.

### **Eco-hydrology's Future**

Finding solutions to practical problems has driven the development of hydrological science throughout its history. Most of these problems have been related to the management of water, agriculture, or related natural resources. The relatively recent recognition of hydrology as a distinct geoscience acknowledges a more question-driven, scientific approach to hydrologic research that has taken hold in the last 30 years or so [*National Research Council*, 1991]. This is a significant milestone in the maturation of the discipline. Understandably, recent assessments of hydrological science emphasize progress that has been made in "scientific" hydrology and the challenges still ahead [*National Research Council*, 1991; *Dunne*, 1998]. However, recent years have also seen dramatic changes in the goals set for water management and the type of information that managers need to achieve these goals. These changes create new demands on hydrologic science and new opportunities, albeit in the traditional area of "engineering" hydrology [*Nuttle*, 1999].

For example, the Water Resources Development Act (WRDA) adopted by the U.S. government in 2000 approves a 40-year public works program that directs water managers to first "restore, preserve and protect the South Florida ecosystem" before pursuing other, traditional goals for water management in the region. This continues a trend in resource management toward adopting broad ecosystem or watershed goals that began with passage of the U.S. National Environmental Policy Act (NEPA) in 1969. Whereas NEPA only committed government agencies to harmonizing their activities with environmental protections, WRDA 2000 sets goals that are more specific and demanding. Water managers in South Florida are now accountable for improving and preserving ecological functions in a natural system that is as yet imperfectly understood and only partly in their control.

Eco-hydrology addresses both the practical needs related to these new, expanded goals for water management and the natural drive of scientists to better understand the water cycle as a component of the biosphere. Thirty years ago, the goal of conserving nature motivated a few ecologists to begin studying the interaction of hydrologic and ecological processes in wetlands, streams, and rivers. This work continues today under the heading of eco-hydrology [*Baird and Wilby*, 1999]. Given the stakes, it seems certain that the need to sustain natural resources will continue to drive the development of the applied aspects of eco-hydrology. At the same time, eco-hydrology has come to be recognized as a fruitful topic of study within "scientific" hydrology [*Hatton et al.*, 1997; *Rodriguez-Iturbe*, 2000]. For these and other reasons, it appears that previously unrelated areas of scientific inquiry are now coming together. This heralds a promising future for eco-hydrology!

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