Watershed Science: A New Frontier for Research

Arthur J. Gold, Professor
Department of Natural Resources Science
Peter M. Groffman, Scientist
Institute of Ecosystem Studies

We are on the verge of a new frontier in watershed science. Watersheds are now recognized by local, state, and federal decisionmakers as natural units that bind and integrate seemingly disparate lands, communities, and ecosystems. In the near future, we can expect to see an increase in the deliberate coordination of watershed activities with the expectation of measurable improvement in the value or function of a particular watershed. This new recognition of the value and importance of the watershed approach represents a huge challenge to scientists. Over the next decade or so, scientists who study processes at a watershed scale (watershed scientists) will be called upon to provide solutions to real and complex problems using the tools and knowledge that have been developed over the last 30 to 40 years of watershed research.

It will not be easy to find these solutions. Nitrogen delivery to coastal waters provides an excellent illustration of the complexity of environmental science and management and shows how environmental problems require multidisciplinary solutions. Because these problems are created and driven by human behavior, our solutions are ultimately constrained by human values and decisions that are difficult to predict and manage.

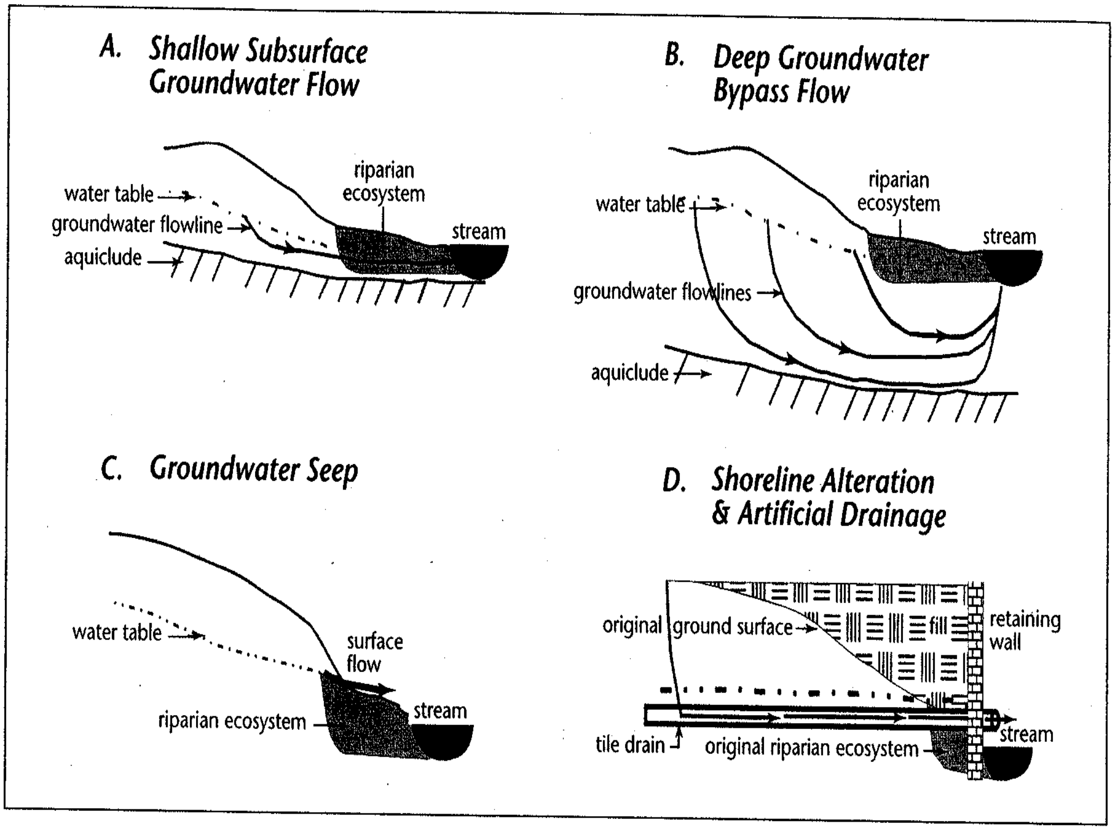
A major focus of estuarine managers is the control and reduction of nitrogen from coastal watersheds. In the Chesapeake Bay, Puget Sound, and Rhode Island's salt ponds, nitrogen inputs from the watershed degrade water quality. The nitrogen generates excessive algal blooms that create a cascade of events resulting in depletion of dissolved oxygen, buildup of organic deposits, and a loss of valuable aquatic habitat. At first glance, it would appear that scientists and managers have a simple and forthright method to evaluate the outcome of their watershed nitrogen control strategies. We can measure the changes in nitrogen output of estuarine tributaries in relationship to changes in management.

However, watersheds continue to baffle us. In a recent study, Thomas Jordan and his colleagues at the Smithsonian Environmental Research Center in Edgewater, Maryland, examined nitrogen inputs and outputs from 17 small (100 to 2,000 hectares) subwatersheds that contribute to the Chesapeake Bay. Although they found that nitrogen discharge increased as the anthropogenic input of nitrogen to a watershed increased, they could not determine the fate of 70 to 85 percent of the nitrogen

---

Art Gold's *research focuses on coastal watersheds and water quality, in particular, the role of riparian wetlands on the export of nitrate from coastal watersheds. As head of URI's Cooperative Extension Water Quality Program, he oversees community-based watershed education.*

Peter Groffman *is a terrestrial microbial ecologist at the Institute of Ecosystem Studies in Milbrook, New York. His research interests include nutrient cycling and transformation of environmental pollutants in wetlands, forests, agro-ecosystems, and groundwater.*



Tracking Water Movement. *Groundwater flow paths through riparian ecosystems can control the delivery of watershed nitrate to streams. A) In shallow aquifers, high nitrate removal can occur as groundwater moves at shallow depths through a riparian ecosystem. B) In deep aquifers, low nitrate removal may occur as groundwater flows below the biologically active zone of a riparian ecosystem. C) Where groundwater emerges as surface seeps, little nitrate removal may occur due to rapid surface flow across the riparian ecosystem. D) With filling and artificial drainage, nitrate removal is very limited as groundwater bypasses the riparian ecosystem.* Illustration by A. Rosenblatt, URI Department of Natural Resources Science.

that entered those watersheds. The investigators suggested that the nitrogen they could not account for might have been removed by or stored in plants, soil, groundwater, and riparian wetlands, and that some of the nitrogen might be residing in groundwater that was slowly moving towards surface waters.

Why all the mystery about nitrogen in these watersheds? Watersheds suffer from non-uniqueness, a mathematical modeling term used to describe situations where a particular outcome can result from a multitude of input scenarios. At a river mouth, the nitrogen in a single gallon of water may originate from a variety of places and at different times. The water may contain nitrogen that entered the watershed from human or animal waste, precipitation, or fertilizer. The nitrogen pool may contain atoms that have resided within the watershed for widely different time periods. Some of the nitrogen may have entered the watershed as precipitation on streets or sidewalks that drain directly into storm drains and then traveled to a river mouth within hours or days. Other nitrogen may have entered the water from septic system effluent and then traveled through the groundwater for years before emerging as springflow that feeds streams and rivers.

The nonuniqueness of watersheds compels watershed scientists to grapple with the cohesiveness of the land areas that they study and manage. We work to define the major sources of specific materials, we identify the flow paths of those materials (which might include infiltration to the groundwater, overland runoff, or interaction with wetlands), and we investigate the fate and transformations that occur as a specific constituent moves from its source to its final outlet at the sea. In our watershed research, we examine the role of landscape setting on nitrogen removal capacity of riparian wetlands. Our research integrates several landscape attributes, including geomorphology, hydrology, and soils. We conduct process-level studies to examine how and why groundwater nitrate is altered within the biologically-active, saturated soil in a riparian zone. We then couple our process-level information with estimates of groundwater flow paths to evaluate the role of riparian zones at the watershed scale. (See illustration at left.) The challenge is to identify the mix of attributes that generate effective nitrogen retention zones and incorporate them into management support tools that have relevance beyond the specific watersheds that we study.

When confronted with the variability and uncertainty generated by the interactions of localized phenomena, scientists often move to a coarser scale of evaluation to find order and meaningful relationships. We find that nitrogen export to a coastal estuary is related to human and animal population densities within a watershed. However, stepping back to a coarser scale of resolution is no help to watershed decision makers who demand finer scales of analyses. They target their activities to specific locales or land-use types to maximize the effect on a given watershed value or function. If the goal is to reduce nitrogen export to coastal waters, how do we balance restoring riparian buffers with upgrading septic systems and reducing atmospheric deposition? Can scientists identify landscape characteristics that result in hot spots of nitrogen pollution? Can we identify natural features that have great potential to remove nitrogen? Can we manage certain vegetated ecosystems to store nitrogen for decades or longer? Most importantly, can we create and test models that demonstrate the linkages between source areas that contribute nitrate to the watershed and sink areas that remove nitrogen from the watershed? And finally, how can we get people to institute the solutions that scientists and land managers develop?

Watershed science in 1999 is analogous to smoking research in 1969. In 1969, researchers knew in a broad sense that smoking was bad and that people shouldn't do it, just as we know today that there are strong links between specific human activities and nitrogen delivery to coastal waters. However, in 1969 we could not describe the specific mechanisms that damaged human health, just as we cannot account for the specific fate of nitrogen in watersheds today. And most importantly, we couldn't, and still can't, figure out how to get people to stop smoking, just as we can't get people to implement effective nitrogen controls. The same interplay of scientific knowledge, values, economic interests, and behavior that make smoking cigarettes a complex problem, are the same issues that complicate watershed management. This complex interplay suggests that watershed science will be exciting and challenging for several decades to come. ■