Nitrogen and Coastal Ecosystems: The Role of Watershed Science

Arthur J. Gold, Professor, Department of Natural Resources Sciences

Research conducted at the University of Rhode Island during the last 15 years has shown that there is a direct relationship between the addition of surplus nitrogen to coastal waters and water quality. Scott Nixon, professor, Graduate School of Oceanography, and Marilyn Harlin, professor, Department of Biological Sciences, demonstrated in separate experiments that the addition of nitrogen can stimulate excessive growth of marine algae and cause subsequent fouling of fish spawning habitats. These findings alarmed Rhode Island's Coastal Resources Management Council (CRMC), which initiated a series of control strategies designed to minimize the contribution of nitrogen from lands that drain into coastal waters.

To ensure the effectiveness of the management measures, CRMC and other coastal managers need to know just where this land-derived nitrogen comes from and how it enters coastal waters. Surface runoff and groundwater discharge from the watershed are the primary conductors of nitrogen that enters coastal waters, but it is not clear where nitrogen originates within the watershed.

My graduate students and I work with other terrestrial scientists to identify and control sources of nitrogen in coastal watersheds. We are interested in documenting the amount of nitrogen added to or removed from a watershed and in understanding the underlying mechanisms and processes that control the fate of nitrogen within a watershed. We are evaluating the short-term and long-term effects that different management activities have on the release or removal of nitrogen through process-level research.

Most nitrogen leaves a particular site in a watershed, such as a fertilized field or a septic tank, in the form of the highly mobile nitrate ion. By nature, nitrate moves through soil and into the groundwater. Once in deep groundwater, nitrate either moves directly into coastal waters or into coastal tributary streams and is subsequently discharged into coastal waters. Agricultural lands, home lawns, and residential developments without sewers are potential sources of nitrogen to coastal waters because fertilizers, animal waste, and septic system leachate contain high concentrations of nitrogen. Knowing this is not enough, however. A number of key research questions must be answered before managers can define the best strategies for protecting coastal ecosystems from nitrogen enrichment. Some of the questions we have been trying to answer are:

- What is the magnitude of nitrogen contamination associated with different types of land use found in coastal watersheds of southern New England?
- How can we use new technologies to minimize nitrogen contamination?
- Are there certain portions of the watershed that have the capacity to remove nitrate?
- Can we describe the underlying processes responsible for the fate of nitrate in coastal watersheds?

William Sullivan, associate professor, Department of Plant Sciences, and I addressed the question of the magnitude of nitrogen contamination from different types of land use, with funding from the Soil Conservation Service of the U.S. Department of Agriculture. We quantified and ranked the nitrogen contributions to groundwater

***Art Gold** received his B.S. (Natural Resources) and his M.S. (Water Resources) from the University of Michigan. He earned a Ph.D. in Agricultural Engineering from Michigan State University and came to URI in 1983. In addition to watershed research, he teaches hydrology and soil physics and coordinates the Cooperative Extension Water Quality Outreach Program.*

from common uses in southern New England—home lawns, septic systems, forests, and agriculture. Our study sites were located on similar soil types within a 6km radius of Kingston, Rhode Island. To avoid contamination from other land use practices, we developed a groundwater leachate method now used by researchers throughout the Northeast. Using this method, we sampled leachate following all precipitation events over two years (see Table 1).

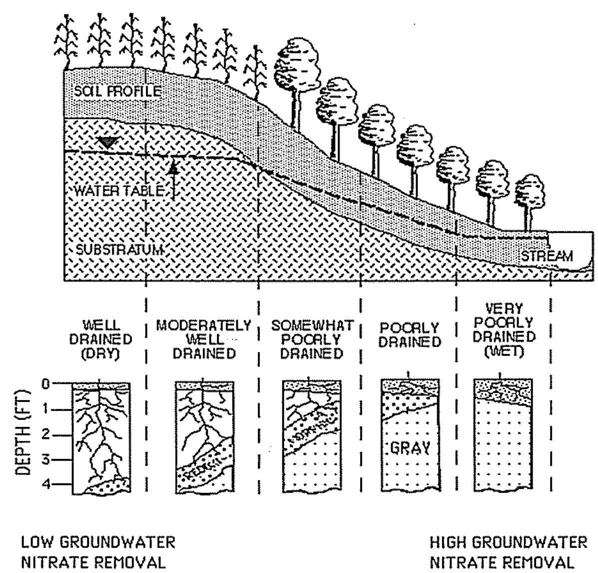
We showed that septic systems and row-crop agriculture are the leading sources of nitrogen entering groundwater in southern New England. Furthermore, our results suggest that the nitrogen contributions to coastal watersheds would increase if the mosaic of old fields, agriculture, and forests were to be replaced with moderate-density residential developments in which individual homes relied on conventional septic systems. We were surprised to discover that home lawns generate little loss of nitrate to groundwater, even when fertilization rates were as high as in row crops which generated substantial nitrogen losses. Follow-up studies with my URI colleague Peter Groffman, associate scientist, who is now at the Institute of Ecosystem Studies in Millbrook, New York, revealed that the dense, perennial growth of lawns actually enhances microbial cycling and retention of nitrogen. Thus, barring a prolonged disturbance such as intense urbanization, lawns actually represent a long-term storage location for nitrogen. Coastal managers can use the information from these studies to focus their management efforts on the control of pollution from septic systems and agricultural practices.

Table 1. Nitrate Losses to Groundwater from Rural and Suburban Land Uses.

Land Use	Nitrogen Added to Surface Soil (kg/ha/yr)	Nitrogen Lost to Groundwater (kg/ha/yr)
Forest (from precipitation)	10	1.3
Fertilized Lawns	244	6.0
Silage Corn	202	75.0
Septic Systems (half-acre zoning)	60	47.4

Several innovative septic system designs were proposed during the last decade to respond to concerns about nitrate contamination. Although these systems incorporated accepted theories on nitrate removal into their design, replicated, long-term field studies were needed to evaluate their performance in the soils and climate of southern New England. George Loomis, research associate, Department of Natural Resources Science, and I, with support from Rhode Island's Sea Grant Program, constructed a field laboratory consisting of smaller replicas of many of these septic system designs at Peckham Farm at URI. We conducted studies on nitrogen removal by systems built at one-fifth to one-third of full scale. Several systems were found to have the potential to remove substantial quantities of nitrogen, as well as microbial patho-

Table 2. Soil Drainage Class as a Method to Identify Nitrate Removal.



gens, from wastewater.

Coastal managers throughout the country are using the findings of this research to formulate policies for alternative wastewater disposal systems in their communities. For example, CRMC requires that newly constructed septic systems remove at least 50 percent of the nitrate in wastewater before it enters the environment. Our research spawned the development of URI's Onsite Wastewater Training facility, a partnership between URI, federal, state, and municipal agencies, and a number of private companies. Eleven types of innovative wastewater treatment systems were constructed above ground to be used for training and system evaluation. The training program, coordinated by Loomis, is unique to the Northeast and stresses realistic solutions to coastal water quality problems. More than 500 professionals have attended short courses in the past year.

Nitrate also may be removed naturally by the environment before it reaches coastal waters. During the past six years, Groffman and I studied the role that natural riparian areas—forested lands bordering surface waters—play in removing nitrate that enters groundwater from upland activities. We were funded by the U.S. Department of Agriculture and the Narragansett Bay Project. Groundwater often enters the biologically active root zone of riparian areas before it discharges into surface waters such as lakes, ponds, or streams. Under the right conditions, nitrate can be removed by plant/microbial activity. To distinguish between actual removal and dilution or dispersion that typically occurs within groundwater, we studied the fate of introduced plumes of nitrate and a "conservative" tracer, a chemical that is not affected by biological or chemical processes. We found that soil wetness (drainage class) is a good predictor of the capacity of riparian zones to remove nitrate from groundwater (see Table 2).

Riparian zones with very poorly drained soils do a good job at removing nitrate from groundwater, while drier, moderately well-drained soils may allow most of the nitrate in groundwater to proceed to adjacent surface waters. We are exploring the relationships among site characteristics such as soil drainage class, depth to groundwater, and nitrate removal rates. This promising approach may assist coastal managers to identify critical riparian areas for preservation and focus their pollution abatement programs on upland locations with a high potential for delivering unwanted nitrate to coastal waters.

The nitrate problem is far from solved. Additional important research topics include variation in climate, changes in nitrate concentrations of rainfall, and the long-term response of terrestrial ecosystems to nitrogen additions. But the watershed studies that we conduct demonstrate that nitrate pollution in coastal areas may begin miles away in seemingly unconnected land-use areas. Our findings affect coastal policy, although not always in straightforward ways. While fashioning viable policies, managers must take into account the political and economic realities of their communities and incorporate the scientific findings.

An increasing number of former graduate students trained in watershed science at URI are in management positions at agencies involved with major coastal areas such as Puget Sound and, of course, Narragansett Bay. Their knowledge of research on watershed processes, combined with their influence as professional coastal managers, creates a powerful medium for watershed science. In this most pervasive fashion, watershed research finds its way into coastal policy through the fundamental role that the University plays in training the next generation of decision makers.

Recommended Reading

Gold, A.J., W.R. DeRagon, W.M. Sullivan, and J.L. LeMunyon. (1990). Nitrate-nitrogen losses to groundwater from rural and suburban land uses. *Journal of Soil and Water Conservation, 45,* 305-310.

Gold, A.J., B.E. Lamb, G.W. Loomis, J.R. Boyd, and V.J. Cabelli. (1992). Wastewater renovation in buried and recirculating sand filters. *Journal of Environmental Quality, 21,* 724-729.

Nelson, W.M., A.J. Gold, and P.M. Groffman. (1995). Spatial and temporal variation in groundwater nitrate removal in a riparian forest. *Journal of Environmental Quality, 24,* 691-699.