Invited Feature

The Land–Water Interface: Science for a Sustainable Biosphere[1]

This Invited Feature examines one of the major challenges of the 21st century: *How can we better manage the land–water interface to meet the increasing demands of a burgeoning global human population, while at the same time protecting aquatic ecosystems and the ecological services that they provide?* Here we explore the magnitude of this challenge and make recommendations for science-based management. How can science be more effectively used to develop guidelines to mitigate the widespread deterioration of natural ecosystems from hydrologic modifications, nutrient and organic loading, or the more cryptic effects of hormone-disrupting chemicals?

The papers that follow are based on presentations made at a national conference entitled "The Land–Water Interface: Science for a Sustainable Biosphere," sponsored by the American Society of Limnology and Oceanography and the Ecological Society of America. The first four papers provide an overview of the magnitude of various water resource problems. The last four papers are site oriented and provide case studies of how science and research can provide a foundation for effective management of the land–water interface.

Sandra Postel, highly acclaimed author of the *Last Oasis* and *Pillar of Sand* starts off by summarizing the magnitude of water scarcity on a global scale. She proposes a global effort to ensure that freshwater ecosystems receive the quantity, quality, and timing of flows needed for them to perform their ecological functions. She encourages society to work toward the goal of doubling "water productivity" over the next three decades by getting twice as much benefit out of each unit of water extracted from natural systems.

Theo Colborn (well known for her provocative book *Our Stolen Future*) and Kristina Thayer provide a synthesis of the threats posed by hormone-disrupting chemicals in the environment. The authors show how aquatic ecosystems have served as harbingers of endocrine disruption. Top predators in the Laurentian Great Lakes and other aquatic systems across the globe have served as proverbial canaries in the coal mine, by indicating transgenerational developmental effects of organochlorine chemicals which involve functional alterations of organ systems rather than overt toxicity. Some of these effects are now being documented in human populations.

Robert Naiman and Monica Turner explore the status and trends in alterations to freshwater ecosystems and discuss their ecological consequences over the next few decades, with a primary focus on the United States. They discuss major categories of change including human demography, resource use, patterns of water consumption, technology development, and social organization. The importance of understanding the variety and magnitude of environmental changes is stressed, along with how these changes interact to produce new environmental states and the need to resolve specific environmental and societal issues as they arise.

Catherine Pringle focuses on how U.S. public lands are increasingly affected by human alteration of hydrologic connections outside of their boundaries. Cumulative effects of dams, impoundments, regulated flows, and groundwater extraction outside of public land boundaries are increasingly affecting the hydrology and biological integrity of these areas. Recommendations for more effective management of hydrologic connections across public land boundaries range from establishment of more stream gaging stations to the development of science-based tools (to predict cumulative impacts and interactions between hydrologic alterations and other outside threats).

Garth Redfield focuses on the relationship between science and resource management in the Kissimmee-Okeechobee-Everglades ecosystem of South Florida. He shows how science is being

[1] Reprints of this 117-page Invited Feature are available for $17.50 each. Prepayment is required. Order reprints from the Ecological Society of America, Attention: Reprint Department, 1707 H Street, N.W., Suite 400, Washington, DC 20006.

used successfully in adaptive management and restoration. A diversity of scientific projects have contributed to general wetland science, ecosystem modeling, and restoration ecology, while providing a sound foundation to support decision making. Redfield stresses the critical need for effective communication of research findings and enhanced interaction between scientists and managers in planning.

The last three papers focus on land–water interfaces in developed coastal areas. Howard Glasgow and JoAnn Burkholder present their research on the poorly flushed, eutrophic Neuse River and Estuary in North Carolina which is characterized by nuisance algal blooms, hypoxia, toxic dinoflagellates, and fish kills. The authors use state-of-the-art technology to improve estimates of volume flow in calculating nutrient loads. They stress the importance of long-term decadal data sets in assessments of fluctuations in algal production and relationships with nutrient inputs in the Neuse River system and elsewhere. Moreover, in the context of global increases in human population in coastal regions, they recommend that management goals for nutrient reduction be interpreted as "moving targets" that will require adjustments every 5–10 years in order to reduce negative environmental impacts.

Michael Mallin and Kathleen Williams focus on patterns of distribution of enteric bacteria in five estuarine streams that are located in southeastern North Carolina and have been closed to shellfishing since the early 1990s because of increased enteric bacterial counts. Patterns in fecal coliform abundance among streams appear to be controlled primarily by degree of watershed development. Results indicate that waterborne human health risks in urbanizing coastal areas can be minimized by environmentally sound land use planning and watershed development which minimizes the use of impervious surface, while maximizing passive water treatment function of "green" areas such as wetlands.

Ivan Valiella and colleagues illustrate how ecologically and socially sustainable plans for the management of coastal watersheds can be designed in Waquoit Bay, Massachusetts. The authors propose that the biomass and production of biotic components such as phytoplankton, macroalgae, and eelgrass are suitable end point measures of nitrogen loading rates within watersheds. Once the relationship of agent of change vs. end point measures are defined, policy makers and stakeholders can decide which critical end point is desirable or acceptable. This example shows how a process of decision making can be used that is based on current scientific results while incorporating stakeholder concerns.

Taken together, these eight contributions illustrate the extent and magnitude of human alteration of the land–water interface and point to the critical need for more effective management. Cumulative effects of human activities have resulted in ecosystem deterioration on a global scale, to the extent that many remnant natural ecosystems found in parks and wildlife refuges are threatened. As an integral part of the biosphere, humans are increasingly vulnerable to these cumulative effects. On a societal level, this is evidenced by the increasing incidence of political instability that is caused by water scarcity and pollution. Our health, development, and reproduction are affected, on both contemporary and evolutionary time frames, by factors ranging from acute effects of pathogens and toxic elements in the water that we drink to the more insidious effects of hormone-disrupting chemicals (which have been found to cause developmental and neurological damage in human offspring at or slightly above ambient concentrations in the industrialized world). This invited feature illustrates the importance of science-based management, policy, and technological development. We hope that this series of papers will stimulate multidisciplinary efforts that will allow us to better manage the land–water interface.

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