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2001 Water and Watersheds Progress Review

April 17-19, 2001
San Francisco, California

NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH

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Introduction

The Environmental Protection Agency/National Science Foundation/United States Department of Agriculture (EPA/NSF/USDA) Water and Watersheds competition is one of four special extramural awards competitions supported by the EPA and the NSF under a partnership for environmental research initiated in 1994. USDA began sponsorship of the program during the 1998 competition.

The Water and Watersheds competition emphasizes interdisciplinary research that adopts a systems approach to water and watershed issues. The goals are to: (1) develop an improved understanding of the natural and anthropogenic processes that govern the quantity, quality, and availability of water resources in natural and human-dominated systems; and (2) improve the understanding of the structure, function, and dynamics of terrestrial and aquatic ecosystems within watersheds.

The 1995 Water and Watersheds competition reviewed 656 proposals and made 36 awards. In 1996, the focus was narrowed to truly interdisciplinary research, and as a result, the 1996 competition reviewed 249 proposals and made 12 awards. The announcement was narrowed further in 1997, primarily in response to concerns about the competition's low rate of proposal success. Proposals were required to integrate physical, ecological, and social science research. For the first time, investigators were encouraged to adopt a community-based approach. The 1997 competition, with an emphasis on urban/suburban research, reviewed 128 proposals and made 13 awards. In 1998, the topical emphasis shifted to watershed restoration, a total of 125 proposals were reviewed, and 14 awards were made. In 1999/2000, an additional 12 grants were funded.

The abstracts in this volume are organized alphabetically within three sections that correspond to the year of award and reflect all active grants. The most recent awards (FY 1999/2000) appear in the first section. These projects have only 1 year of research to report, and consequently, these abstracts indicate goals and plans rather than results. The FY 98 cohort of projects appears next. These abstracts report early findings and describe plans for future years. The projects that were initiated with FY 97 support are in the third section and will report results based on several years of research.

Progress reviews, such as this one, will allow investigators to interact with one another and to discuss progress and findings with program officers and other federal officials interested in the program.

Any opinions, findings, conclusions, or recommendations expressed in this report are those of the investigators who participated in the research and in the Progress Review meeting, and are not necessarily those of the EPA, the NSF, or the USDA. For further information on the EPA/NSF/USDA Water and Watersheds competition, please contact the Program Coordinators: Ms. Barbara Levinson, EPA, levinson.barbara@epa.gov; Dr. Douglas James, NSF, ldjames@nsf.gov; and Dr. Michael O'Neill, USDA, moneill@reeusda.gov.

Section 1.

Projects Initiated With Fiscal Year 1999/2000 Support

The Impact of Lawn Care Practices on Aquatic Ecosystems in Suburban Watersheds

Kevin L. Armbrust[1], Larry Shuman[1], Judith Meyer[2], Marsha Black[3], Raymond Noblet[4], Andrew Keeler[5], Ted Gragson[6], James B. Williams[7], and Dee West[8]

[1]Department of Crop and Soil Science, University of Georgia, Griffin, GA; [2]Institute of Ecology, [3]Department of Environmental Health Sciences, [4]Department of Entomology, [5]Department of Agricultural Economics, [6]Department of Anthropology, University of Georgia, Athens, GA; [7]Peachtree City Developmental Services, Peachtree City, GA; [8]Alpharetta Environmental Services, Alpharetta, GA

The working hypothesis of this project is that homeowner beliefs, values, and socioeconomic status will determine loads and ecological impacts of turf-care chemicals (pesticides and nutrients) in aquatic ecosystems in suburbanized watersheds. The objectives of this research project are to: (1) measure the loading to streams and temporal trends in concentrations of turf-care products and biological indicators of stream ecosystem health in creeks receiving stormwater drainage from residential neighborhoods with different socioeconomic statuses; and (2) compare the cultural models of lawn and lawn care held by "experts" and "homeowners" to determine their points of commonality and divergence, and establish the nature of variation.

This investigation integrates the physical, ecological, and social sciences to understand the impacts of residential lawn care chemicals on aquatic ecosystems at six locations in Metropolitan Atlanta as well as at two locations on a golf course. A team of university researchers and community-based stream monitoring programs will monitor pesticide and nutrient loads leaving residential neighborhoods and residue levels in receiving water and sediment of streams (physical/chemical); monitor aquatic organism populations and multiple biological indices in these streams to determine the impact of lawn care practices (ecological); and work with selected homeowners in these neighborhoods to understand their general beliefs and values of lawns and the lawn care practices they display to assess the impact "expert" groups have in forming these beliefs (social).

Confirmatory laboratory investigations of biological effects from individual and multiple stressors will provide added confidence that observed instream toxicity can be tracked to a particular chemical or chemicals. The results of this research will be communicated to interested citizens via research exhibits and educational materials produced by community-based environmental protection programs.

During the past summer, the State of Georgia has experienced one of its worst droughts on record, and extreme water restrictions were placed on the irrigation of both golf courses and residential lawns. However, water and sediment samples collected on a monthly basis since July have contained detectable residues of pesticides and pesticide degradation products associated with landscaping as well as nutrients at all sites. Effects thus far observed in leaf pack decay rates and mussel biological indices have not been found to be different between creeks draining suburban areas and reference creeks.

Laboratory testing has indicated that certain insecticides detected in the streams were more toxic to black fly larvae and to mussels in mixtures than when added individually. Preliminary data from surveys of homeowners have shown that the demographics of the study location are typical of most other communities of similar sizes in the Metropolitan Atlanta area.

Due to drought conditions there were few rainstorms, generating virtually no runoff events during the periods of highest lawn care chemical use, which is atypical of what would occur in a normal year. The levels of the pesticides and nutrients detected were below any level of concern, and no significant effects were observed in any organism. Most impacts to leaf-degrading fungi in different streams were attributed to leaf pack burial by sediment.

Monthly sampling of water for pesticides and nutrients and sediment for pesticides and metals will continue during the coming year, as will additional field monitoring experiments with mussels, aquatic insects, and leaf packs. Additionally, storm event sampling will occur, and more detailed surveys of individual homeowner lawn care practices will be conducted. Select homeowners will be keeping lawn care diaries, and followup surveys will be conducted to assess homeowner lawn care attitudes and practices.

PULSES—The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Louisiana

***John Day*[1]*, Jaye Cable*[1]*, Dubravko Justic*[1]*, Brian Fry*[1]*, Paul Kemp*[2]*, Enrique Reyes*[1]*, Paul Templet*[3]*, and Robert Twilley*[4]**

[1]Department of Oceanography and Coastal Sciences, [2]Center for Coastal, Energy, and Environmental Resources, [3]Institute for Environmental Studies, Louisiana State University, Baton Rouge, LA; [4]Department of Biology, University of Louisiana, Lafayette, LA

Riverine inputs to coastal wetlands, floodplains, and marshes are important to long-term ecological productivity and development of watershed resources. In many cases, levees and dams constructed during the past 100 years have effectively isolated rivers from their natural connections to adjacent floodplain and deltaic wetlands. To help revitalize these productive systems, the ecological restoration of historical river-floodplain connections is being attempted.

The PULSES Project focuses on evaluating the effects of pulsed river inputs in one such coastal watershed, the Breton Sound Watershed, just south of New Orleans. In this area, Mississippi River water is introduced through gated river diversion structures at the head of the estuary at Caernarvon, LA. Diversions have been ongoing for a decade (since 1991) at Caernarvon, but have received little scientific attention and study.

The physical science objectives of this research project are to evaluate marsh accretionary responses to two different levels of river pulsing, 1x (14 m^3/s) and 13–16x (184–227 m^3/s). The diversions will be experimentally conducted in 2-week episodes within the winter/spring operating schedule of the Caernarvon structure that is controlled by the Louisiana Department of Natural Resources. Figure 1 shows replicated high flow and low flow diversions scheduled for the winter and spring of 2001; similar diversions are planned in 2002. In addition to marsh accretion studies, historical down-core studies will evaluate the effects of the great 1927 flood event (approximately 650x base flow of 14 m^3/s) at this site.

The ecological science objectives are to evaluate marsh and phytoplankton plant growth responses to river pulses, and to evaluate marsh nitrogen nutrient removal via denitrification. Stable isotope studies will assay effects of river pulses on recreational and commercial fisheries of this area.

The social science objectives are to make linkages between the human and natural systems more understandable in three separate modeling efforts: landscape simulation modeling, multicriteria analysis, and cost/benefit economic analysis.

To document the effects of physical pulsing on the overall ecosystem dynamics of this area, the experimental treatments of high and low river input diversions are being used. The research group is taking advantage of natural storm and tide “pulse treatments.” Human reactions to natural pulsing (flooding) usually are negative, and the various planned modeling interfaces will explore minimizing negative effects while maximizing positive effects of natural flood events.

The field program began in the fall of 2000, and some indication of moderate to high chlorophyll levels has been found in the fresher bays and lakes in the upper end of the estuary most impacted by the diversion. State and federal agencies are monitoring results of this project closely for possible management implications. The first main field season began in January 2001.

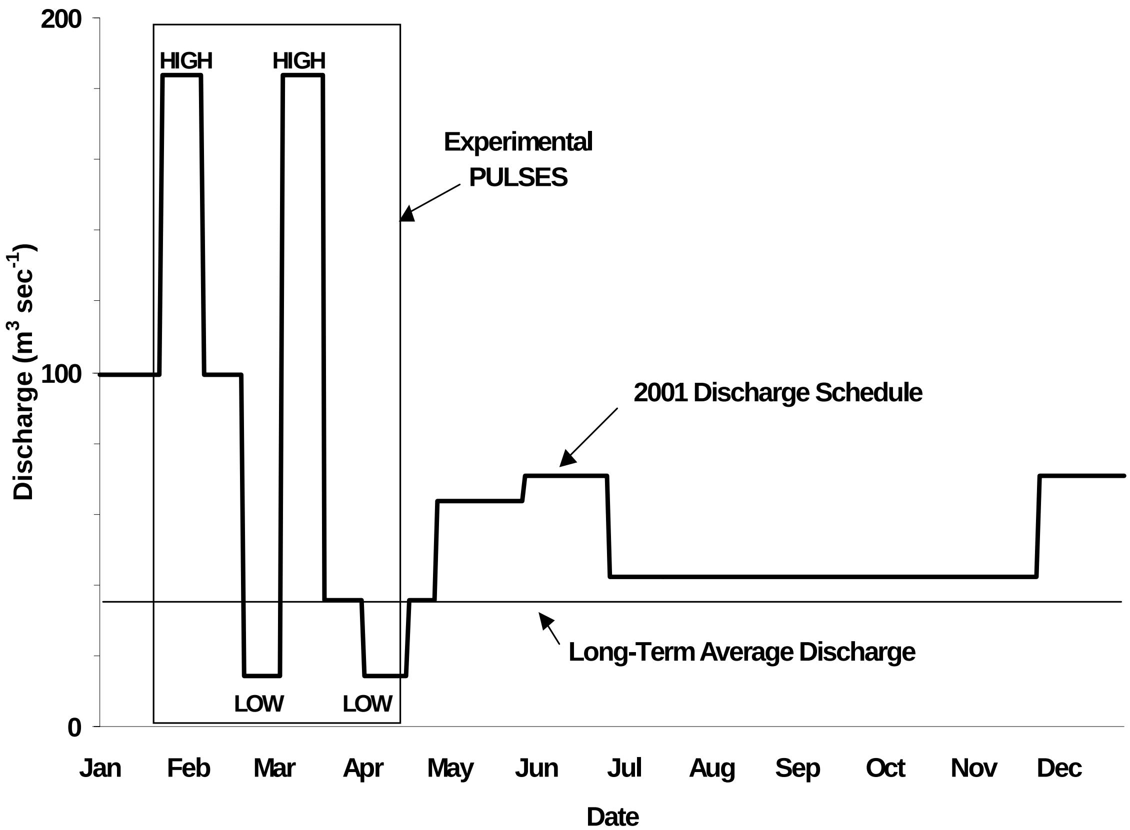


Figure 1. Mississippi River inflows (PULSES) at Caernarvon, LA.

Linking Environmental and Social Performance Measurement for Management at National and Watershed Levels: Modeling and Statistical Approaches

Scott Farrow [1]***, Mitchell Small*** [1]***, Tim Bondelid*** [2]***, Andrew Solow*** [3]***, George Van Houtven*** [2]***, James Sinnott*** [2]***, and Martin Schultz*** [1]

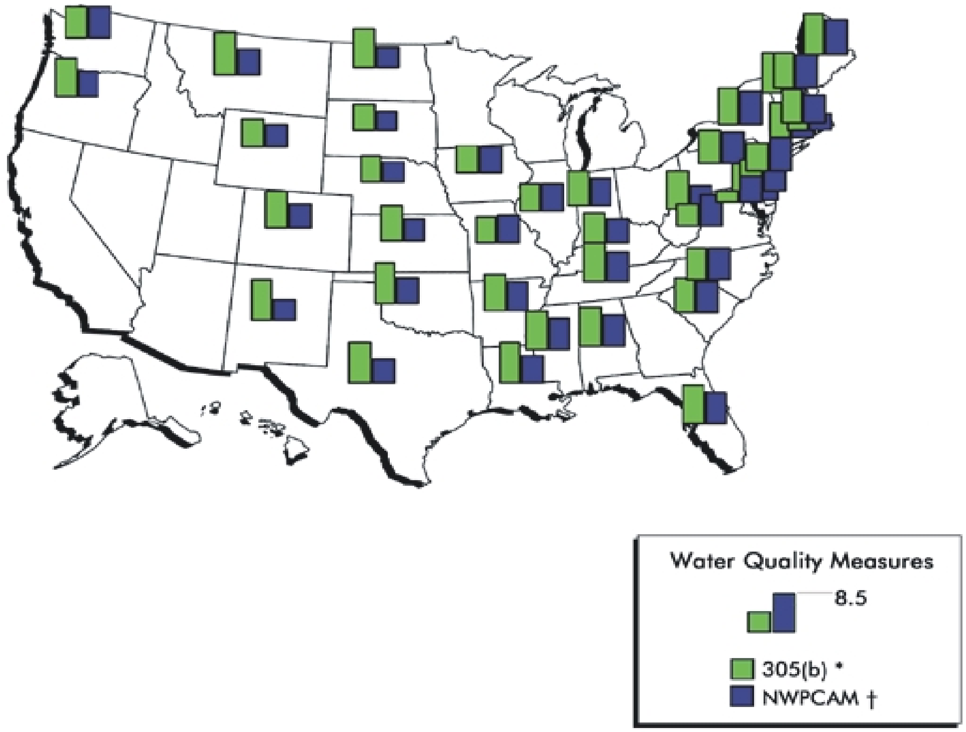
[1]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA; [2]Research Triangle Institute, Research Triangle Park, NC; [3]Woods Hole Oceanographic Institution, Woods Hole, MA

The goal of this research project is to integrate physical, ecological, and social science models and data to provide an evaluation tool for surface water quality managers at various levels of spatial aggregation. The objectives of the study are to: (1) estimate year-to-year changes in water quality for conventional water quality parameters at the national and watershed level by using index numbers, and multivariate and ordered mean rates of change; (2) estimate the net benefits of alternative policies for total maximum daily loads (TMDLs) trading; (3) estimate the economic benefits of water quality improvement at the watershed level; (4) improve modeling of wet weather events in a policy model; and (5) estimate the link between water quality pollution abatement and control expenditures at the facility level and water quality performance indicators for the nation and specific regions and watersheds.

Both modeling and statistical approaches are being investigated. As a point of departure, the National Water Pollution Control Assessment Model (NWPCAM) is being used (see Figure 1). With that model, sensitivity to various input parameters, the linkage between its output, and other indices of surface water quality are being investigated. Econometric techniques are being applied to facility-specific data.

In the initial partial year of implementation, the major sources of uncertainty in the model approach have been characterized, investigation of the weak statistical links between model-based and state reports of water quality has begun, and the hypothesis about the crossmedia pollution abatement control costs and the actions of polluting firms at the local level have been econometrically tested.

Although the results are preliminary, they point the way to local, state, and regional integrated water quality assessments that combine environmental and social performance measures. Investigation of the behavioral modeling of state water quality reports and integration of cost data into the water quality model also have begun. With this integration, it is hoped to move toward evaluation of alternative policies for water quality management where TMDLs have been defined.



* State average values based on Lyon and Farrow Uniform estimate.
† Based on unweighted average state water quality estimates from NWPCAM 1.0.

Figure 1. Preliminary water comparison: 305(b) and NWPCAM.

Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems

Richard C. Lathrop [1,2]***, Kenneth W. Potter*** [2]***, Jean M. Bahr*** [2]***, Kenneth R. Bradbury*** [2]***, Steven R. Greb*** [1]***,***
James A. LaGro, Jr. [2]***, Edward B. Nelson*** [1]***, Peter Nowak*** [2]***, and Joy B. Zedler*** [2]
[1]*Wisconsin Department of Natural Resources, Madison, WI;* [2]*University of Wisconsin, Madison, WI*

The urbanization of agricultural landscapes is occurring throughout the United States, resulting in the degradation of aquatic systems. Fundamental changes in watershed hydrology result from the construction of impervious surfaces (roofs, streets, sidewalks). As impervious surface area expands, runoff peaks and volumes increase, and water quality and groundwater levels decline. Increased runoff peaks cause channel erosion and habitat degradation—increased erosion of soil and associated nutrients causes sedimentation and eutrophication of lakes and wetlands. The diminished groundwater levels desiccate wetlands and lead to a reduction in the discharge of high-quality groundwater to lakes, streams, and springs, and wetland biodiversity declines. These impacts of urbanization are exacerbated in regions where groundwater is pumped for domestic use and irrigation.

This group will evaluate alternative management practices and patterns of urbanization by considering a range of urban development issues, including storm runoff, groundwater depletion, wastewater treatment, eutrophication, and wetland degradation. The interaction among these issues and the social and political opportunities for, and constraints on, effective management also will be addressed. The goal is to fill critical knowledge gaps and extend (or develop) analytical and modeling tools that will minimize the hydrologic and ecological impacts of urbanization. This new knowledge and enhanced modeling tools will be applied to a case study of the North Fork of Pheasant Branch near Madison, WI (see Figure 1).

An abundance of data, several ongoing research projects, and a high level of public interest make this an excellent research site. Comparable land use/water management scenarios for this watershed will be constructed, including "low-impact development" designs, and their approximate economic costs, social/political acceptability, and hydrologic and ecological impacts will be evaluated. Extant groundwater and surface water models calibrated for the region and structurally modified by the research group will be used to correctly simulate the infiltration practices, thermal pollution, well locations and pumping schedules, and wastewater treatment options.

Urban impacts on wetlands, especially their biodiversity, will be examined. Those native species that can thrive in constructed urban bioretention wetlands will be determined. Farmer behaviors needed to reduce high soil P concentrations in agricultural lands that are likely to be converted to urban development will be evaluated, and water clarity and algal bloom responses to scenarios of P loading changes downstream in Lake Mendota will be modeled.

Finally, the social and institutional barriers to low-impact development will be evaluated through interviews and focus groups with engineers, planners, homeowners, and other key players. This multidisciplinary research will allow for recommendations to be made that should help local governments and citizen groups improve the management and protection of critical aquatic resources in rapidly urbanizing landscapes.

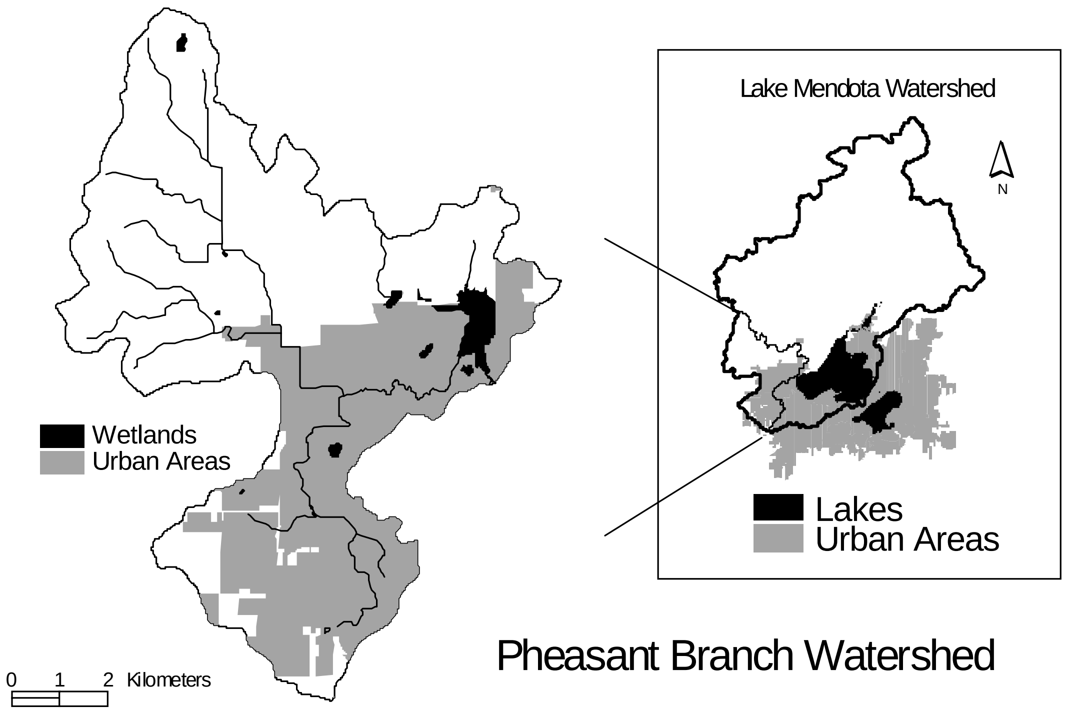


Figure 1. Map of Lake Mendota Watershed, including Pheasant Branch Subwatershed and the Madison metropolitan urban area. The enlarged map of Pheasant Branch shows the major downstream wetland and the North Fork Creek area that is still in agricultural land use (not shaded).

An Integrated GIS Framework for Water Reallocation and Decisionmaking in the Upper Rio Grande Basin

Olen Paul Matthews [1] ***and David Brookshire*** [2]

[1]*Department of Geography,* [2]*Department of Economics, University of New Mexico, Albuquerque, NM*

Reallocating water is a politically sensitive issue in the Western United States. Changes from agricultural uses to urban or environmental uses are occurring, but the process tends to polarize competing water users, thus creating barriers to reallocation. Other barriers are inherent in the appropriation doctrine, and some barriers exist because of poor data or inadequate science. These barriers could be more easily overcome and the process made less political if the impacts of change were better known.

The biophysical and behavioral models currently used to predict the impacts of change do not account for spatial complexity or information uncertainty in ways that overcome barriers to reallocation. An integrated approach that couples a spatial and temporal framework to biophysical, institutional, and behavioral science can reduce uncertainty. Process-based geographic information systems (GISs) can fill that role by allowing impacts to be assessed more accurately.

A coupled physical, environmental, and human system model is being developed in an integrated GIS framework to simulate interactions and changes within the Rio Grande Watershed, NM. The coupled model will operate entirely within a GIS, unlike other models that use a GIS mostly for display. This approach will permit the evaluation of impacts if any component of the model changes as a result of natural or anthropogenic causes. Because water law and economics will be integrated with physical and biological components, the coupled model can be used to evaluate the economic consequences of water reallocation and the impacts of different environmental policies. Stakeholders will use the model to evaluate policy questions.

The project has two components: (1) development of the GIS model, and (2) stakeholder evaluation of policy options. The modeling framework of this study utilizes a raster-based distributed water balance approach in which each raster element represents a bucket through which inputs and outputs may be routed. The model utilizes a hierarchical resolution grid scheme based on a quad-tree subdivision of the landscape. The raster data structure is designed to allow an infinite number of process specific resolutions on an as needed basis (i.e., finer cells where detail is required, coarser cells where data limitations preclude the finer scales or where processes operate on coarser scales).

Stakeholders will identify issues and create future water use scenarios. The information gained during these early stages will be hypothetical to a large extent. A pseudo-real time decision analysis tool will be developed that incorporates real consequences, via monetary payoffs, to minimize the potential bias in hypothetical responses. Stakeholders will make water use decisions in an experimental setting. The cumulative effects of individual stakeholder decisions will be simulated using a GIS model developed during the first 2 years of this research.

The model's data structure is being developed and stakeholders are identifying the issues. Preliminary experiments with stakeholder participation are occurring. These are the first steps needed for model development. The routing mechanism for water movement needs to be developed, different elements of the model need to be linked, the decision analysis tool needs to be refined, and water use scenarios need to be developed.

The Spatial Pattern of Land Use Conversion: Linking Economics, Hydrology, and Ecology To Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems

Margaret A. Palmer [1]***, Nancy E. Bockstael*** [2]***, Glenn E. Moglen*** [3]***, N. LeRoy Poff*** [4]***, James E. Pizzuto*** [5]***, Cameron Wiegand*** [6]***, and Keith Van Ness*** [6]

[1]Department of Biology, [2]Department of Agricultural and Resource Economics, [3]Department of Civil and Environmental Engineering, University of Maryland, College Park, MD; [4]Department of Biology, Colorado State University, Ft. Collins, CO; [5]Department of Geology, University of Delaware, Newark, DE; [6]Department of Environmental Protection, Montgomery County, Rockville, MD

Conversion of land to residential use has degraded freshwater ecosystems throughout the United States. This research project is interested in how the timing, rate, and spatial configuration of land conversion influences stream habitat and ecosystem health.

The basic design is to contrast two watersheds with an older development closer to Washington, DC, with two watersheds in the rapidly expanding rural-urban fringe of Montgomery and Howard Counties, MD. This design provides a broad mix of intensity, spatial configuration, and history of land use development.

By working with these counties, access to existing high-resolution geographic information system (GIS) and biomonitoring databases is maximized. Through collaboration with the Montgomery County Department of Environmental Protection, the effectiveness of current land use policies and restoration programs in minimizing the ecological consequences of land use conversion in urbanizing watersheds is being evaluated.

The project objectives are to: (1) examine, using past and current conditions, how the type, timing, and rate of development in conjunction with its spatial configuration influence stream hydrology and geomorphology, which influence the structure and function of stream ecosystems; (2) evaluate the effectiveness of local government policies in altering the pattern of development and in mitigating the impact of development on stream ecosystems; and (3) use empirical and theoretical models from hydrology, geomorphology, and economics to make and test projections about future development and its ecological implications, and to compare stream health measures under different spatial and temporal patterns of development.

To accomplish these objectives, this research is building on recent econometric work aimed at modeling and forecasting not only the quantity of land use change, but also future spatial development patterns. This project will incorporate the temporal dynamics of land conversion decisions and the details of Montgomery and Howard Counties' regulatory instruments that have been aimed at altering the spatial and temporal characteristics of development. This extension to the modeling approach allows for testing the effectiveness of these specific public policy instruments, assessing the effect of increasingly stringent stormwater management plans on development costs and the amenity value of stream-side properties, and forecasting future development patterns.

Spatially explicit models are being developed that predict, conditional on land use history and pattern, the change in hydrologic and geomorphic parameters that influence conditions along stream flowpaths in multiple watersheds across an urban-rural gradient (see Figure 1). These models either are embedded directly within the framework of the GIS or are linked to the GIS in a batch-style configuration so as to fully consider the spatial and temporal dynamics of the land use change within the study watersheds.

The flow of information from one discipline to another likewise is mediated by the common framework provided by the GIS, which is critical to providing a meaningful and precise linkage between economic, hydrologic, geomorphic, and ecological quantities.

Ecological and geomorphic data will be collected over the 3 years of the project at multiple locations within the watersheds. These locations are organized along a series of nested subwatersheds allowing for the aggregation of data at different spatial scales to follow the natural structure of the drainage network. The intent is to determine how land use patterns and history of development influence local ecological conditions. Specifically, this will allow for an assessment of whether ecological responses occur at thresholds under various combinations of extent, spatial configuration, and history of land use configurations.

This research offers a synthesized approach to evaluate the environmental consequences of alternative future development scenarios in urbanizing watersheds where the spatial pattern and tempo of development is a growing public policy issue.

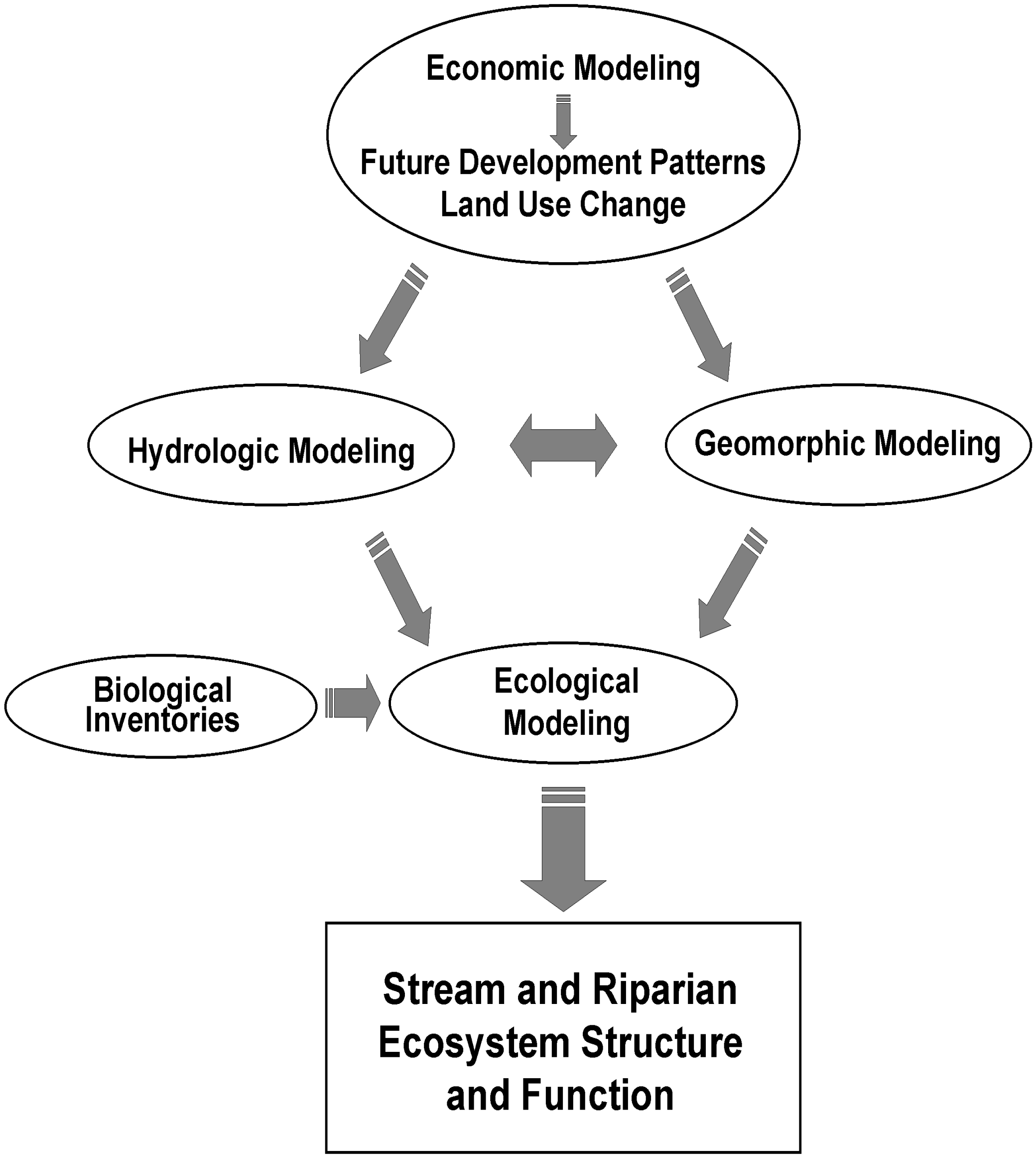


Figure 1. Predicting impacts of land use change in urban/suburban lotic ecosystems by integrating models operating on different spatial-temporal scales.

Integrating Coral Reef Ecosystem Integrity and Restoration Options With Watershed-Based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-Use Practices

***Robert H. Richmond*[1], *Michael Hamnett*[2], *and Eric Wolanski*[3]**

[1]Marine Laboratory, University of Guam, Mangilao, GU; [2]Social Sciences Research Institute, University of Hawaii at Manoa, Honolulu, HI; [3]Australian Institute of Marine Sciences, Townsville, Queensland, Australia

The objectives of this research are to: (1) characterize watershed discharges affecting coastal reefs chemically, temporally, and spatially; (2) determine the classes and concentrations of coastal pollutants that are of greatest concern to coral reef sustainability, and provide quantitative data for revising local and regional water quality standards; (3) develop techniques that can identify sublethal stress in corals, before outright mortality occurs; (4) determine if coral reef recovery and restoration activities are practical following both anthropogenic and natural disturbances; (5) quantify the cultural and economic impacts of land-based developments that affect coastal resources, and incorporate this information into the decisionmaking process; (6) develop educational materials for a variety of users and stakeholders; and (7) develop a set of recommendations to prevent damage to coral reef ecosystems, and when such occurs, mitigation measures that may be undertaken.

These objectives are being met by addressing the following questions: (1) What is being discharged onto reefs from within selected watersheds? (2) How effective are present mitigation measures in controlling watershed discharges, and how can these be improved to provide measurable results? (3) Of the five chemically mediated steps essential for successful coral reproduction and recruitment, which are most sensitive to diminished water quality and what are the threshold levels? (4) When land-based development occurs, what are the societal costs when coastal resources are affected? What are the parameters to be considered when attempting to balance economic development and cultural preservation on small islands? (5) Are coral reef restoration activities practical, and if so, under what circumstances? (6) How can data from this and other studies be presented to stakeholders, as well as traditional and elected leaders to allow for effective environmental policy development and implementation?

The approach includes performing ecological studies on coral reefs as well as laboratory-based bioassays; quantifying levels at which sedimentation and selected classes of pollutants become problematic; studying coastal water characteristics of flow, residence time, and spatial extent of watershed discharge to determine measures that can be implemented to reduce negative impacts; quantifying the societal costs to island communities resulting from watershed and related reef degradation; and testing reef restoration techniques coupled with land-based remediation.

Coral fertilization and recruitment bioassays were performed during the summer spawning event. Copper was found to inhibit both fertilization and larval recruitment at levels of 100 ppb and below. Watershed discharge effects, including impacts of reduced coastal salinity (see Figure 1) and increased substratum cover by algae, also were documented. Techniques for recruitment bioassays using metamorphic inducers were refined and are being tested for precision. Coral cultivation techniques were refined and applied to producing additional colonies for bioassays and transplantation/reseeding trials.

Current meters were purchased and deployed to gather data on coastal circulation patterns and characterize the extent of freshwater plumes being discharged into reef areas from select watersheds. The first set of circulation models was developed. A workshop was held to set priorities and identify the deliverables that would be of most value. The workshop was attended by 14 resource managers, researchers, educators, and community-based organizational representatives.

This information is being incorporated into the research plan, and there will be a followup later this year. The "deliverables" are expected to include tools necessary for assessing coral reef health, for monitoring changes related to human activities, as well as information to guide development and policy in a responsible manner.

The next steps are to: (1) begin the assessment of the societal costs associated with poor land-use practices; (2) begin work on the educational materials; (3) continue characterization of coastal water quality during the dry season, and prepare for sampling during the onset of the rainy season; and (4) continue experiments on the application of biomarkers in corals.

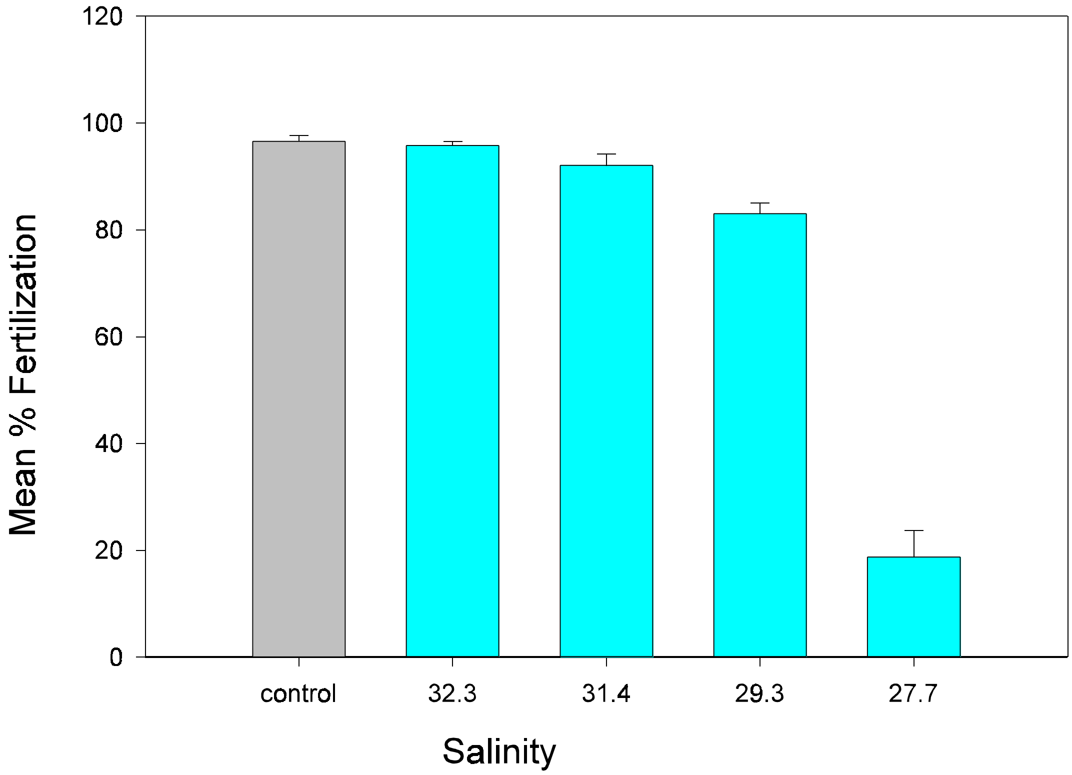


Figure 1. Effect of altered salinity on fertilization of *Acropora surculosa*. Control = filtered seawater with salinity of 34.1 o/oo. Statistically significant effects of reduced salinity from control; 15 percent dilution, p value 0.003; 20 percent dilution, p value < 0.0001.

Identification and Control of Nonpoint Sources of Microbial Pollution in a Coastal Watershed

***Brett Sanders*[1]*, Stanley Grant*[1]*, Alex Horne*[3]*, Robin Keller*[2]*, and Mark Sobsey*[4]**

[1]*Department of Civil and Environmental Engineering,* [2]*Graduate School of Management, University of California, Irvine, CA;* [3]*Department of Civil and Environmental Engineering, University of California, Berkeley, CA;* [4]*School of Public Health, University of North Carolina, Chapel Hill, NC*

The goals of this project are to: (1) characterize the spatiotemporal variability of microbial pollution in urban runoff and to identify the association between pathogens and indicator organisms; (2) develop a novel strategy to control the impact of urban runoff on the microbial water quality of beaches and coastal wetlands during nonstorm periods; and (3) develop a multiple-objective decision model to aid stakeholders in selecting strategies to mitigate microbial pollution problems in coastal waters.

A well-defined and controllable system of flood control channels and a constructed marsh in southern California will be utilized as the test site. The flood control infrastructure includes a network of pump stations with forebays that are engineered to lift runoff from below sea-level subbasins into tidally influenced flood control channels that drain to the ocean.

A sampling survey of forebay water and channel water will be undertaken to ascertain the spatiotemporal variabilility of pathogens (enteric viruses) and indicator microorganisms (*Escherichia coli*, enterococci, spores of *Clostridium perfringens*, fecal coliform, and male-specific and somatic bacteriophage) present in the watershed to address the goal of ascertaining the association between pathogen levels and indicator organisms both at the inlet to open channel waterways, and at the outlet where runoff drains to the near-shore region. The control approach involves combining both active and passive control strategies to mitigate the impact of urban runoff that is transported by flood control channels, through a constructed wetland, and into a recreational near-shore area.

Pump station operation schedules that minimize the impact of urban runoff on coastal water quality will be determined, and the principal mechanisms responsible for pathogen removal by tidally influenced constructed wetlands will be identified through a series of microcosm studies.

Stakeholders will be interviewed or surveyed to evaluate preferences towards various objectives associated with active and passive control strategies, and a decisionmaking model will be developed to assess the efficacy of existing control alternatives and to identify previously unrecognized approaches for water quality control.

Because flood control channels are a ubiquitous feature of urban watersheds and constructed wetlands have become an important resource for pollution mitigation, the primary data, control strategies, and stakeholder information obtained in this study could lead to regional and national strategies for reducing the adverse impact of urban runoff on coastal water quality.

Strategic Renewal of Large Floodplain Rivers: Integrated Analysis

Richard E. Sparks[1], Deborah Beal[5], John B. Braden[2], Misganaw Demissie[6], Andrew M. Isserman[2], Douglas M. Johnston[7], Jungik Kim[3], Yanqing Lian[6], Da-Mi Maeng[1], Zorica Nedovic-Budic[3], Daniel Schneider[3,8], Diane M. Timlin[4], and David C. White[2]

[1]Department of Natural Resources and Environmental Sciences, [2]Department of Agricultural and Consumer Economics, [3]Department of Urban and Regional Planning, [4]Department of Geography, University of Illinois, Urbana, IL; [5]Department of Environmental Studies, Illinois College, Jacksonville, IL; [6]Illinois State Water Survey, Champaign, IL; [7]National Center for Supercomputing Applications, Champaign, IL; [8]Illinois State Natural History Survey, Champaign, IL

This research extends an earlier Water and Watersheds project (96-13562) by refining and linking ecologic, hydrologic, and economic models to support restoration planning for a large river floodplain system. A suite of models is being developed to provide insights to stakeholders concerning likely impacts of restoration strategies by simulating essential aspects of a large floodplain-river ecosystem so that alternative restoration strategies can be evaluated.

Component models that are being linked include: (1) one- and two-dimensional hydraulic models of the river, (2) a floodplain forest simulator, (3) a herbaceous plant simulator, (4) numerous habitat suitability indices, and (5) regional economic input/output models. An 80-mile section of the Illinois River serves as the study site.

Water levels in the river govern the inundation pattern on the floodplains, except where levees prevent flooding of lands developed mostly for row crop agriculture. The inundation pattern determines the vegetation communities, which in turn provide habitat and food for fish and wildlife.

Restoration involves "de-development," or conversion of some land from existing agricultural and other commercial uses, to uses such as flood conveyance, restoration of native plant and animal communities, and outdoor recreation. The impacts of such conversions on local and regional economies are important political and policy issues.

A second issue is naturalization of the seasonal flood regime. Models indicate that simply removing some levees will not restore native plant and animal communities. Operation of the navigation dams, and other factors now cause excessive, unnatural water fluctuations during the summer growing season, which destroy valuable plant communities.

Policy options include opening the levees and modifying the operation of the navigation dams to achieve more natural flooding; or alternatively, keeping the levees intact and using pumps to create water regimes in the areas behind the levees that are "ideal" (e.g., for waterfowl). Variations on each of these options (e.g., regulating flooding of land behind levees using control structures installed in the levees) have complex consequences both in terms of costs and degree of restoration of plant and animal communities and ecosystem functions.

The connections between the river and its floodplain, and therefore between the hydrology, ecology, and economic processes, are fundamentally spatial interactions. A geographic information system will serve as a data repository, a link between the various models, and a tool for analyzing the effects of alternative management strategies. State-of-the-art visualization tools will translate the spatially integrated model results into visual presentations to improve understanding of environmental processes and facilitate communication with stakeholders.

Watershed-Scale Assessments of *E. coli* Contamination Implications of Source Identification for Public Policy Debate

Ronald Turco, S. Brouder, C. Nakatsu, A. Bhunia, J. Frankenberger, J. Harbor, and G. Thomas
Environmental Sciences and Engineering Institute, Purdue University, West Lafayette, IN

In watersheds in Indiana (as in most of the Midwest), contamination from *Escherichia coli* exceeds water quality standards in most locations where monitoring has been conducted. This study area, in the Tippecanoe River Watershed, drains into Lake Shafer. Lake Shafer is a 522-ha water supply in north central Indiana that has shown significant and repeated high levels of bacterial contamination as well as some contamination from plant nutrients, but fairly low levels of pesticides. Since 1993, approximately 49 percent of the 775 Lake Shafer water samples collected for general coliform testing have tested over the acceptable U.S. Environmental Protection Agency standard for whole body contact. The significance of this concern is in the exposure route. Drinking water supplies are treated (i.e., with chlorine) before coming into contact with humans. Recreational waters are not treated, and exposure is through whole body contact, including some ingestion.

This project has five specific objectives. Objective 1 is to facilitate the use of scientific evidence (generated from other parts of this project) in practical efforts to improve water quality in Lake Shafer by defining the setting for information assessment and public interaction. Objective 2 is to estimate locations and types of fecal sources available to the water supply through a pathway analysis, and to describe water flow within the two subwatersheds. Objective 3 is to define the sources of the bacterial pollution by developing a comprehensive identification scheme and database for *E. coli* strains using a sensitive DNA fingerprinting technique (e.g., amplified fragment length polymorphism). Objective 4 is to fully characterize the role that land application of manure plays (if any) in facilitating the introduction of bacterial populations into surface water. Objective 5 is to deliver scientific evidence (generated from other parts of this project) to stakeholders in the watershed as part of the evolving dialog established in Objective 1, and to assess how this is used to reach consensus concerning the set of solutions the community will adopt as the most cost-effective and equitable approaches to addressing the *E. coli* problem.

To meet Objectives 1 and 2, the contribution of *E. coli* from different land uses along two rivers that feed into the lake is being tested by comparing samples collected at 21 different locations. A new hypothesis on *E. coli* fate in the landscape is being developed. To meet Objective 3, more than 1,900 environmental "*E. coli*," defined as *E. coli* from known and unknown environmental sources, have been collected. These presently are being genetically characterized. To meet Objective 4, data from a controlled field site receiving seasonal applications of manure are being collected. From these data, clear evidence has been found indicating that the longevity of *E. coli* in the environment may be longer than anticipated.

Integrated within these programs has been a series of community/stakeholder events. A Web site and newsletters have been developed, and a number of presentations describing the project have been given. The final stages of data analysis for the baseline survey of environmental awareness are underway. As these data sets begin to be used in educational efforts, community awareness and response to data collected in their watershed will be evaluated.

An Acre an Hour: Documenting the Effects of Urban Sprawl in a Model Watershed Near Philadelphia, Pennsylvania

***Claire Welty*[1]*, Susan S. Kilham*[1]*, Aaron I. Packman*[2]*, and Robert J. Brulle*[1]**

[1]School of Environmental Science, Engineering, and Policy, Drexel University, Philadelphia, PA;

[2]Department of Civil Engineering, Northwestern University, Evanston, IL

The principal objective of this project is to document the effects of urbanization on the Valley Creek Watershed, which lies in a rapidly developing area of suburban Philadelphia, PA. Valley Creek is a tributary of the Schuylkill River and runs through Valley Forge National Historic Park. The watershed lies in the Piedmont physiographic province and supports a reproducing brown trout population in its limestone-fed stream. In addition to the common effects of development such as increased surface runoff and sediment loading, the watershed has experienced point-source pollution problems from Resource Conservation and Recovery Act and Comprehensive Environmental Response, Compensation, and Liability Act hazardous waste sites, and dewatering of the aquifer due to quarrying operations and pumping for a municipal water supply.

A historical review of land use is being conducted in an attempt to quantify the changes in the stream caused by development during the last 200 years. Specifically, changes in population, building permits, road mileage, and land use patterns from colonial times to the present are being examined. After the effects of prior development in the watershed have been established, the effect of the continuing urbanization of the area will be assessed. Because the watershed is actively undergoing urbanization, this research group will attempt to directly examine the development-induced geomorphologic changes in the stream over time. The primary conditions being observed are: stream flows (base and storm flows), channel morphology, bed composition, and suspended sediment concentrations.

The degree and pattern of heterogeneity of hydraulic conductivity of this fractured rock aquifer will be quantified at multiple scales from existing hydrogeologic data. The effect of aquifer heterogeneity and three-dimensional flow pathways on stream-subsurface exchange rates and contaminant transport subsequently will be evaluated using groundwater flow and transport models. This information will be used to assess the chemical loadings to the fish and other biota in the stream. Stream tracer-injection experiments are being used to directly assess stream-subsurface exchange in Valley Creek and storage of tracer in the hyporheic zone.

Several aspects of the interaction between environmental quality and the biota in this watershed are being investigated. First, sediment distribution data are being collected to assess the impacts of changes in channel characteristics on the community structure of macroinvertebrates and fish. Second, polychlorinated biphenyl (PCB) levels and supply rates are being compared with PCB levels in the organisms from the same areas. Third, the positioning of species in the food web is being assessed to measure biomagnification via food web processes. Fourth, general stress levels in the organisms are being measured—these measurements are being related to PCB levels as an independent indicator of environmental impacts on organisms. This analysis will allow for the development of a comprehensive picture of how urbanization-induced changes in the watershed affect invertebrate and fish communities.

Political controversies in this watershed have left a documented historical record of the political struggles that develop in the process of urbanization. The major development activities that have had an impact on the watershed over time will be identified, and the political decisionmaking associated with these activities will be examined. By examining these political decisions, an understanding of the political forces involved in urbanization can be developed.

The social science research is based on the use of three social science perspectives: (1) Advocacy Coalition Framework, (2) network analysis, and (3) discourse analysis. These sociological perspectives define an image of watershed politics as the result of the formation of different advocacy coalitions, each with a specific network structure and unique belief system. A comprehensive historical view of the process of urbanization, including the influence of social, economic, and political factors will emerge from this research.

Section 2.

Projects Initiated With Fiscal Year 1998 Support

Development and Testing of a Decision Support System for River Rehabilitation

J. David Allan, Gloria Helfand, and Joan Nassauer
School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI

The goal of this research project is to develop a conceptual and quantitative watershed model that will aid in identifying opportunities for the rehabilitation of stream ecosystems that are socially acceptable, ecologically beneficial, and cost effective. Research is organized around a series of modules, each of which can be linked to a geographic information system (GIS).

The final product will be an integrated, spatially explicit, multiscale model to display information on land use, land cover, and ecological condition of tributary streams in a 5,000 km^2 agricultural and urbanizing region. Using "build-out" projections of local government master plans, as implemented by conventional or alternative innovative landscape scenarios, the approach is intended to support decision-makers' capacities to advocate for ecologically beneficial landscape change and to anticipate ecological effects of landscape changes that are likely to be proposed for agricultural landscapes.

Module A: Landscape and Hydrological Processes. The Huron (drainage area 2,320 km^2) and Raisin (2,780 km^2) Watersheds together comprise much of the landscape of southeastern Michigan external to Greater Detroit. The Huron has substantial urban land, including small cities and outlying sprawl, while the Raisin has less urban development. The Huron Basin is less agricultural compared with the Raisin Basin, and it contains more wetland and a similar amount of forest. Considerable spatial heterogeneity is observable at the scale of the subcatchments associated with headwater streams. Based on approximately 50 small subcatchments from both watersheds, agricultural land use varied from 2–80 percent, with the top quartile more than 60 percent agricultural. Urban land use ranged from 0.2–70 percent, with the top quartile more than 20 percent urban.

Comparison of 100-m riparian buffers to total subcatchment area reveals overall strong correlations. Wetland and grass are overrepresented in buffers and forest, agriculture, and urban land uses are underrepresented, on average. Patch number, not patch size, appears to underlie differences among subcatchments in wetland and forest extent.

Module B: Social Acceptability and Economic Feasibility of Alternative Landscape Scenarios. The premise of this module is that forms of development and forms of agriculture that are ecologically beneficial, and viewed as desirable and affordable by the public are more likely to be implemented and sustained. Using alternative landscape designs as experimental treatments, suburban and rural southeastern Michigan residents' perceptions of the attractiveness and prices for alternatives site and subdivision designs were surveyed using traditional pencil-and-paper questionnaires and a Web-based survey.

Survey results will be used to determine whether the more ecologically friendly designs are perceived and valued similarly, in which case there is no social cost (there is a social benefit) associated with improving ecological quality in the rivers. If people prefer the less ecologically friendly designs, then this research will calculate how much people might have to be compensated for more protective designs. Survey results also have scale (landowner versus subdivision) implications for planning development in rural areas.

Results to date indicate that at the subdivision scale, design treatments characterized by the most beneficial ecological function, with less lawn area and more forest or prairie, were more attractive. In contrast, at the front yard scale, the most ecologically beneficial designs were not found to be as attractive as moderately ecologically beneficial designs or the least ecologically beneficial designs. This scale hierarchy may suggest an ecologically beneficial and socially acceptable approach to the aggregation of small-scale ecological improvements at the subdivision and watershed scale.

Module C: Ecological Integrity of Stream Ecosystems. One or more field sites on 48 tributary streams were assessed using biological (fish macroinvertebrates), habitat metrics, and chemistry. Analysis of macroinvertebrate data is not complete. Landscape metrics (subcatchment land use, buffer land use, subcatchment geology) alone accounted for approximately 30 percent of the variation in the fish-based index of biotic integrity (IBI). Habitat metrics accounted for 41–54 percent of variation in the IBI. This analysis is preliminary, using simple combinations of variables. Further analyses will use multivariate approaches to explore the interrelationships among landscape, habitat, and biological measurements required to determine the best set of predictive relationships for model-building.

The project was initiated in June 1999. Work to date has concentrated on module development, with integration efforts slated for summer of 2001.

An Integrated Systems Approach to Watershed Restoration With Community Involvement Applied to a Small Rural Watershed

J. Boll[1], J.D. Wulfhorst[2], S. Chen[3], C.O. Stockle[3], D.K. McCool[3], D.C. Brown[4], D. Feichtinger[4], and A.J. Vitale[5]

[1]Department of Biological and Agricultural Engineering, [2]Department of Agricultural Economics and Rural Sociology, University of Idaho, Moscow, ID; [3]Biological Systems Engineering Department, Washington State University, Pullman, WA; [4]Natural Resources Conservation Service, Coeur d'Alene, ID; [5]Coeur d'Alene Tribe, Fish, and Wildlife Program, Plummer, ID

In watersheds today, it is imperative to develop a scientifically based, integrated watershed restoration process with community input. The geographic area being studied in this research project is the Northwest Wheat and Range Region in Idaho, Washington, and Oregon. The objectives of this project are to: (1) develop a geographic information system (GIS)-based integrated systems approach for watershed restoration (see Figure 1); (2) adapt the adoption-diffusion model to identify institutional and attitudinal barriers to the adoption of erosion and water quality control practices; (3) test and improve an existing model for enhanced ability to determine critical source areas and to evaluate management practices and climatic variation in watersheds; and (4) develop an optimization technique for integration with the systems approach, including socioeconomic, physical, and ecological aspects. The study watershed is Lake Creek Watershed in the Coeur d'Alene Lake Basin in Idaho/Washington State.

Watershed restoration consists of the selection of "best management practices," which consider a physical, socioeconomic, and cultural component. Restoration efforts in Lake Creek Watershed since 1991 provide data on hydrology, water quality, and ecological aspects. Using these data, a hydrology model coupled with simple crop growth, erosion, and economic models has been developed and tested to determine the cost of erosion without the use of control practices.

Current land use conditions are characterized by bluegrass seed production and future conditions by the conversion to winter wheat. This approach is being expanded to include the cost of different tillage operations and implementation of control practices. Interviews were held in the watershed to strengthen the sociological aspects of erosion control. Multiple meetings with the Watershed Working Group were held which, among others, consists of the local community and tribal, state, and federal agencies.

Given the desire to transfer the integrated system to county-level resource managers, two constraints were placed on model development. First, input data are based on publicly available data sources, and second, the models do not require calibration. Application to Lake Creek Watershed shows that using these constraints provided very reasonable results. The hydrology model successfully simulated observed stream flow and distribution of runoff-generating areas in the watershed.

Erosion distribution in the watershed determined using the empirical Revised Universal Soil Loss Equation (RUSLE), which used a length-slope factor based on upslope contributing area, agreed reasonably well with the distribution of runoff-generating areas. In addition, total erosion amounts appeared to be in agreement with observed sediment measured in the stream. The crop growth modeling approach based on actual evapotranspiration and water use efficiency yielded reasonable, although somewhat low, spatially distributed estimates of bluegrass and wheat yields. Yield reductions after 75 years of soil erosion using the adjusted topsoil depths were somewhat low, resulting in small yearly price reductions.

The example application shows the potential of the integrated systems approach in yielding very useful site-specific information. It is believed that this tool eventually will assist resource managers to identify critical source areas within a watershed and properly assign load reductions for individual landowners. An optimization procedure is being developed based on the RUSLE. The objective function is minimizing the total cost of restoration of an entire farm in a watershed, or all the farms in the entire watershed. Integration of an expanded version of the physical-economic systems approach with the sociological data will follow another round of interviews with landowners in the watershed.

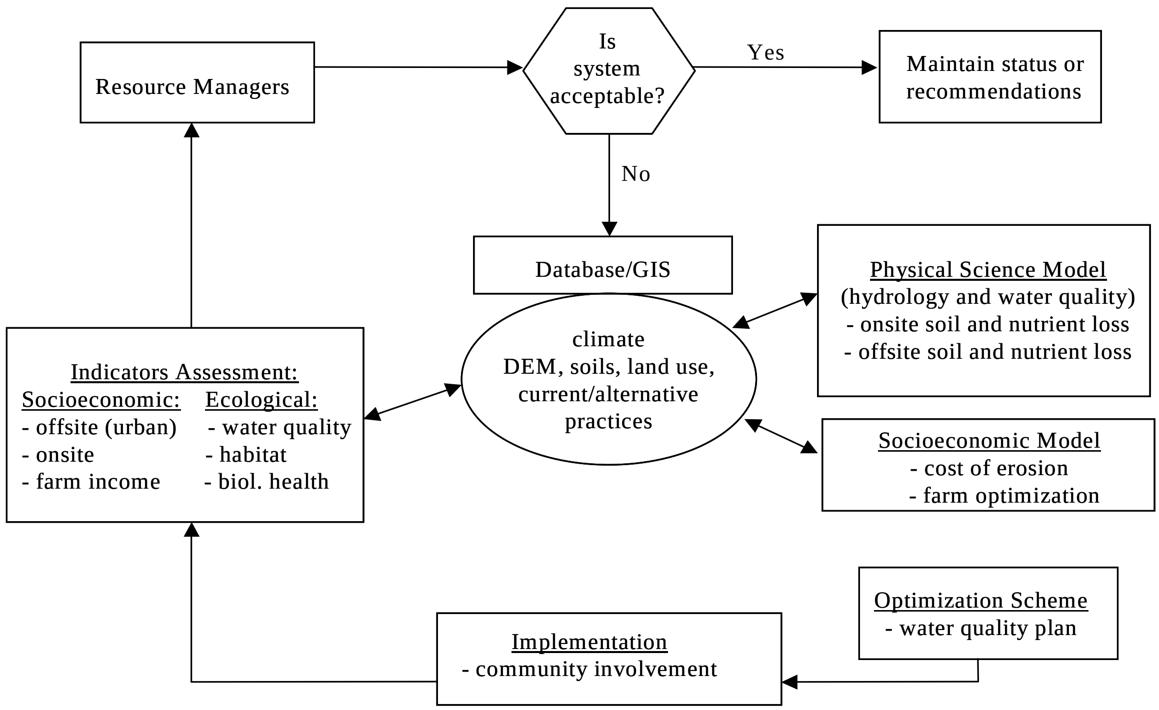


Figure 1. Schematic representation of the GIS-based integrated systems approach.

Integrating Ecological, Economic, and Social Goals in Restoration Decisionmaking

John Bolte
Bioresource Engineering Department, Oregon State University, Corvallis, OR

The integration of ecological, economic, and social goals is an important element of watershed restoration planning and prioritization. It generally is accepted that for restoration efforts to be successful, each of these goals must be addressed in a manner that reflects stakeholder priorities, objectives, and constraints. Additionally, it is becoming increasingly apparent that restoration strategies based solely on opportunistic, site-scale activities frequently do not accomplish watershed-scale goals.

Because watersheds are complex systems involving integration of human, hydrologic, and ecological processes, it can be difficult to understand the consequences of particular restoration activities on meeting restoration goals. Synthesis tools capturing spatially explicit data are needed to couple human and ecological processes with landscape features to assist in developing effective restoration plans.

The overall goal of this project is to refine and integrate spatially explicit models of watershed function and economic characterizations of restoration options with stakeholder-determined constraints and priorities. The resulting tool can assist stakeholders in identifying feasible restoration strategies and evaluate the ecological and economic effectiveness of these strategies at addressing watershed-level ecological, economic, and social function.

A geographic information system-based multiobjective decision support tool that contains a series of rules that relate specific site-based restoration alternatives, stakeholder goals, and site-specific landscape features is being developed to generate feasible restoration plans that reflect stakeholder concerns. This research group is cooperating with two watershed councils representing diverse watershed types and disturbance levels to evaluate the effectiveness and transferability of the methodology between distinct ecological and economic systems. The analysis framework uses a landscape generator to apply design heuristics that embody ecological, economic, and social constraints and preferences to allocate restoration activities to specific sites based on site features. It then evaluates the resulting landscape options using a series of ecological, social, and economic watershed-scale models. The utility of the tool for addressing stakeholder needs and its impact on stakeholder decisionmaking is being explicitly evaluated using sociological and applied anthropological methods.

Sociological analysis of the stakeholder groups represented in the two watershed councils has been completed. Also, the landscape generation tool has been completed, and a collection of approximately 400 rules relating the utility of particular restoration strategies for meeting stakeholder preferences to site features have been developed. Preliminary results have been presented to the watershed councils with positive results. Stakeholder suggestions currently are being incorporated into the analysis framework.

Initial results indicate that using a rule-based framework for capturing qualitative relationships between restoration strategies, stakeholder objectives, and site features is an effective way of representing these relationships in a manner that stakeholders can readily understand. Making restoration recommendations at a site level, distributed across a watershed, allows for the evaluation of the effectiveness of basinwide plans at meeting stakeholder goals. Further, the use of multiobjective methodologies provide a stakeholder-accessible method for weighing and balancing competing economic, social, and ecological objectives. It is anticipated that these rules could be readily adaptable to restoration strategies, other situations, and stakeholder goals. Although it is too soon to evaluate the usage of the tool by the watershed councils, the initial response has been very positive.

Social Impact Assessment of Human Exposure to Mercury Related to Land Use and Physicochemical Settings in the Mobile-Alabama River Basin

Jean Claude Bonzongo [1], ***Eric E. Roden*** [2], ***Milton G. Ward*** [2], ***C. Hobson Bryan*** [3], ***W.B. Lyons*** [4], ***and Indrajeet Chaubey*** [5]

[1]Department of Environmental and Engineering Sciences, University of Florida, Gainesville, FL; [2]Department of Biological Sciences, [3]Department of Geography, University of Alabama, Tuscaloosa, AL; [4]Byrd Polar Research Center, Ohio State University, Columbus, OH; [5]Department of Biological and Agricultural Engineering, University of Arkansas, Fayatteville, AR

There four objectives of this research project are to: (1) determine levels and speciation of mercury (Hg) in water, sediments, and fish from different aquatic systems in the Mobile-Alabama River Basin (MARB) (see Figure 1); (2) investigate the linkage between land-use types or the presence of wetlands and microbial Hg transformation and bioaccumulation; (3) predict Hg levels in fish using recent and historical land-use data; and (4) use a participatory approach to environmental decisionmaking to ameliorate conflict, and achieve an effective understanding and support for Hg policy.

Water, sediment, and fish (largemouth bass) were collected from 52 sites with different land uses across the MARB. Recreational tournament fishermen were utilized for part of the fish collection effort. Water chemistry, Hg levels, and speciation in these samples are being determined. Following this survey, several sites will be selected for more intensive sampling and laboratory studies, directed toward linking observed trends in fish Hg levels with processes-controlling Hg transformation and bioaccumulation. Next, a database will be developed and used to map Hg concentrations and to determine their correlation with biogeochemical and physical variables. Lastly, the public will be involved in and informed of this research to aid in the assessment of risk imposed by elevated Hg levels in fish and to help formulate possible remedial policies.

Total mercury concentrations in the water samples (0.43–2.23 ng L^{-1}) fall among background levels typically found in natural waters worldwide. After analyzing the majority of the fish samples, at least one fish from each major river basin within the MARB was found to have a total Hg concentration greater than 0.5 ppm, a level at which limited consumption is recommended by some regulatory standards. Mercury concentrations of greater than 1 ppm were detected in fish samples from three locations thus far, two of which are categorized as being impacted by wetland area. Project personnel have met with recreational fishermen, municipal groups, and several energy industries to exchange ideas and issues. These groups have come to appreciate the complexity involved in understanding Hg behavior in the environment, and they are willing to remain involved through the life of the project.

Preliminary results suggest that while mercury concentrations in water samples from all sites are very low, elevated levels of mercury are found in selected fish samples across the watershed. The data support the idea that wetland abundance may result in higher concentrations of mercury in fish in those areas. It is anticipated that the mapping and statistical analyses will be helpful in predicting the potential for Hg accumulation in predatory fish in other similar locations in the Southeast United States, and that the approach of involving stakeholders throughout the project will result in positive approaches to developing mercury policy.

After completion of all sample analyses, database development, and statistical analyses and mapping, informed decisions will be made on which sites to focus for the detailed biogeochemical studies. The social assessment continues by gathering input from stakeholders and identifying mutual concerns.

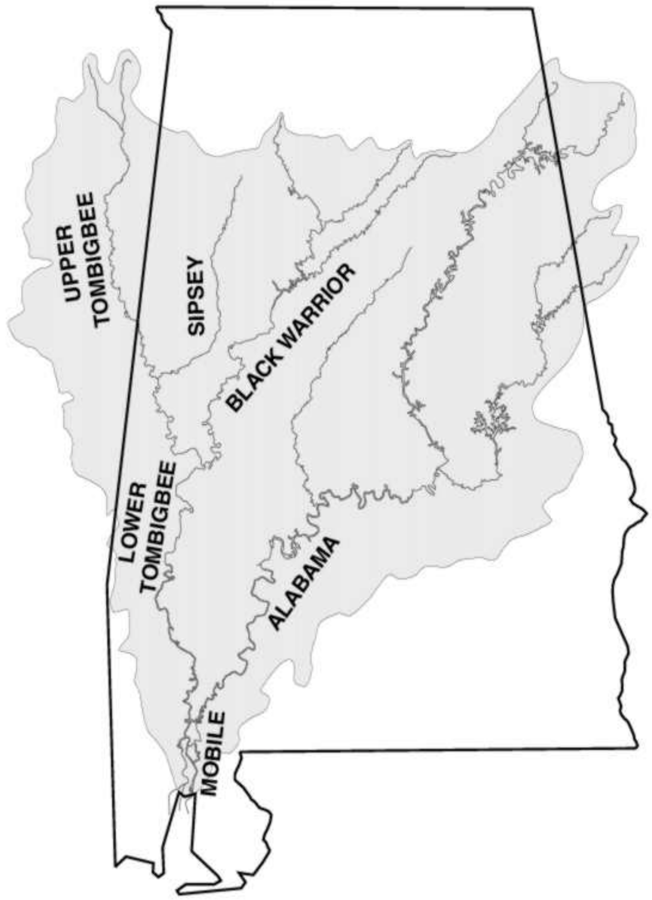


Figure 1. The Mobile-Alabama River Basin.

Applying the Patuxent and Gwynns Falls Landscape Models To Designing a Sustainable Balance Between Humans and the Rest of Nature

Robert Costanza, Alexey Voinov, Roelof Boumans, Tom Maxwell, Ferdinando Villa, Helena Voinov, and Joshua Farley

Institute for Ecological Economics, University of Maryland, Solomons, MD

As part of a previous Environmental Protection Agency/National Science Foundation-funded project, an integrated, spatially explicit model of the Patuxent Watershed, MD, has been developed (http://iee.umces.edu/PLM). The model is being further developed to use as a tool for whole watershed analysis and restoration. This includes development of methods to assess the ecological health of ecosystems and watersheds, development of preferred future states for the watersheds using broad stakeholder participation, and development of dynamic links between the ecological and socioeconomic sectors of the model. Based on the above, the degree to which various management policies can restore the ecological health of the Patuxent and Gwynns Falls Watersheds and achieve the preferred future states will be tested.

In the Patuxent Landscape Model (PLM), the watershed is represented as a grid of cells with a process-based ecological model replicated in each of the cells. The ecological model includes modules to simulate local and spatially distributed hydrologic fluxes, nutrient dynamics, plant growth, dead organic matter decomposition, and so on. These modules were tested and calibrated separately, and then put together within a Spatial Modeling Environment, created by this research group, to represent the watershed as a whole.

The model runs are in good agreement with available data. Analyses for numerous scenarios of land-use change and nutrient loading were performed. The model output is compared in the different scenarios examining nitrogen concentration in the Patuxent River as an indicator of water quality, changes in the hydrologic flow, and changes in the net primary productivity of the landscape, as indicators of ecosystem services.

The PLM has been calibrated to mimic the hydrologic flows in the Villa Nova Subwatershed of Gwynns Falls. This research project will be expanded to other subwatersheds and the full watershed as the data for calibration become available. The human capital model has been further developed and tested. Calibrations were successful against data from the U.S. Census Bureau on population dynamics in Baltimore between 1790 and 1994.

A stakeholder workshop (Patuxent and Gwynns Falls Watersheds) was held on February 14 at the University of Maryland College Park Campus. Breakout groups discussed the most appropriate uses of the model, assessed what model scenarios would prove most useful to stakeholders, and sought common ground concerning preferred future states of the Patuxent and Gwynns Falls Watersheds as a step towards defining endpoints for restoration efforts. The workshop proved valuable in developing future directions for model development to better meet stakeholder needs, and initiated the task of defining preferred states for the watersheds.

To ensure broad stakeholder participation, this research group is working in close collaboration with the Patuxent River Commission (PRC). A Scenario Development Working Group has been formed with the PRC to oversee and coordinate the development of the model with the needs of the stakeholders. As an outcome of this effort, several focus subwatersheds have been identified for case studies and specific applications for restoration projects, such as riparian buffer design and stormwater management.

The model has been applied in an optimization framework to find optimal patterns of land use and fertilizer application in a watershed. The goal function was chosen to take into account both economic and ecological considerations. The integration of both of these indicators makes the approach very promising for purposes of valuation of landscapes and watershed. Outreach efforts include maintaining a Web page with all the significant project developments and applications for public participation and dissemination of results. The project also became part of an educational effort in collaboration with the Calvert Department of Planning and Zoning and Calverton School to introduce high school students to watershed dynamics and modeling.

Understanding the Social Context for Ecological Restoration in Multiple-Ownership Watersheds: The Case of the Cache River in Illinois

Steven Kraft[1], Christopher Lant[2], Jeffrey Beaulieu[1], Leslie Duram[2], J.B. Ruhl[3], David Bennett[4], Jane Adams[5], John Nicklow[6], and Tim Loftus[2]

[1]Agribusiness Economics Department, [2]Geography Department, [3]Law School, [5]Department of Anthropology, [6]Department of Civil Engineering, Southern Illinois University, Carbondale, IL; [4]Geography Department, University of Kansas, Lawrence, KS

A conceptual framework that has been developed to help focus this work on the watershed planning process. As part of this process, the research team identified 30 individuals who were significant players in the recently completed watershed planning process in the Cache River Watershed. Using an open-ended questionnaire, indepth interviews of these key informants were conducted. The informants came from three main groups: Technical Committee and other agency personnel, local activists, and Resource Planning Committee members. Interviews were based on questions relating to the individual, the planning group, and outside influences. Interviews have been transcribed and are being analyzed.

Based on the interviews and literature review, a set of preliminary findings have been developed that will help to guide the remainder of the research. As analysis of the interviews continues and the focus group and telephone surveys are developed, it is important that these initial findings are used as a foundation for broader investigation within the watershed.

Findings deal with the following topics: (1) the Watershed Plan provides agency legitimacy; (2) there are divergent views between agency personnel and farmers regarding the format and substance of the planning meetings; (3) differences in the power base between farmers and environmentalists in the region have developed over time, so that environmentalists rely on the agencies, while farmers rely on elected officials; and (4) theories of power structure are relevant in the Cache and must be illuminated to understand the planning process and its outcomes.

There has been a complete review of both state and federal laws that impinge on watershed planning. Identifying the legal framework within which watershed planning takes place in conjunction with the analysis of the indepth interviews and literature review is expected to shed light on the question of the legitimacy of the planning process and the resulting watershed resource management plan. The question of the legitimacy of the planning process and the resulting resource management plan has occupied many of the research team meetings during the last year. A review of the literature indicates that this is a critical question in the planning process that has not been addressed.

The development and refinement of a spatial decision support system (SDSS) has continued throughout this phase of the research. For the SDSS, the research team is developing a graphical user interface that will facilitate the use of the SDSS with community members who are part of a watershed planning process. The goal is to have an SDSS that will show the economic and environmental consequences of different policy scenarios designed to enhance environmental quality. Watershed planners then would be able to develop a number of "what if" scenarios and see their economic consequences as well as the implications for the watershed's landscape. To enhance the SDSS, use of genetic algorithms (GAs) is being explored.

The development of the genetic algorithm code is complete. The Soil and Water Assessment Tool (SWAT) source code has been linked to the genetic algorithm for the single objective function. This model will directly evaluate the optimal land-use distribution to minimize sediment yield. Figure 1 demonstrates a solution convergence to a minimum sediment yield from a hydrologic response unit. This model will directly evaluate the optimal land-use distribution to minimize sediment yield.

In light of practical constraints, a database of feasible land-use management alternatives currently is being assembled for SWAT that are appropriate for the study area. These will be incorporated into the GA-SWAT optimal control model for the singular sediment objective. Simultaneously, linkages between the SWAT source code and MINOS (a mathematical programming program) are being developed for an economic-related objective. The next phase of work will consist of integrating the sediment and economic model to create one multiobjective optimal control model that interfaces SWAT and the GA for minimizing sediment yield and maximizing farming income.

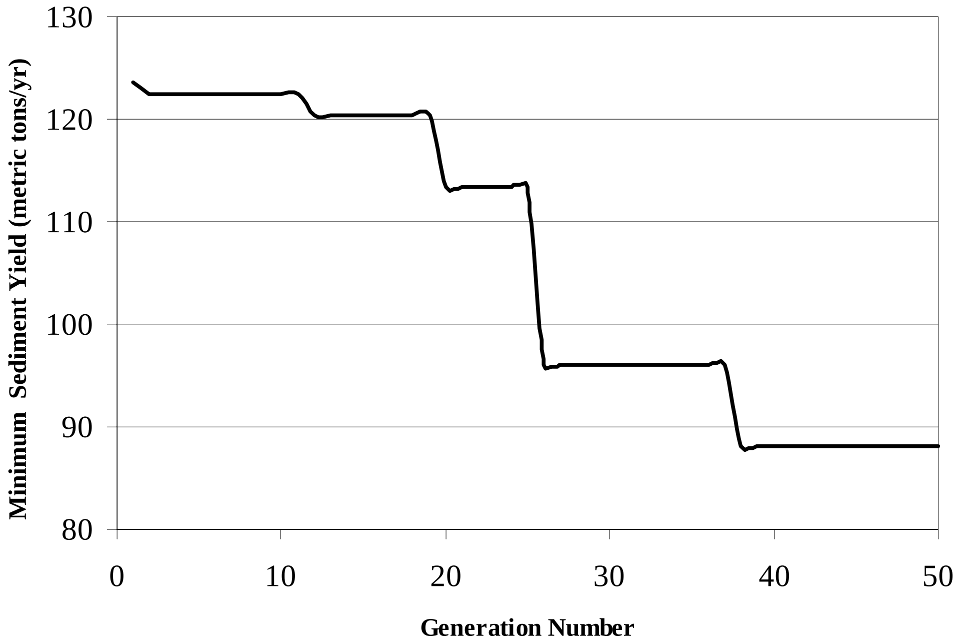


Figure 1. Solution convergence for a hydrologic response unit.

Restoring and Maintaining Riparian Ecosystem Integrity in Arid Watersheds: Meeting the Challenge Through Science and Policy Analysis

***Thomas Maddock, III*[1]*, Kathryn Baird*[1]*, Victor Baker*[1]*, Bonnie Colby*[2]*, Robert Glennon*[3]*, and Julie Stromberg*[4]**

[1]Department of Hydrology and Water Resources, [2]Department of Agricultural and Resource Economics, [3]College of Law, University of Arizona, Tucson, AZ; [4]Department of Plant Biology, Arizona State University, Tempe, AZ

This research project combines expertise from four disciplines whose knowledge is critical to restoring and maintaining rivers in the Southwest: hydrology, ecology, economics, and law. Hydrologic models, a riparian ecosystem integrity index, and economic analyses are being integrated into a user-friendly decision support system (DSS). Coupled with legal analysis, this integration is designed to aid in understanding the impact of development and in evaluating strategies for maintaining or achieving environmental restoration.

To improve estimates of riparian evapotranspiration (ET), ET measurements were taken in conjunction with climate, surface water, and groundwater parameters on the South Fork Kern River Basin. Detailed river elevation profiles and vegetation transects were surveyed. ET (stem flux) measurements are being analyzed in conjunction with the tree structure, hydrologic, and climatic information. Joint ET and abiotic measurements elucidate how abiotic parameters combine with tree physiology to determine the amount of water required by riparian trees. Community water requirements are scaled up from ET measurements, density and size class information, and coverage estimates from habitat maps derived from recent aerial photographs. To simulate surface water and groundwater behavior, the HEC-RAS and MODFLOW models are used. Flood flows associated with riparian recruitment events were determined from tree ring and river gauge data.

To develop an index of biotic integrity (IBI), field studies on two community types in the San Pedro Basin are underway to identify metrics that are sensitive indicators of site moisture availability. Research was conducted on sites spanning a gradient from wet (perennial stream flow) to dry (ephemeral flow). Vegetation variables from three categories were measured: individual productivity, population abundance and size structure, and community composition. Abundance and composition of terrestrial arthropods also were measured.

Correlation and univariate regression analyses are being used to determine the relationship of plant and insect variables with depth to groundwater, surface flow frequency, and soil moisture. Multiple regression analysis is used to determine whether the vegetation metrics vary with geomorphology, site elevation, and site hydrology. This allows for a determination of whether the IBI will require stratification by geomorphic reach type and/or site elevation. Threshold values, above or below which vegetation metrics change sharply, or which specific plant associations do not occur, are identified.

An economic model of costs and benefits associated with restoring riparian areas is being constructed. Economic activities relating to instream and consumptive uses of water, and estimates of local income related to differing water uses have been identified. The physical location and land ownership patterns along the South Fork Kern have been documented, giving background to the region's history, describing the population centers, providing an economic setting, and outlining both the surface water and groundwater users. A Kern River Preserve visitor's survey was implemented and will allow for an estimation of the local economic impacts of visitation to the riparian preserve. A parallel study is underway for the San Pedro. Both surveys assess visitor economic benefits from riparian area protection.

California groundwater and surface water law and the role of the Endangered Species Act (ESA) in managing rivers are being studied. A lawsuit filed by The Southwest Center for Biological Diversity that challenges, under the ESA, the administration of waterflow from Lake Isabella is being examined.

Development of an Urban Watershed Rehabilitation Method Using Stakeholder Feedback To Direct Investigation and Restoration Planning

Marty D. Matlock[1], *Charles D. Samuelson*[2], *William H. Neill*[3], *Tarla Rai Peterson*[4], *Ann L. Kenimer*[5], *and Guy D. Whitten*[6]

[1]*Department of Agricultural Engineering,* [2]*Department of Psychology,* [3]*Department of Wildlife and Fisheries Sciences,* [4]*Department of Speech Communication,* [5]*Department of Agricultural Engineering,* [6]*Department of Political Science, Institute for Science, Technology and Public Policy, George Bush School of Government and Public Service, Texas A&M University, College Station, TX*

This project has developed and is testing a method for restoring the ecological integrity of urban watersheds that integrates ecology, engineering, and social science. Research is being conducted on two streams in the San Antonio, TX, metropolitan area. Research questions include: (1) Can a risk-based watershed model linked with two ecoindicators in a regressive ecological risk assessment for a complex watershed quantify the uncertainty associated with ecosystem rehabilitation? (2) Will stakeholders' understanding of nonpoint source pollution issues, ability to use scientific information about watershed management strategies, and communication competence improve as a result of a collaborative learning (CL) intervention? A watershed model of ecological risk assessment is being developed. Models of stakeholder knowledge levels and environmental attitudes also are being developed.

A watershed model linked with an instream model has been developed to evaluate and optimize ecosystem management strategies. CL is being used to structure and facilitate stakeholder group activities among large, heterogeneous groups affiliated with the Salado and Leon Creek Watersheds in San Antonio. Two integrated ecoindicators are being used to evaluate and communicate risk to the stakeholder groups.

This risk-based approach is used to shape discussions between stakeholders and scientists in an iterative process that results in an informed and stakeholder-driven action plan for watershed rehabilitation. Social dilemma/game-theoretic analysis will be used to develop models of compliance under different assumptions about time and other actors' behavior. A simulation of the interactive effects of human and nonhuman factors on watershed nutrient levels will be developed.

A public opinion survey was designed to obtain detailed measures of public opinion on general and specific environmental issues and on local watershed issues among others, and to identify potential participants in the stakeholder recruitment process. The survey was administered to 1,017 randomly selected residents of Bexar County, TX. These data currently are being analyzed. The issues of representation and implementation are being examined (e.g., issues of efficacy, trust, participation, and optimism).

In November 1999, through December 2000, the project team held monthly meetings with the Salado and Leon Creek stakeholder groups. Potential participants were identified in a number of ways, including the public opinion survey and face-to-face contact with community groups. A snowball technique was used for additional recruitment. Three surveys—a pretest, followup, and posttest—were given to each of the stakeholder groups. These survey data allow for direct comparisons between the large sample telephone survey of Bexar County residents and the stakeholder groups participating in the CL meetings.

The statistical analysis of survey data will be conducted during 2001 to assess the effectiveness of the CL program in meeting project objectives. Followup interviews with stakeholder group members will be conducted in 2001 as well. Data from individual interviews with stakeholders and CL workshops will be analyzed to identify critical social processes and communication practices.

Field investigations of ecological processes were initiated in August 1999. Two sites were selected on two streams (one upstream and one downstream) flowing through San Antonio. Periphyton response to nutrient loading (nitrogen and phosphorus) was measured *in situ* using the Matlock Periphytometer. The survival, growth, and metabolic capacity of bluegill acclimatized in ambient stream water also were measured at each of the sites. The data currently are being analyzed, and field investigations will continue in 2001.

Geographic data have been compiled from a variety of sources (U.S. Geological Survey, Texas Natural Resource Conservation Commission [TNRCC], Environmental Protection Agency, National Aeronautics and Space Administration) to develop input data files for the Better Assessment Science Integration Point and Nonpoint Sources-Hydrological Simulation Program-Fortran (BASINS-HSPF) modeling program. Calibrating BASINS-HSPF in Salado and Leon Creeks has been completed in collaboration with the San Antonio River Authority and TNRCC.

Combining Economic and Ecological Indicators To Prioritize Wetlands Restoration Projects Within a Spatial GIS Framework

James J. Opaluch[1], Marisa J. Mazzotta[1], Peter August[2], Robert Johnston[1], and Frank Golet[2]
[1]Department of Environmental and Natural Resource Economics, [2]Department of Natural Resources Science, University of Rhode Island, Kingston, RI

Restoration and rehabilitation of damaged or degraded ecosystems is an important component of many of today's environmental and natural resource management strategies. It not only is important to protect and preserve watershed ecosystems, but also to restore degraded components so that the functioning of the entire system is maintained or improved. This project focuses on developing methods for setting priorities for wetlands restoration projects and applying the tool to restoration of coastal wetlands. The research will address three issues related to valuing wetlands: (1) spatial aspects of value, (2) cost-effective methodologies for valuation, and (3) transferability of methods and values. The research employs a three-phased approach to provide sequential links from physical wetlands features, to functions provided by the wetlands, to values of those functions, and ultimately, to setting priorities for alternative restoration projects.

Phase I develops the methodology of the study, and provides initial steps in identifying and defining indicators. This phase includes development of the conceptual linkages between indicators, indices, and valuation methods; linking indicators with benefits transfer methods; coordinating the approach with data collection efforts by the Rhode Island Department of Environmental Management; and identifying an initial set of indicators to serve as a starting point for the field research, included in Phase II.

Phase II develops and implements two surveys—a survey of technical experts, and a survey of the general public. The survey of technical experts identifies specific features that contribute to the potential for the wetland to provide important functions. For example, open water and tidal creeks can contribute to a wetland's potential for fish and bird habitat. The general public survey elicits public values for important wetland functions.

Phase III uses the methods and data developed in Phases I and II to develop and implement the geographic information system-based tool for identifying wetland priorities based on indicators of social and economic values. It also will test the transferability of the method to other sites by applying results to additional locations in Rhode Island and in another state.

To date, the project has focused on habitat functions of wetlands, as they appear to be the principal function of Rhode Island coastal wetlands. The research group is in the process of completing focus group pretests that are critical to development of the public survey. Simultaneously, meetings have been held with wetland experts to learn about important wetland issues and to develop a method for eliciting expert opinion on the linkage between physical features and habitat quality for the various species groups.

When complete, the approach will provide input into prioritizing wetlands restoration programs. The research group is working closely with the state's interagency restoration team, which is in the process of developing tools to prioritize restoration actions. The research project's efforts have been designed to be complementary—in particular, to provide public input that is needed by the state.

Integrating Science and Technology To Support Stream Naturalization

Bruce L. Rhoads, David Wilson, Edwin E. Herricks, Marcelo Garcia, and Rebecca Wade
University of Illinois at Urbana-Champaign, Urbana, IL

Recent initiatives by federal agencies, including the Environmental Protection Agency, have supported a move toward integrated watershed management that emphasizes community-level decisionmaking based on sound science. The concept of stream naturalization, which seeks to establish sustainable, morphologically and hydraulically varied, yet dynamically stable fluvial systems that are capable of supporting healthy, biologically diverse aquatic ecosystems, is consistent with this new perspective. Naturalization integrates biological, physical, and social science within a local decisionmaking context over multiple temporal and spatial scales.

This research project seeks to develop an integrated scientific and technological framework for stream naturalization. Empirical and modeling aspects of the research are focusing on case studies of stream naturalization in two small watersheds in the Chicago metropolitan area. These case studies highlight the scientific and technological challenges associated with naturalized stream-channel designs as well as the vital role of social interaction and community perceptions in the naturalization process.

The research design combines social analysis, both of community-based environmental visions and of decisionmaking about stream naturalization, with a scientific/technical analysis aimed at generating a predictive understanding of, and technical basis for, stream naturalization. The social methodology includes analysis of the historical development of the environmental vision within each community, and case-study investigations of current components of this vision and the role of scientific information in sustaining this vision. Scientific/technical research is developing and integrating engineering-based modeling of stream dynamics with geomorphological analysis of stream processes and ecological analysis of physical habitat and fish population dynamics.

The two study sites for this project are the West Fork of the North Branch of the Chicago River, Northbrook, IL, and Poplar Creek, Elgin, IL. Results of the social analysis in Northbrook highlight some tensions associated with the implementation of the concept of naturalization. These tensions stem from the dichotomy between stakeholder values and desires and "expert" sense of best usage and vision. Naturalization centers on the implementation of pool-riffle sequences within a section of the North Branch in downtown Northbrook. The research team has assisted local decisionmakers with project design. The pool-riffle structures are based on ecogeomorphological principles and have been tested via hydraulic modeling.

Social analysis in Elgin is examining discourses of environmental resource provision. Current plans call for a channelized section of Poplar Creek to be remeandered and its floodplain restored to presettlement conditions. The creek is viewed as a natural resource for community use. Social analysis is examining the values, ideologies and languages that underlie the provision of this resource.

Geomorphological research has focused on the pattern and movement of large woody debris in the creek and characterizing the influence of this debris on patterns of three-dimensional flow and channel erosion and deposition in meander bends. This analysis provides a framework for ecological studies of fish and macroinvertebrate habitat and for modeling-based assessments of stream remeandering.

Selection of Wetland Restoration Sites in Rural Watersheds To Improve Water Quality: Integrating Ecological and Economic Approaches

Curtis J. Richardson, Randall A. Kramer, and Neal E. Flanagan
Nicholas School of the Environment, Duke University, Durham, NC

The primary objective of this study is to develop a procedure for configuring mosaics of restored wetlands on the landscape to yield the greatest positive cumulative effect on watershed-level water quality given a set of ecological, economic, and political constraints. This study focuses on the development of a decision support system (DSS) to assist land managers in the site locations of restored wetlands with the objective of maximizing watershed-level water quality improvement.

The DSS will rely upon a water quality model that examines the watershed-level water quality impact of restoring wetland areas. An economic model also will be included in the DSS, which assesses the willingness of landowners to participate in wetland restoration programs based on their socioeconomic characteristics, various aspects of the program, and other factors that affect land-use decisions. Economic data for use in the DSS were collected through a survey of roughly 500 landowners/operators in selected areas of North Carolina.

The survey was developed through an extensive period of literature reviews, collecting background information, and conducting focus groups. It used a conjoint analysis methodology to assess the preferences of landowners for wetland restoration programs with different options. Various socioeconomic and land-use information also was collected. Soil, hydrology, and land cover data were used to identify potential wetland restoration sites.

A classification and regression tree (CART) model was used to relate water quality and watershed characteristics at sites monitored by the U.S. Geological Survey National Water Quality Assessment Project. A dynamic nonpoint source water quality model was used to explore alternative restoration scenarios, and site-level data at a coastal wetland restoration site were used to validate the regional simulation models.

Survey administration commenced in November 2000, and was completed in January 2001. Survey data are being analyzed through statistical and econometric methods to develop a model predicting the participation decisions of landowners/operators. Preliminary survey results indicate that landowners generally favored restoration programs that allowed for shorter-term contracts (10–15 years), that allowed them to lease land for undeveloped recreational use, and that were administered by state agencies.

The ecological portion of this study examined the relationship between wetlands and water quality at local, watershed, and regional spatial scales. Preliminary statistical models utilizing both CART and discriminant analysis models classified 300 samples into one of three water quality categories using watershed characteristics and hydrologic flux. The model predictions were correct for 80 percent of the sample analyses.

The key findings from these studies will be instrumental in determining which sites have the highest potential for wetland restoration success in terms of water quality improvement on the landscape. Most important are findings concerning the reasons for and willingness of landowners to participate in programs to convert current agriculture lands into restored wetlands. After survey data have been analyzed, they will be integrated into the ecological modeling effort to build the DSS. The DSS will combine both biophysical data on the water quality impacts of wetland restoration and socioeconomic data, such as the willingness of landowners to participate in various restoration scenarios, relevant demographic information, and their land-use preferences.

When Do Stakeholder Negotiations Work? A Multiple Lens Analysis of Watershed Restorations in California and Washington

Paul Sabatier, William Leach, and Neil Pelkey
Department of Environmental Science and Policy, University of California, Davis, CA

This paper reports some preliminary results from the Watershed Partnership Project at the University of California at Davis. The project uses a database consisting of random samples of approximately 60 watershed partnerships in California and Washington. In each case, 3–5 diverse participants are interviewed, mail surveys are sent to all participants and some knowledgeable outsiders, and relevant documents are coded. This results in about 350 variables per case.

The project seeks to: (1) measure partnership success on five different dimensions, and then (2) explain variation in success using three different conceptual frameworks: Transaction Costs Economics, Ostrom's Institutional Analysis and Deliberation Framework, and a version of the Advocacy Coalition Framework developed by Sabatier and Jenkins-Smith that has been expanded to include Alternative Dispute Resolution (Bingham, Carpenter).

Preliminary results from an analysis of 30 cases reveals that development of trust within the partnership usually is the most important factor explaining most success measures. It also was found that a certain age (usually around 40 months) is necessary for partnership success, but that success does not necessarily increase with age above that threshold.

Members' satisfaction with the quality and accessibility of technical information also tends to be correlated with several dimensions of success. Conversely, the size of a partnerships' budget, whether it has a paid coordinator, and the extent of belief conflict within the partnership do not appear to be consistently associated with success measures. The findings of this research project should, however, be viewed with great caution until the number of cases analyzed can be increased to approximately 50 (it is hoped to accomplish this by the time of the Progress Review).

Integrating Models of Citizens' Perceptions, Metal Contaminants, and Wetlands Restoration in an Urbanizing Watershed

Robert K. Tucker [1], ***George S. Hawkins*** [1], ***Peter R. Jaffe*** [2], ***Kerry Kirk Pflugh*** [3], ***and Branden B. Johnson*** [3]
[1]*Stony Brook-Millstone Watershed Association, Pennington, NJ;* [2]*Princeton University, Princeton, NJ;* [3]*Division of Science, Research, and Technology, New Jersey Department of Environmental Protection, Trenton, NJ*

The overall goal of this project is to use the scientific information from this research to increase public understanding and support for the vital role wetlands play in the integrity of watersheds. The approach involves scientific investigations of metals interactions in wetlands, education, and social science assessment of the outreach efforts. One focus of this research is nonpoint source pollution, particularly toxic metal impacts on wetland function and water quality.

The nonpoint contamination is closely related to the degree of development and intensity of human activity within the watershed. This has been documented in a comprehensive assessment and characterization of one of the subwatersheds, Beden Brook. Data on water quality, threatened and endangered species, invasive species, contaminated sites, land use and management, and area geology and demographics are included.

Research conducted by investigators at Princeton University will provide detailed information on metals behavior in the oxygen-depleted soils of wetlands, particularly as affected by the roots of plants. The University has made significant progress with electrochemical techniques to measure concentration profiles of electron acceptors and trace metals in pore water and on developing the model to simulate trace metal dynamics in wetland sediments. Figures 1a, 1b, and 1c illustrate the simulated profiles in wetland sediments of the key electron acceptors, their corresponding reduced species, ammonia, and arsenic. Arsenic is used to illustrate the effect that the wetland rhizosphere has on the speciation of a metalloid of concern in the environment.

New Jersey Department of Environmental Protection social scientists have interviewed selected experts on wetlands from federal and state government, academic, consulting, and nonprofit sectors for their attitudes about wetlands. They also have started conducting a survey of citizens on their attitudes about wetlands. All experts thought preservation of existing wetlands was by far the best management approach, although they differed fiercely on how to prevent wetlands development.

Information from this research already has played a key role for local citizens in opposing such environmentally harmful projects as a sewer extension into a largely undeveloped and environmentally sensitive area, and in persuading the Governor of New Jersey to mandate a comprehensive environmental impact study of a proposed road adjacent to wetlands along the Millstone River.

A model stream protection ordinance for area municipalities has been drafted, and environmentally protective "river friendly" strategies for residents, golf courses, and other businesses have been developed. Venues for dissemination of information include the Natural Lands Network, which the Stoney Brook-Millstone Watershed Association helped organize. The Network meets with 40 local land trusts, environmental commissions, and planning board members.

A Watershed Institute also has been formed to provide support and assistance to growing watershed associations—this research group is working with the New Jersey Council of Watershed Associations to unify these associations and advocate for policies that protect water quality and natural resources. On January 29–30, 2001, this research group sponsored a seminar at the Woodrow Wilson School, Princeton University, for local municipal officials. The seminar was titled "Preserving This Place Called Home," and included information on wetlands protection.

Next steps include field measurements of metals and intensive characterization of another of the subwatersheds, Rocky Brook, in the headwaters area of the Millstone River. Additional educational efforts and surveys of the effectiveness of the educational outreach will be conducted.

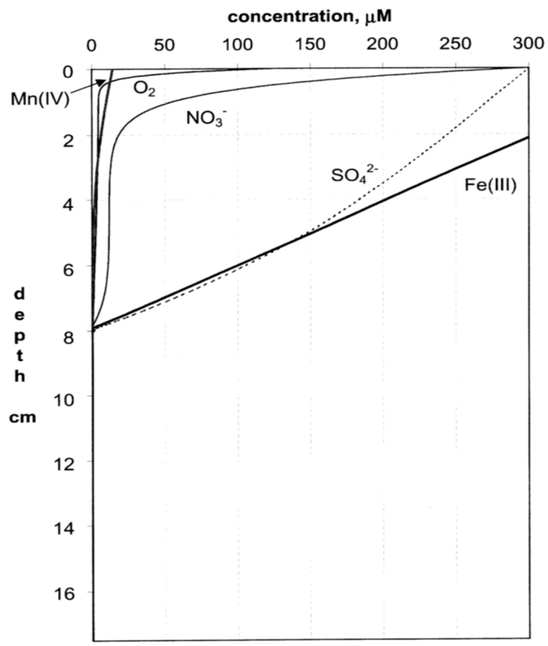


Figure 1a.

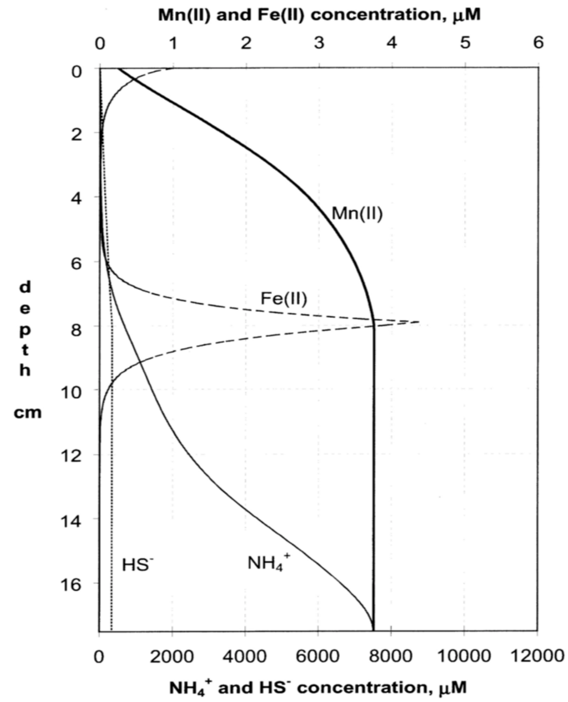


Figure 1b.

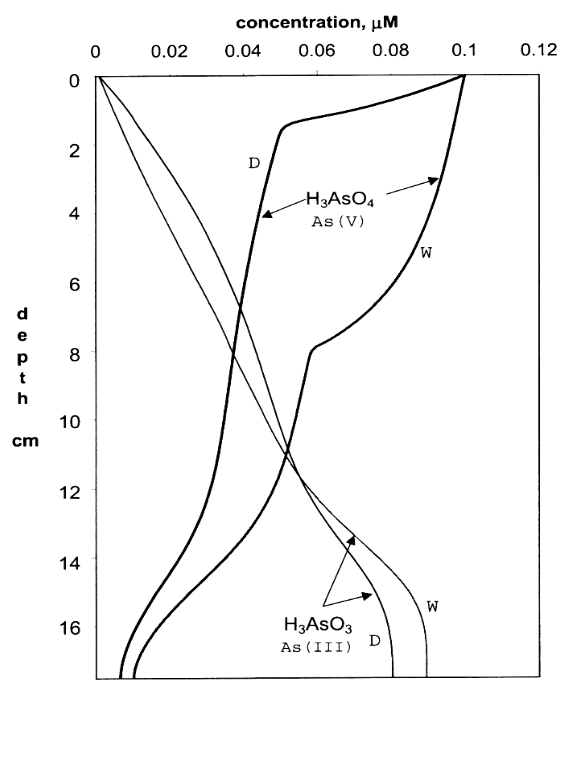


Figure 1c.

Figures 1a, 1b, and 1c. Simulated concentration profiles in wetland sediments. Figure 1a: Electron acceptors; Figure 1b: Reduced species; and Figure 1c: Arsenic. Figure 1c shows the effect of roots on the simulated arsenic profiles (D = no roots, W = roots that penetrate 8 cm into the sediments, which are the same conditions as for Figures 1a and 1b).

Changes in River-Land Uses and Management: Implications for Salmonid Habitat Restoration in the Lower Cedar River, Washington

***Robert C. Wissmar*[1], *Thomas M. Leschine*[2], *Ray Timm*[1], *David Fluharty*[2], *and John Small*[3]**
[1]School of Aquatic and Fishery Sciences, [2]School of Marine Affairs, University of Washington, Seattle, WA;
[3]King County Department of Natural Resources, Seattle, WA

This joint societal-ecological research project is elucidating how the distribution of human development and conflicts affect salmonid habitat restoration efforts in the Lower Cedar River Basin, and what restoration efforts make riverine ecosystems and habitats more resilient to human influence. Any biodiversity in the system is beneficial, even if it is short lived, functionally. Also, approaches to increasing longevity are essential given restoration costs.

The goal is to develop societal-ecological approaches that can be applied to restoration initiatives and conflicts ranging from human actions that alter local habitats to growth management policies that influence ecosystem functions at larger geographic scales (e.g., connectivity between habitats, fish migrations). Humans today and historically have modified the river (e.g., flow regulation-diversion and channel-confining structures), resulting in unnatural channel forming processes that homogenize habitats. These actions and other uses have caused the Cedar River and floodplains to lose habitat biodiversity and to be unavailable to fish and wildlife.

Contemporary and historic changes must be accounted for in restoration planning. Conflicts between human development and salmonid habitat restoration are very common due to direct competition for land and water resources. Problems arise when restoration of habitats in river channels depend on existing mandates (Endangered Species Act listings) that conflict with provisions for reducing impacts of flood hazards on human activities. Other problems arise when restoration activities within the basin are based on an opportunistic model. For instance, where resources are available for specific actions (e.g., habitat mitigation), there is a higher likelihood of restoration taking place. Together these issues indicate the need to bring comprehensive, risk-based approaches to restoration planning.

The research group currently is using a geographic information system-based approach to identify areas where human influences most compromise the functional ability of current and potential restoration sites. Some research questions include: (1) How can contemporary habitat restoration best compensate for the heterogeneity that has been lost? (2) How successful are restoration projects that take advantage of opportunities offered by other management programs? (3) What approaches provide effective ways of resolving conflicts between human development and salmonid habitat restoration?

Section 3.

Projects Initiated With Fiscal Year 1997 Support

Community Values and the Long-Term Ecological Integrity of Rapidly Urbanizing Watersheds

M. Bruce Beck [1], A.K. Parker [1], T.C. Rasmussen [1], B.C. Patten [2], K.G. Porter [2], B.G. Norton [3], and A. Steinemann [3]

[1]Warnell School of Forest Resources, [2]Institute of Ecology, University of Georgia, Athens, GA; [3]School of Public Policy and College of Architecture, Georgia Institute of Technology, Atlanta, GA

This research project seeks to integrate ecological, hydrological, and social/policy sciences in a study of a rapidly urbanizing watershed (Lake Lanier, GA), where preservation of long-term ecological integrity is perceived as being at stake. More speifically, the goals are to: (1) develop a concept of environmental decisionmaking in which science-based models are responsive to identified community values, as they evolve in both the short and long term; (2) develop and apply a procedure for identifying those scientific unknowns crucial to the "reachability" of the community's desired/feared environmental futures; and (3) improve understanding of basic aspects of lake ecosystem behavior, with special reference to the roles of the microbial foodweb, sediment-nutrient interactions, and geochemistry.

There are six steps involved in the overall procedure of environmental decisionmaking. These steps ideally would be implemented in the following sequence: (1) elicitation and elaboration of stakeholder concerns for the future; (2) development of the mathematical model cast in terms (state variables) compatible with these concerns; (3) computational analysis of target futures; (4) communication to stakeholders of plausibility (implausibility) of target futures; (5) identification of key scientific unknowns upon which plausibility hinges, and specification of experimental studies designed to reduce these uncertainties; and (6) entry into a second iteration of the sequence, from (1) adapted in the light of (4). Progress can be reported according to the logic of this procedure.

Thus, this research group has experimented with two instruments (a survey and a participatory "Foresight" Workshop) designed to elicit stakeholder hopes and fears for the longer term target futures (step [1]), with varying degrees of success. In general, the survey revealed an extremely high concern for the well-being of Lanier, and a possibly counterintuitively yet greater concern for the longer term, as opposed to the shorter term, future—a form of "reverse time preference." There clearly was a tendency for respondents to be most troubled by threats over which they perceived they (and their cohorts) had least control. The Foresight Workshop appears to have proved to be the more successful instrument in anchoring comunity/stakeholder concerns to the quantitative scales attaching to the state variables of these models (step [2]). One of these, a foodweb model incorporating the microbial loop hypothesis of Pomeroy, has been designed expressly for the purpose of analyzing the reachability of the so-derived futures (step [3]).

Another model, the Generalized Lake Lanier Ecosystem Model, has been constructed to serve the purpose of communicating scientific concepts to a (scientifically) lay audience (step [4]), wherein the issue of quality assurance—given the notion of "models as languages"—also can be addressed, as an important question of research in its own right. To identify from the foodweb model the key scientific unknowns (step [5]), computational and methodological extensions of the so-called Regionalized Sensitivity Analysis have been explored, specifically the multivariate procedure of Tree Structured Density Estimation.

On the basis of these computational studies and, more importantly, from intensive field work on manipulating a small pond system, this research group has come to the view that the classical paradigm of P cycling (see Figure 1) does not apply to the case of Piedmont impoundments with iron-rich sediments. In response to clearly and strongly expressed stakeholder concerns (from step [1]), a significant portion of the research under step (5) has been devoted to implementing field work on the pond system intended to provide a qualitative conceptual model of the propagation and fate of pathogens in a water-watershed system.

Within the scope of the present project, it seems unlikely that the features of this conceptual model can be given more quantitative expression. However, development and preliminary testing of a biogeochemical impoundment model have been completed. This model combines fairly detailed accounts of the carbonate-pH and Fe-sediment subsystems with the more conventional nutrient (C, N, P)-phytoplankton subsystem to explore the behavior of the vertical dissolved oxygen (DO) profile and sediment-water interactions of Lanier. In the light of what may have to be a revised view of P cycling in Piedmont impoundments, this research group is especially interested in understanding the scope for P being cleaved from Fe under substantial, transient, phytoplankton-induced excursions in DO and pH conditions.

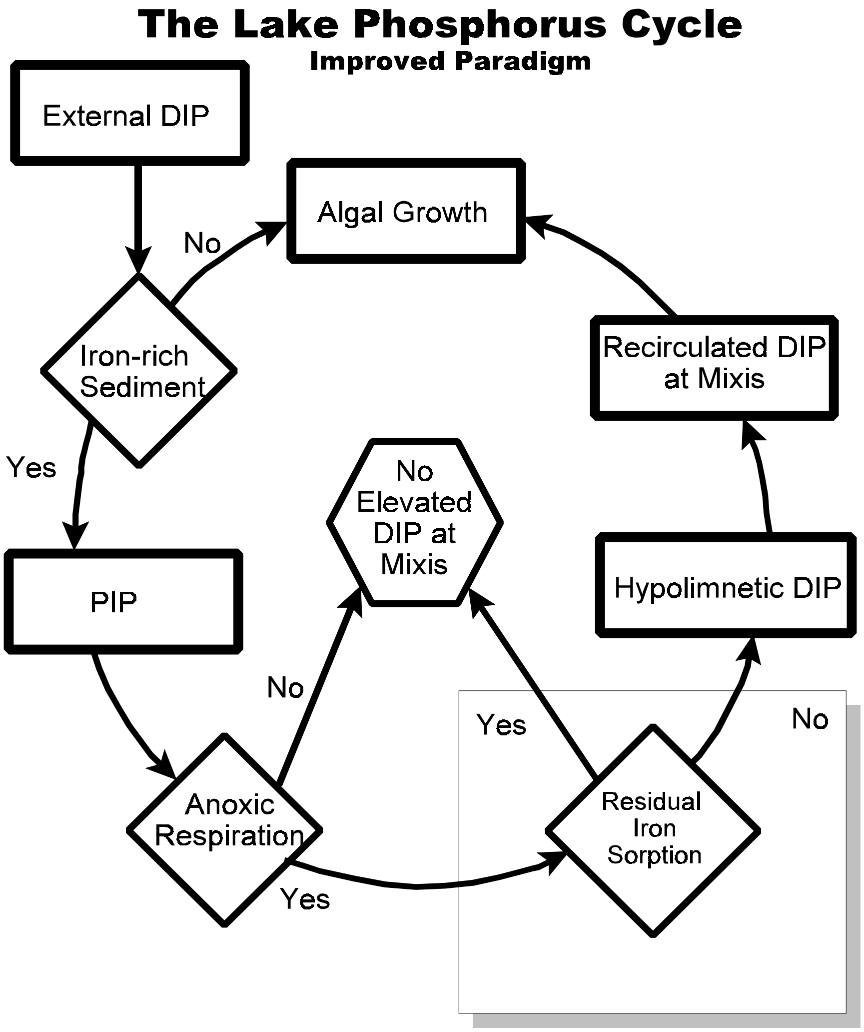


Figure 1. The phosphorus cycling program in lakes is based on data from systems in northern temperate regions. Phosphorus sorbs to iron-rich sediments from tributaries and runoff to form particulate inorganic phosphorus (PIP). Anoxic respiration in the hypolimnion of north-temperate lakes creates strongly reducing conditions that liberate dissolved inorganic phosphorus (DIP) from settling particulates. Hypolimnetic DIP steadily increases during summer stratification as phosphorus is liberated, and is mixed throughout the water column at fall overturn. This paradigm fails to explain phosphorus cycling in Southeastern Piedmont lakes. No increase in DIP is found in the anoxic hypolimnion during summer stratification, nor is an increase in DIP observed during fall overturn in Southeastern Piedmont lakes. It is hypothesized that the conventional paradigm is not appropriate in iron-rich Southeastern Piedmont systems because: (1) iron-oxide sorption reduces the bioavailability of DIP, and (2) the abundance of oxidized iron prevents DIP accumulation in the anoxic hypolimnion.

Connecting Ecological and Social Systems: Watershed Research Relating Ecosystem Structure and Function to Human Values and Socioeconomic Behaviors

Gaboury Benoit, S. Kellert, M. Ashton, P. Barten, L. Bennett, D. Skelly, and S. Anisfeld
Yale Environmental Studies, New Haven, CT

The goal of this research project is to elucidate ways in which ecological and social systems shape each other, and to understand the mechanisms by which the structure and function of natural systems influence, and in turn are influenced by, human values and socioeconomic behaviors. In the current phase of the research, a paired watershed approach was used, involving the collection of original data from 18 subwatersheds within the basin formed by the three rivers (Qunnipiac, West, Mill) entering New Haven Harbor, CT.

The aggregated area of the subwatersheds studied totaled more than 8,000 ha and included the homes of 18,000 people. Subwatersheds were selected from tributaries of the three major rivers and range in size from 113–826 ha and are drained by low-order streams (first or second). Watersheds were chosen to include a broad range of human population density, from rural to urban.

Within each subwatershed, teams of researchers measured hydrological, chemical, and biological attributes (39 variables) of the streams and the surrounding uplands. Direct observation and responses to surveys of individual watershed residents also were used to quantify the values, beliefs, and behaviors of the human residents of each subwatershed. Human responses included a total of 25 variables collected by direct observation (household quality and neighborhood quality measured on an ordinal scale, number of households per hectare), and in the form of two surveys conducted in each subwatershed. Most answers were used to calculate a set of 15 indices that previously were developed. Responses from a mail survey in each subwatershed were used to calculate valuations of water quality, appearance, biological diversity, and the willingness to pay for conservation of these values. Finally, previously collected information on land use and land cover (34 mutually exclusive categories) was used within each subwatershed to quantify landscape patterns.

Principal components analysis (PCA) was used to reduce the dimensionality of each data set. The number of components was determined using the broken-stick method in each case. Canonical correlation analyses were used to evaluate the null hypothesis that there is no linear relationship between variables within the two multivariate data sets. Three such tests were conducted to evaluate the relationships between biophysical and social data sets ($p > 0.05$), biophysical and landscape data sets ($p < 0.01$), and between social and landscape data sets ($p < 0.01$).

PCA results show strong correlations between landscape and biophysical variation and between landscape and social variation. Thus, these data are consistent with the hypothesis that human beliefs, attitudes, and values are associated with the structure of the landscapes we live in, and in turn, with the composition and functioning of the ecosystems those landscapes represent. The original conceptual model consisted of three components (ecosystem health, human environmental values, and socioeconomic benefits) linked to each other by direct, but unknown, feedback processes.

Results to date suggest a different set of linkages (see Figure 1), with ecosystem health and human environmental values connected through the intermediary of landscape structure. Interestingly, these associations seem not to be strong functions of differences in wealth or education among people living in the subwatersheds. Further statistical tests (factor analysis) indicated that the relationship between social and biophysical variables was manifest in certain subwatersheds more than others, and this result corroborated elements of the hypothesized link between human values and ecosystem structure and function.

Additional funding is being sought for the next phase of this research. The plan is to conduct large-scale field experiments to probe causal mechanisms for correlations revealed to date.

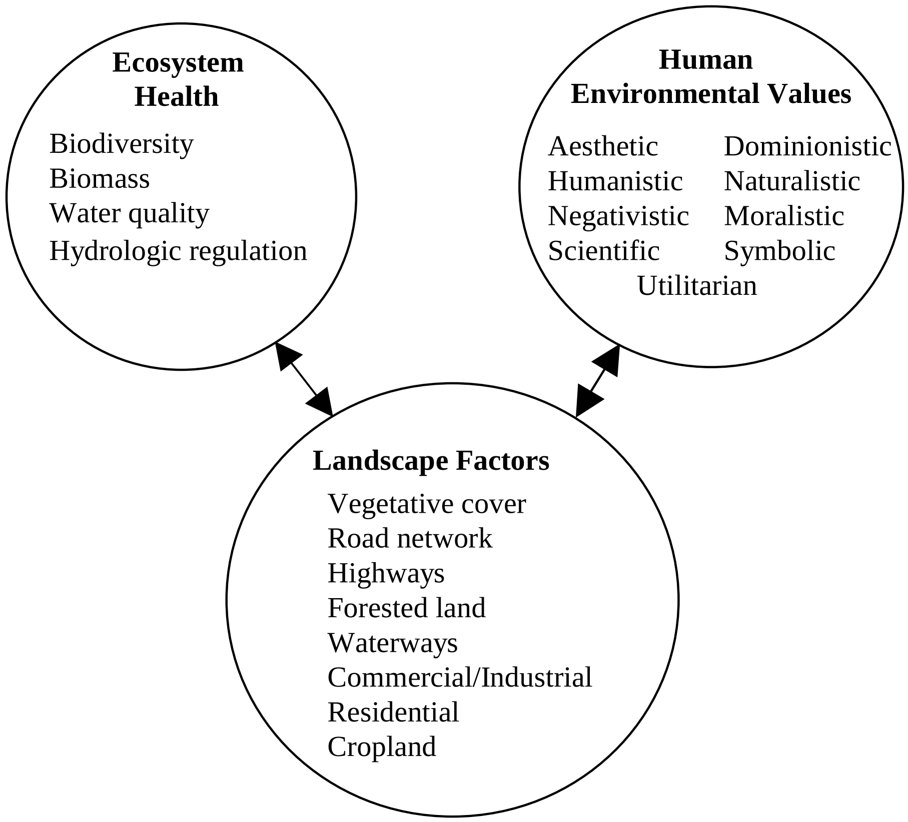


Figure 1. Results of this project to date suggest that ecosystem health and human environmental values are connected through the intermediate of landscape structure.

Social and Ecological Transferability of Integrated Ecological Assessment Models

***Linda A. Deegan*[1]*, James Kremer*[2]*, and Thomas Webler*[3]**
[1]*Marine Biological Laboratory, Woods Hole, MA;* [2]*Department of Marine Sciences, University of Connecticut, Groton, CT;* [3]*Social and Environmental Research Institute, Leverett, MA*

The goals and objectives of this research project are to: (1) create a model of broad generality that links land-use patterns and nitrogen loading to ecologically important and socially relevant endpoints of water quality, eelgrass habitat, and fish diversity and abundance; (2) measure estuarine fish habitat and community structure throughout a range of estuaries in southeastern New England, and develop empirical relationships of biotic integrity and habitat quality; and (3) investigate perceptions of ecological models and modeling science by town planners, with the objective of determining the best and most efficient way to encourage scientifically aware decisions at the crucial, local level of land-use debate.

The team is working to develop an estuarine ecosystem response model (Changing Land Use and Estuaries [CLUE]) that will aid in understanding how several biological and physical factors influence the range of ecological responses to nutrient inputs. The goal is to develop a model that is more readily transferred to other systems, and thus amenable to management applications when extensive and expensive scientific studies are unavailable or not feasible. One unique aspect of the output is its probabilistic character, an important and usually underemphasized aspect that planners should understand if they are to make realistic, scientifically informed decisions. Data to build and test the model derive from studies of water quality, fish habitat, and community structure in 16 estuaries of Buzzards Bay and Cape Cod, MA, sampled from 1993–1999, and eight estuaries of south coastal Rhode Island and Connecticut.

The social science has focused on three major components of estuarine science in the community: (1) attitudes and beliefs about ecosystem models among local governmental officials in small towns in southern New England; (2) performance of a participatory modeling tool (MANAGE) as applied in Jamestown, RI, by the cooperative extension service of the University of Rhode Island; and (3) characterization of views on ecosystems models and their application in local decisionmaking by modelers and outreach professionals in southern New England.

In several submitted manuscripts, this research group has documented large, eutrophication-driven changes in the fish community and fish habitat structure during the past decade in 24 estuaries of southeastern Massachusetts, Rhode Island, and Connecticut. It was shown that the biotic integrity of many of these estuaries has been severely degraded from historical levels over a relatively short time interval (1–5 years) (see Figure 1). The estuarine biotic integrity (EBI) index that was developed has been shown to have broad applicability within the southern New England ecoregion, and could be a valuable monitoring tool to assess the recovery of ecosystem function after eutrophication remediation.

Juvenile fish community characteristics and fish abundance in the studied estuaries are strongly influenced by the integrity and sustainability of eelgrass (*Zostera marina*) habitat. Healthy eelgrass beds are necessary to sustain estuarine carrying capacity and biodiversity. In those communities bordering estuaries with extant eelgrass beds, land-use decisions can jeopardize the integrity of this essential fish habitat. The CLUE model of nitrogen loading and ecosystem response will be a useful land-use planning tool. Improved understanding of the use and perceptions of ecological models by planners will facilitate design of presentation styles and formats by scientists to promote informed land-use decisionmaking at the local level.

Recent results show that the inherent optical properties and the contribution of colored dissolved organic matter and nonpigment particles to water clarity also may be important in controlling estuarine plant and algal production. Previous work has shown very unsatisfactory relationships between chlorophyll and the diffuse attenuation coefficient in these coastal waters, and resolution of this issue is a *sine qua non* for the modeling effort.

This research group also has found a striking mismatch between local policymakers' desires for models to reveal consequences of development on the scale of a single building lot and scientists' admonishments of using models to justify decisions at this level. Modelers perceive the endpoints local decisionmakers request as improper uses of models.

This research group will integrate the EBI index into the CLUE ecosystem response model and test its usefulness in new estuarine settings. Field data from 1998–2000 will be used to formulate the bathymetric and watershed characteristics that force the model, and to display observed estuarine data against which to evaluate model goodness-of-fit in as many as 13 estuaries. It is anticipated that the Jamestown, RI, study will be completed this spring, and analysis of results will be written.

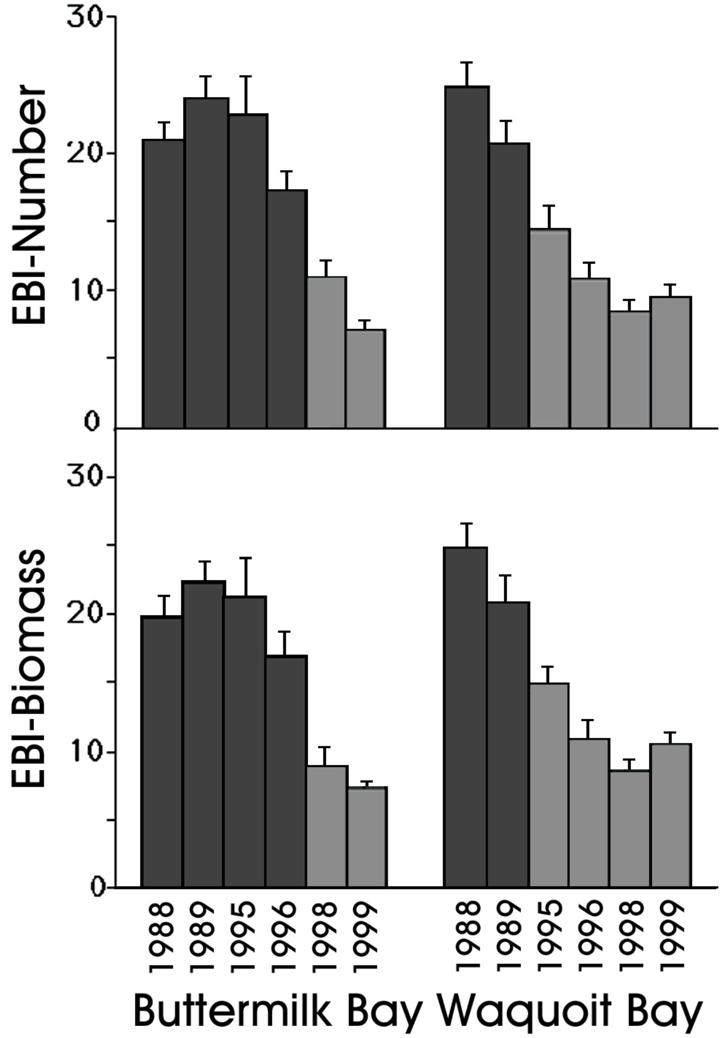


Figure 1. Estuarine biotic integrity (EBI) index measurements averaged over sampling sites in Buttermilk Bay (four sites) and Waquoit Bay (five sites), 1988-1999. Dark gray bars indicate years in which eelgrass was present in at least two sites in Buttermilk Bay and three sites in Waquoit Bay. Light gray bars indicate the absence of eelgrass in any sites.

From Landscapes to Waterscapes: An Integrating Framework for Urbanizing Watersheds

P. Diplas[1], E.F. Benfield[2], D.J. Bosch[3], W.E. Cox[1], R. Dymond[1], D.F. Kibler[1], V.K. Lohani[4], S. Mostaghimi[5], P.S. Nagarkatti[2], D.J. Orth[6], L.A. Shabman[3], and K. Stephenson[3]

[1]Department of Civil and Environmental Engineering, [2]Department of Biology, [3]Department of Agricultural and Applied Economics, [4]Department of Engineering Fundamentals, [5]Department of Biological Systems Engineering, [6]Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA

Urbanization, farming, and other types of land-use change activities can significantly alter storm hydrographs and sediment erosion rates within a watershed. These effects can cause more frequent flooding and increased pollutant loading, which in turn might result in the degradation of the physical and biological integrity of streams and other aquatic ecosystems. Regardless of these problems, watershed development appears inevitable.

The central issue, therefore, is how to reconcile development with acceptable environmental quality at an affordable price. The overarching goal of this project is to develop procedures for integrated assessment of the hydrologic, ecological, and economic consequences of alternative landscape scenarios occurring during the urbanization/suburbanization process.

More specific objectives include: (1) development of an integrated hydrologic framework for assessing the impacts of alternative landscapes on surface and subsurface water flows and movement of sediments and pollutants; (2) development of procedures to predict the response of fish and macroinvertebrate communities to urbanization-induced changes in water quantity, water quality, and other biological conditions; and (3) identification and assessment of policy and economics consistent with alternative landscape scenarios as well as estimation of the effects of alternative landscapes on land values and fiscal consequences for local governments. A case study focusing on the Upper Roanoke River Watershed is employed to test the operation of the integrated framework that currently is under development.

The various components of this research project are addressed by the following groups: hydrology/hydraulics, biology, economics/policy, and geographic information systems/problemsolving environment. The computer models HSPF and MODFLOW are utilized to determine the changes in the surface and subsurface runoff taking place within a subwatershed triggered by a certain amount of development. The first tends to respond more rapidly while the latter, depending on the local geology, might take many years to reach quasisteady-state conditions. It is, therefore, this longer time horizon that needs to be considered when examining the impacts of land-use change.

The output from these models becomes input to RMA-2V, the computer model that was used to simulate the river flow. Usually, a major difference between streams in heavily developed areas compared to those found in areas of low level of development is in terms of channel topography or complexity. Biologists have identified channel complexity as an important ingredient of stream ecology. New methods have been devised for modeling the localized flow patterns generated by these topographic features. Spatial metrics have been developed and found to better describe the abundance of stream habitat.

Extensive fish and macroinvertebrate data collected from streams representing different size watersheds indicate that changes in diversity and richness of species are connected with land-use practices. Vegetation strips along the river significantly reduce the adverse effects of land-use changes within the watershed. Immunotoxicological tests indicate that fish may serve as excellent biomarkers for environmental pollutants, and therefore may act as warning systems for human health hazards.

Four development footprints, which vary from low to high density, are used to estimate the effects of alternative settlement patterns on public service costs and land value estimates, and the concomitant environmental consequences. A computer interface that integrates hydrological and economic aspects of this study was developed recently. A Web-based version of this model currently is underway. During the remaining part of the project, the integration of the various components, as well as issues regarding the interfaces between hydraulics and biology, hydrology, and economics will be examined further. A specific subwatershed has been selected to apply the entire modeling procedure for various degrees of urbanization and alternative settlement patterns.

Conversion of Science Into Management Decisions at Lake Tahoe (CA-NV)

Charles R. Goldman[1], John E. Reuter[1], S. Geoff Schladow[2], Alan Jassby[1], M. Levant Kavvas[2], Alan C. Heyvaert[1], Theodore J. Swift[1], and Jennifer E. Coker[2]

[1]Department of Environmental Science and Policy, [2]Department of Civil and Environmental Engineering, University of California, Davis, CA

Deteriorating environmental conditions at Lake Tahoe have been documented since the 1960s and include loss in transparency of 0.3 m annually, increased algal growth at 5 percent per year, changes in biodiversity, increased loading of nutrients and fine sediment, wetland loss, invasion of nonnative biota, air pollution, and decline in forest health. Data suggest that if degradation continues, the remarkable clarity of Lake Tahoe will be lost in 30 years. This precipitated the Presidential Forum in 1997, and necessitated a more rapid conversion of basic limnological studies into management decisions.

To date, long-term data collection and basic research have been key to better understanding and managing the lake, its surrounding watershed, and air quality. With this grant and related investigations, the primary goal is for science (monitoring, research, and modeling) to assist in the restoration of water quality and ecosystem health at Lake Tahoe. Reduction in phosphorus and fine-sediment loading is considered critical to reduce the accelerated decline in water clarity.

The approach can be summarized in a series of three questions that need to be understood to achieve effective management of lake clarity: (1) What are the sources and relative contributions of nutrients and fine sediments? (2) How much of a reduction in this material is needed to attain desired water clarity? (3) How will this reduction be achieved?

A budget has been completed that shows direct runoff and atmospheric deposition (AD) as important P sources and highlights the need for additional study. Phosphorus reduction strategies will have to address multiple sources, including direct runoff, AD, streamflow, and groundwater. The contribution of AD to the N budget clearly dominates. Using dissolved P to approximate biologically available P (BAP), the budget shows that BAP is 30-35 percent of total P; this is not uncommon. Research to determine P bioavailability and its relation to restoration efforts has been proposed. Sedimentation losses to the bottom of Lake Tahoe are 401.7 MT yr^{-1} (TN) and 52.8 MT yr^{-1} (TP), and agree with loading estimates.

Watershed mitigation at Lake Tahoe may take 15–20 years to complete. Because the lake also has a retention time of decades for nutrients, the direct effect of restoration on lake clarity may not be detected for many years. Watershed and lake modeling provides tools to overcome this long time lag. To explore management options for loading reduction, a one-dimensional modeling approach has been adopted. The model, DLM, is driven hydrodynamically by daily inputs of meteorological and streamflow data. Water quality inputs are from streams, surface runoff, groundwater, and atmospheric loading (see Table 1).

The model seeks to predict the distribution of nutrient concentration, algal concentration, and suspended particle concentration. Water clarity, a function of light absorption and scattering, can in turn be calculated from the algal concentration and the size distribution and concentration of particles. Intensive data collection has been initiated to provide sufficient calibration and validation data for the optical part of the model. Preliminary results from the optical component are presented in Figure 1.

Achieving loading reductions requires adaptive management, wherein data are collected to: (1) optimize best management practice effectiveness for individual projects, (2) assign project priority based on nutrient/fine sediment sources, (3) provide expectations of a project's load reduction to be directly coupled with a clarity model, (4) facilitate timely changes to project design, and (5) assess success/failure.

Table 1. Summary of loading estimates to Lake Tahoe expressed as metric tons per year.

	Total N	Total P	Dissolved P
Atmospheric deposition	234 (56%)	12.4 (26%)	5.6 (37%)
Stream loading	82 (20%)	13.3 (28%)	2.4 (16%)
Direct runoff	42 (10%)	15.5 (33%)	3 (29%)
Groundwater	60 (14%)	4 (9%)	4 (27%)
Shoreline erosion	1 (<1%)	1.6 (3%)	No Data
Total	**419**	**46.8**	**15.0**

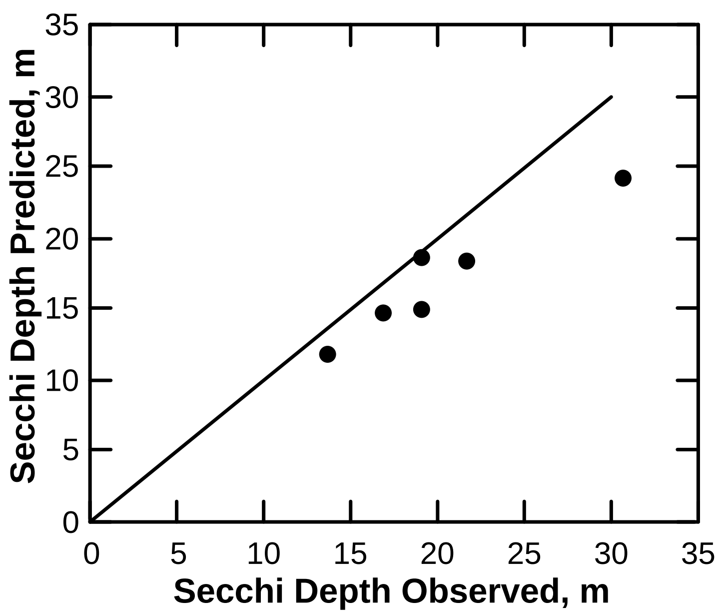


Figure 1. Preliminary comparison of predicted Secchi depth transparency to actual field measurements over a wide range of observed values.

An Integrated Ecological and Socioeconomic Approach To Evaluating and Reducing Agricultural Impacts on Upper Mississippi River Watersheds

Prasanna H. Gowda[1], Roger J. Haro[1], and Ted L. Napier[2]
[1]Department of Biology, University of Wisconsin, La Crosse, WI; [2]School of Natural Resources, Ohio State University, Columbus, OH

The objectives of this project are to: (1) use a spatial-process model to predict agricultural discharges from two watersheds in the Upper Mississippi River Basin; (2) use the model to evaluate potential water quality benefits associated with the adoption of alternative management strategies on these watersheds; (3) develop regional-scale predictive models of ecosystem "health," biodiversity, and sustainability by relating information on biota and ecosystem functional processes to current and potential landscape composition and structure; and (4) identify factors that affect adoption of conservation production systems among land owner-operators in the two watersheds. The Lower Minnesota River Watershed in eastern Minnesota and the Maquoketa River Watershed in northeastern Iowa are being studied. The study recently was extended to include the Big Darby Creek Watershed in central Ohio for a socioeconomic survey of farm owners-operators.

Calibration of the ADAPT model, was performed for six tributaries of the Lower Minnesota River Watershed. Statistical evaluation of the modeling results indicates that model performance is best for subwatersheds dominated by agricultural land use. Pollutant loadings from the remaining ungauged watersheds were estimated using the calibrated ADAPT model. For this purpose, subwatersheds in the Lower Minnesota River Watershed were grouped into four regions: (1) southeastern, (2) western, (3) north-central, and (4) northeastern.

Four alternative agricultural management practices were developed considering developments in the Lower Minnesota River Watershed in consultation with local experts, and evaluated. They were: (1) increased adoption of conservation tillage, (2) conversion of crop land to pasture, (3) varying N-fertilizer application rates, and (4) increased subsurface tile drainage. Of the simulated scenarios, greatest reductions in nitrate-N loads (up to 7%) were observed in southeastern and western regions of the watershed when N-fertilizer application rates were decreased by 20 percent. Crop lands in these regions typically are poorly drained. A major portion of the land is equipped with subsurface tile drainage systems. Model results indicate that a 75 percent increase in adoption of conservation tillage can reduce average annual sediment loads by up to an additional 57 percent. Increased adoption of conservation tillage also is predicted to increase nitrate-N losses. The impact of conservation tillage on nitrate-N losses offsets reduced losses of nitrate-N due to reduction in N-fertilizer application rates.

Relationships between landscape and stream habitat characteristics and benthic macroinvertebrate community compositions in study watersheds were evaluated using macroinvertebrate data collected in 1998. Soil erosion potential was estimated for key landscape features using the University Soil Loss Equation. In the Maquoketa River Watershed, stream habitats were of relatively low quality and were highly variable across sites. Benthic macroinvertebrate-index of biological integrity (BM-IBI) scores were strongly related to stream habitat variables, but were not related to soil erosion potential.

In the Lower Minnesota River Watershed, stream habitats were of relatively higher quality and were evenly distributed across sites. BM-IBI scores were not related to individual habitat variables, but had a strong relationship to soil erosion potential. In both study watersheds, BM-IBI scores increased with increased rates of soil permeability and conservation tillage; however, percent of row crop agriculture or forested land had no effect on BM-IBI scores.

Data collected by a socioeconomic survey of land owner-operators were analyzed and compared. Study findings revealed that farmers in all of the study watersheds had adopted some form of soil and water conservation production practices; however, they continued to use production practices that could negate the positive environmental benefits of the conservation practices employed at the time of the data collection. Many farmers reported that they did not expect to transfer their farm operations to their children.

At present, this research group is operating on a 1-year no-cost extension. Efforts will concentrate on: (1) modeling the Maquoketa River Watershed for water quality, and developing and evaluating various alternative management practices; (2) processing, taxonomic identification, and analysis of the macroinvertebrate samples collected in 1999; and (3) developing manuscripts for publication in peer-reviewed journals and presenting research findings at water resources-related professional conferences.

Nutrient Sources, Transformations, and Budgets at the Watershed Scale in Ipswich River, Massachusetts

Charles S. Hopkinson [1]***, E. Rastetter*** [1]***, J.V. Vallino*** [1]***, M. Williams*** [1]***, and R.G. Pontius*** [2]

[1]*Marine Biological Laboratory, Woods Hole, MA;* [2]*Clark University, Worcester, MA*

Patterns of land-use change, nutrient and water export from land, riverine processing and retention of nutrients, and the overall mass balance for nutrients in the Ipswich River Watershed are being studied and modeled. There have been major changes in land cover and land use since European settlement. For example, agricultural land has decreased by more than 70 percent, and urban land now comprises about 32 percent of the total cover.

Land-use change is modeled based on spatial physical factors, legal constraints, and extrapolations of quantities of change. Maps of suitability for deforestation are calibrated with maps of real change between 1971 and 1985 by using multicriteria analysis. The maps of 1971 and 1985 also serve as the basis to extrapolate the quantity of predicted future deforestation. The extrapolated quantities and calibrated suitability maps predict the location of deforestation from 1985–1991. The predicted deforestation maps are validated with the map of real forest area of 1991. To predict land-use change into the future, a validated simulation method is used to sketch various scenarios.

The relation between land use and nutrient export is being evaluated in two ways. At the finest temporal scale, flow-integrated sampling is used in first-order streams draining 1–1.5 km^2 catchments with homogeneous land cover: forest, urban, or agricultural. At the broadest spatial scale, seasonal sampling of 60–80 first-order streams draining 1–1.5 km^2 catchments of varying land use is employed. All phosphorus fractions and ammonium generally are not related to land use and are present in low concentrations. NO_3^- concentrations can exceed 100 M and are strongly related to the fractional cover in urban and agriculture uses. Dissolved organic nitrogen and carbon (DON and DOC) are related to the relative amount of wetlands within a catchment, but only during late summer and fall. Total dissolved nitrogen typically is most related to fractional urban and agricultural land uses.

The land-use change model has been coupled with the land-use/nutrient relationships to evaluate how stream nutrient loading might increase in the future with and without laws restricting development. For every decade in the two land-use change scenarios, an empirical nitrate loading relationship is applied to several hundred subcatchments. The results are time series of spatially distributed surfaces of nitrate loading, with corresponding transects of potential nitrate concentrations for the Ipswich River Stream Network. Simulation results for realistic development scenarios indicate a doubling in nitrate delivery to the Plum Island Sound Estuary from 1991–2101.

The changing landscape and associated socioeconomic activities, together with a changing climate, are having a major impact on the watershed hydrology. Precipitation has increased at a rate of 3 mm/year since 1933, while streamflow has remained relatively constant, even after correcting for increased net diversions. The long-term water budget indicates an increase in evapotranspiration. The analyses show that during the period of 1949–1998, the effect of a changing climate on evapotranspiration is stronger than the effect of a changing land use. Future water budgets also have been predicted using global climate model output and output from the land-use change model. At the anticipated rate of urban expansion and climate change, the Ipswich River Basin will experience serious problems in allocating its water resources within the next 100 years. The research group is working with the Massachusetts Executive Office of Environmental Affairs, the Department of Environmental Protection, the Ipswich River Watershed Association, and the U.S. Geological Survey to develop sound, sustainable watershed management plans for the watershed.

The Hydrologic Simulation Program-Fortran (HSPF) hydrologic and nutrient processing model is being used to examine spatial aspects of nutrient sources, sinks, and export to the coastal zone. An extensive database has been developed on in-stream nutrient concentrations that, when coupled to the HSPF model, allows for the identification of critical habitats in the Ipswich River Watershed where nutrient retention and processing are strongest. First-order streams draining urban land covers and extensive riverine wetlands are the primary sites where nutrients (N) are retained.

Finally, a whole watershed budget of nitrogen inputs, losses, and export has been constructed. Nutrient mass balance indicates that of about 500–1,000 Mt N input to the watershed annually, about 64–82 percent is retained on land and 8–16 percent is retained in the river. In addition to substantial N losses during downstream transfer, there also are changes in the composition. Inorganic components comprise 58 percent of total N in first-order streams, while DON and particulate N comprise 61 percent of total N at the river mouth. With a predicted doubling of nitrogen inputs to first-order streams over the next 100 years, there is concern about the uptake capacity of the river system and whether nutrient loading to the productive Plum Island Estuarine System will increase concomitantly.

Linking Watershed-Scale Indicators of Changes in Atmospheric Deposition to Regional Response Patterns

J. Kahl[1], I. Fernandez[2], J. Rubin[3], J. Cosby[4], S. Norton[5], L. Rustad[2,7], D. Mageean[3], and P. Ludwig[6]
[1]Water Research Institute, [2]Department of Plant, Soil and Environmental Studies, [3]Margaret Chase Smith Center for Public Policy, [5]Department of Geological Sciences, University of Maine, Orono, ME; [4]Department of Environmental Sciences, University of Virginia, Charlottesville, VA; [6]International Paper, Inc., Bucksport, ME; [7]U.S. Department of Agriculture Forest Service, Durham, NH

This research group is determining the patterns and indicators of response of a specific ecosystem response to experimental watershed acidification. A major goal is to scale this knowledge to the regional level to determine the extent of acidification and N-saturation in a sensitive subpopulation of high elevation lakes. Concurrently, the Tracking and Analysis Framework (TAF) model used in the Adirondacks under the National Acid Precipitation Program (NAPAP) is being recalibrated to examine the effects of acid deposition on Maine's high elevation lakes.

The project activities are hierarchical from site-specific to regional. First, the indicators of and model predictions for acidification and N saturation have been examined in the whole-watershed N enrichment experiment at the Bear Brook Watershed (BBWM), ME. This site is in its 11th year of experimental treatment with dry ammonium sulfate. From new and ongoing data collection on soils, stream chemistry, and forest growth, the indicators of response at this site are being assessed (see Figure 1).

Second, the site-intensive information is being scaled to the region using data from High Elevation Lakes in Maine (HELM) and their watersheds. Their acidification status is similar to lakes in the Adirondacks. The potential for parallel relationships between soils and surface water in HELM and BBWM is being tested.

Third, the HELM data are being used to recalibrate the aquatic effects submodel within the TAF to predict changes in acid neutralization capacity, pH, aluminum, and calcium using the Model of Acidification of Groundwater in Catchments (MODEL). The possible effects of increases and decreases in N and S on lake chemistry and the viability of HELM fish populations are demonstrated.

The whole-watershed experiment at BBWM has resulted in increases in S and N flux of 2x and 20x, respectively. The process of acidification has altered base cation flux and ratios, resulting in a depletion of Ca relative to Mg in streamwater, which is inferred to reflect changes in watershed soils. HELM lakewater Ca is positively and significantly correlated with soil Ca saturation. Aluminum concentrations are inversely correlated with soil Ca saturation. Nitrate concentrations remain high in these lakes in contrast to the regional trend, confirming the acidified condition of these lakes, but without significant correlations with measured watershed N properties.

This information will be used by the Environmental Protection Agency to meet the Congressional mandate of determining the effectiveness of the Clean Air Act Amendments on influencing these trends. Site-specific data from BBWM scaled to the regional HELM population also will provide a template for the recognition and understanding of possible N saturation, base cation depletion, and indicators of ecosystem recovery. The recalibration of the TAF for Maine's high elevation lakes advances the science of integrated natural and social science research by providing the ability to contrast the effects of acidification in Maine's lakes with those of the Adirondacks.

The project is in the final stages of data analysis. The relationships between soil chemistry in the two watersheds at BBWM and in the HELM lakes are being analyzed. The soils data will be related to surface water chemistry to develop indicators of response. Deliverables will include papers on the indicators of recovery in natural systems, the controls of N chemistry in high elevation lakes, the experimental response at BBWM, and the application of the TAF to Maine 10 years after the NAPAP.

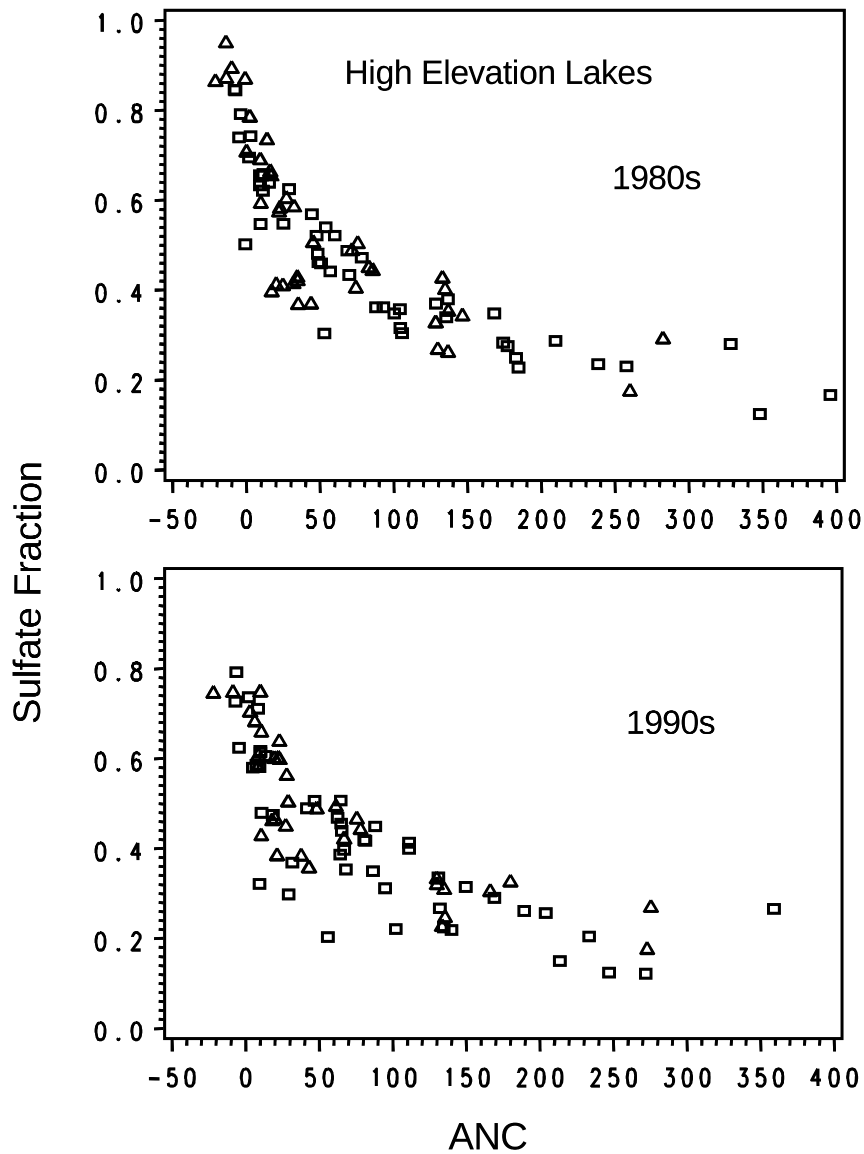


Figure 1. The sulfate fraction is the ratio of sulfate to total anions. The decline in this ratio, especially the loss of the high ratios, is an indicator of recovery in these lakes despite the lack of increase in alkalinity (ANC).

REKA, a New Comprehensive Watershed Management System

C. Gregory Knight[1,2,3], Jeffrey J. Carmichael[2,7], Heejun Chang[1,2], Dimitar Dimitrov[5], Barry M. Evans[3], James M. Hamlett[3,5,6], Todor N . Hristov[5], Vania D. Ioncheva[5], Ivan I. Nikolov[5], Marieta P. Staneva[2,4], and Petko S. Varbanov[5]

[1]Department of Geography, [2]Center for Integrated Regional Assessment, [3]Environmental Resources Research Institute, [4]Penn State Altoona, Pennsylvania State University, University Park, PA; [5]Institute of Water Problems, Bulgarian Academy of Sciences, Sofia, Bulgaria; [6]University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria; [7]University of British Columbia, Vanvcouver, BC, Canada

River Environmental Knowledge and Assessment (REKA) is a spatial water quality assessment system designed to answer two questions: (1) If pollution control is invested in at one place, where and to what degree will stream quality goals be achieved? and (2) To attain certain quality standards for a given reach (or reaches) of the basin, what alternative strategies could be implemented under various probabilistic levels of stream flow resulting from climatic variability and with input from the local community? REKA was developed in the context of the Yantra River Basin (see Figure 1) in Bulgaria (reka = "river" in Bulgarian) as a transferable geographic information system (GIS)-based tool to link process and decision models related to water quality in a comprehensive framework. The project is a collaboration between the Institute of Water Problems in the Bulgarian Academy of Sciences and the Environmental Resource Research Institute and the Center for Integrated Regional Assessment at the Pennsylvania State University.

REKA has three subcomponents (see Figure 2). Basin Impacts of Simulated Transport from Rural Areas (BISTRA; bistra = "clean" in Bulgarian) uses a new articulation of the Generalized Watershed Loading Function in the ArcView GIS program. This component calculates river loads of nutrients (N, P) and sediments based on weather, soil, topography, and land use, including both nonpoint and point sources of pollution.

Validation and Optimization for Decision Analysis (VODA; voda = "water" in Bulgarian) is a substantial revision of the STREAMPLAN model of the International Institute of Applied Systems Analysis. This component uses a reduced-form process model to derive stream hydraulics and pollutant transport and processing. REKA delivers loadings and water volume data to VODA by stream reach. VODA then computes flows, pollutant concentration, and loads by reaches.

In VODA, the user has several model design choices. VODA can be used to generate a scenario based on current conditions (e.g., for calibration and validation) or to simulate the water quality impacts of proposed treatment facilities or discharge regulations. Alternatively, VODA can calculate financially optimal strategies to achieve water quality improvement goals or to meet specified standards for all or some of the stream reaches. Decision choices include alternative allocations of reservoir water for dilution (with lost value from alternative uses); temporary or permanent closing of polluting entities; and capital and operational costs of pollution pretreatment and treatment.

VODA also provides for input of alternative weather conditions, based on the validation period or a typical wet, average, or dry year. It also is possible to input temperature and precipitation change scenarios derived from global climate change models. Typically, simulations will be framed in terms of low-flow months during relatively dry years.

The numerical results of VODA's simulation and optimization then are passed back to ArcView for presentation of Protection Location and Action Network (PLAN; the same meaning in Bulgarian as in English). PLAN provides maps of water quality status and tabular information on goal achievement, cost, and decision variables that entered into the solution. Dissemination of the model includes a CD in preparation that will have the full model structure for a simple, heuristic river basin, as well as selected scenarios derived for the Yantra Basin itself.

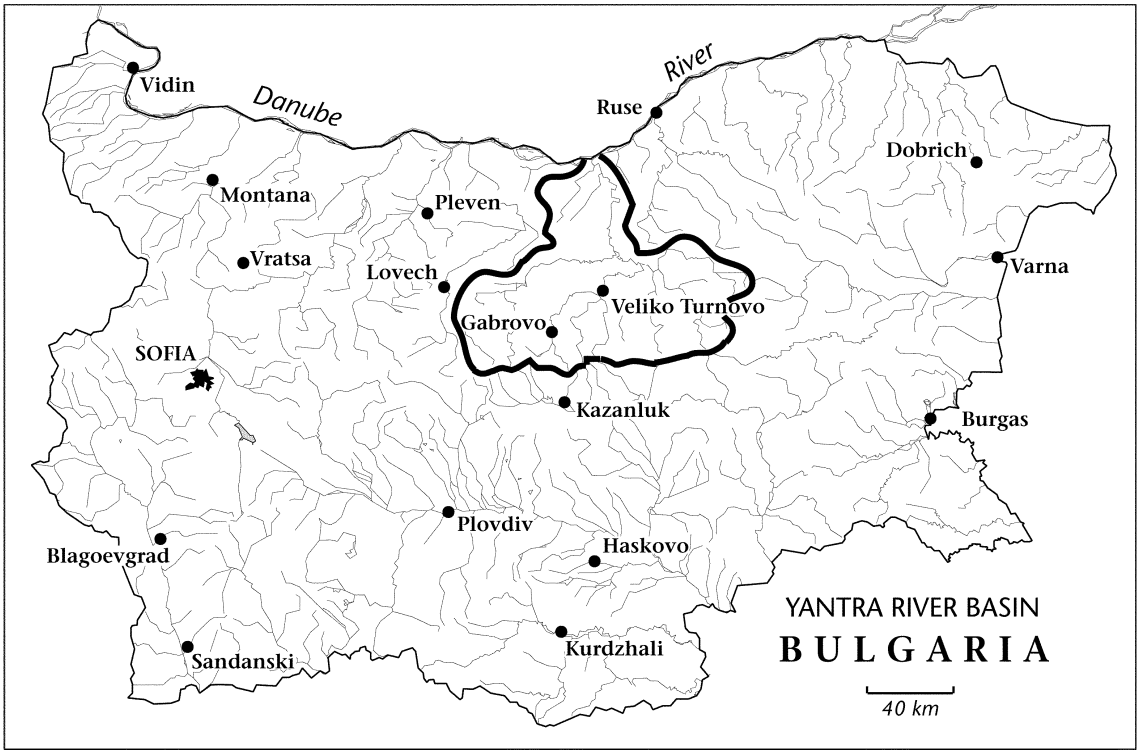


Figure 1. The Yantra River Basin, a Danube sub-basin in Bulgaria.

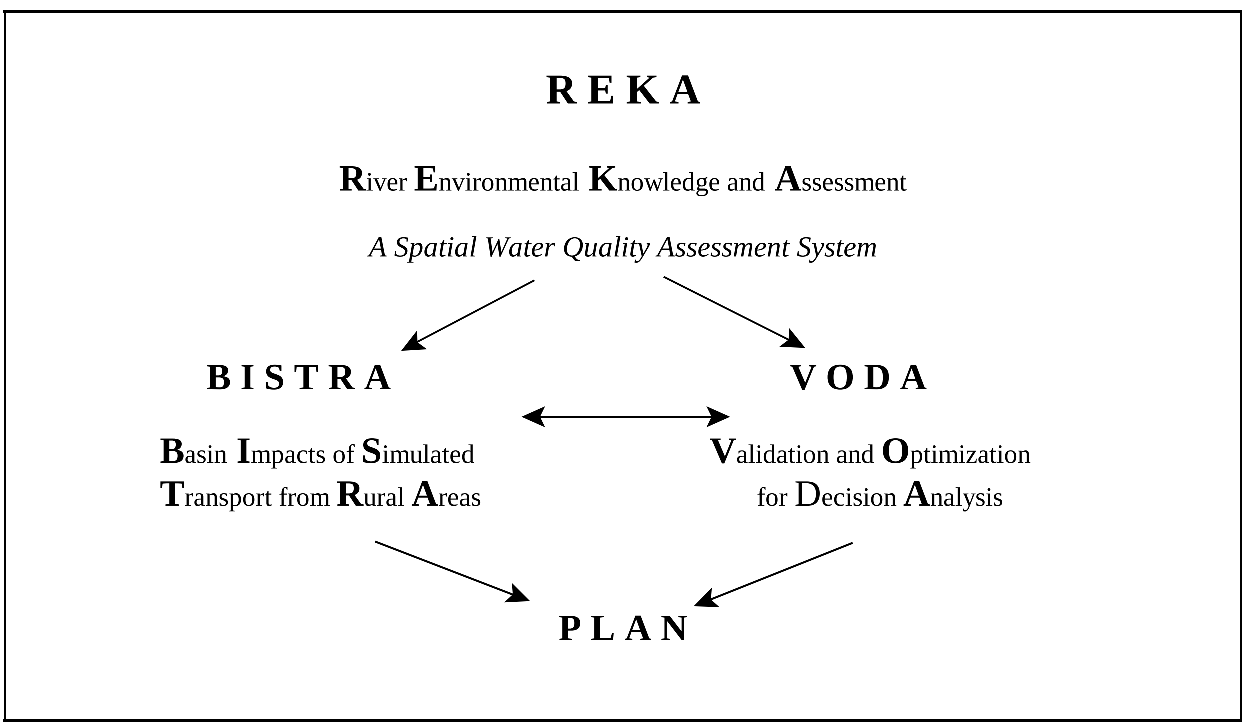


Figure 2. REKA, a spatial water quality assessment system.

Coping With Nature: Accepting Risk, Adopting Technology, and Assuming Ignorance

James McManus [1]***, Courtland L. Smith*** [2]***, Jesse Ford*** [3]***, Paul D. Komar*** [4]***, Debbie Colbert*** [4]***, and Michael Styllas*** [4]

[1]*Large Lakes Observatory, University of Minnesota, Duluth, MN;* [2]*Department of Anthropology,* [3]*Department of Fisheries and Wildlife,* [4]*College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR*

The National Research Council (NRC) recommends evaluating incentive-based approaches to environmental regulation to replace command-and-control measures. The NRC further recommends the use of comparative examples that combine natural scientific study with risk assessment and benefit-cost analysis.

Landowners in the Tillamook Basin, OR, have 150 years of adapting to natural processes that pose risks of flooding, tidal currents, wind and wave action, fire, disease, earthquake, and tsunami. In addition, land uses have contributed to water quality problems that affect the ecology of Tillamook Bay, particularly oyster growing and fishing.

This group's research on sediments, water chemistry, ecosystem health, and social science has identified a number of situations in which landowners make risk-benefit calculations. The results of these calculations include building the dairy industry and a major commercial area in the flood plain. Another is planning a destination tourist resort on a sand spit breached by ocean waves. In trying to explain these decisions, it was found that landowners conducted their own risk-benefit calculations, employed technology to minimize risk, and accepted higher risk because of ignorance.

Why do many landowners make decisions that appear to go against natural processes? One hypothesis is that they are ignorant of the effects of natural processes. A second hypothesis is that they think technology can overcome the forces of nature. A third hypothesis is that they make a risk-benefit calculation. Data support each of these hypotheses, but risk-benefit calculations explain more than the others.

These hypotheses were tested in a number of situations in the Tillamook Basin. For example, historical evidence shows a pattern of learning about the effects of natural processes, the use of technology to minimize risk, and most of all, calculated risktaking. Learning began in the 1850s, when the first settlers brought dairy cattle to the area. The dairy industry persists because of risk calculations made by dairy owners about relative economic impacts of water quality problems and the probability of floods wiping out their herds.

The dairy industry is the biggest contributor of fecal coliform to the Bay, which is closed to oyster harvest approximately 100 days per year. Agriculture persists because the risk of major reductions in fecal coliform levels is far greater than the oyster harvest and fishing benefits. Further, much of the science as to causes and processes still is uncertain. The other major natural threat to agriculture is flooding. Here, the effort is to make modifications in the basin to move floodwaters out as quickly as possible and keep the number of milkings missed to fewer than six. More than six missed milkings results in the loss of productive cows.

Examination of other decisions about forest, urban, and recreation land use suggests that reduction of ignorance, technological innovation, and risk-benefit calculations all affect land-use decisions. The risk-benefit calculation typically is the one hypothesis that explains most about landowner decisionmaking. These examples of risk-benefit analysis by local landowners responding to market incentives show that people will take risks against natural hazards. They often are ignorant of risk probabilities, and these are not well communicated in the community.

The risk assessments are not quantitative. Landowners seek technology believing they can armor themselves against risks. Because of ignorance and belief in the benefits of technology, the risk-benefit calculation is often wrong in the short term, but the collective result over the long term is local adaptation to the occurrence of natural processes.

Ecological Risks, Stakeholder Values, and River Basins: Testing Management Alternatives for the Illinois River

***Mark Meo* [1], *Baxter Vieux* [2], *Blake Pettus* [3], *Edward Sankowski* [4], *Robert Lynch* [5], *Will Focht* [6], *Keith Willett* [7], *and Lowell Caneday* [8]**

[1]Science and Public Policy Program, [2]College of Engineering, [3]College of Architecture, [4]College of Arts and Sciences, University of Oklahoma, Norman, OK; [5]College of Public Health, University of Oklahoma Health Sciences Center, Oklahoma City, OK; [6]College of Arts and Sciences, [7]College of Business Administration, [8]College of Education, Oklahoma State University, Stillwater, OK

The objective of this research project is to identify and compare different environmental and social values held by stakeholders in Oklahoma's Illinois River Watershed, and to test a management protocol that is technically effective, economically efficient, and socially and politically acceptable. In the first phase of the project, baseline technical, economic, and sociopolitical assessments were conducted that serve as the basis for subsequent interactive visualization workshops with policymakers and stakeholders to define alternative management policies that meet the three criteria for acceptance.

In the second phase, alternative policy assessments are being modeled and prepared to help watershed stakeholders attain consensus about alternative land and water uses. In the final phase of the project, the project's acceptability will be determined through a telephone survey of watershed stakeholders.

The technical analysis involves a geographic information system (GIS)-based modeling of watershed hydrology and nutrient flows, and ecological risk characterization of selected species. Distributed parameter hydrologic modeling has been used to relate land-use alternatives to impacts on water quality. Simulations use digital representations of rainfall, soils, topography, and land use in GIS format. To date, the project team has collected water quality data (see Figure 1) over the period for which the distributed runoff nonpoint pollution (DRIP) model is run; developed model data sets derived from GIS maps of soils, land use, topography, and radar estimates of rainfall; assembled GIS maps that depict population density, roads/transportation, and political boundaries; and completed the visualization of the digital elevation models and water quality simulations using the AVS software. The objective of the ecological risk effort has been to identify at-risk ecological communities that: (1) rely on available data, (2) enable quantification of visually communicable risk measures, (3) are relevant to groups of stakeholders, and (4) are responsive to alternative management strategies.

Accomplishments include the collection of data from sites on 24 tributaries within the river basin over the past several years to monitor the influence of land use on receiving waters, and a comprehensive survey of all agency databases and the calculation of community integrity indices for fish, periphyton, and benthic macroinvertebrates. The economic assessment has been focused on the development of databases and modeling structures that capture the most significant economic activities in the watershed.

Regional impact of these activities is estimated through the use of the IMPLAN input-output model, which enables the calculation of the economic impact of individual expenditures on total gross output, employment, employee compensation, property income, value added, and indirect business taxes. In addition, the role of poultry production in the regional environment and economy has been analyzed by incorporating poultry feeding and production decisions for disposal of waste litter. The sociopolitical assessment has been undertaken and completed through a series of joint activities that were based on stakeholder interviews in each of eight study regions identified for the watershed. Concurrent activities included 150 in-person interviews, 60 mental modeling interviews, and 120 Q methodological interviews.

Computer visualization is being used as a decision support tool to facilitate stakeholder understanding and as an aid for negotiating alternative land and water use policies. The visualization team has focused on: (1) developing a graphic infrastructure for organizing research data; (2) collecting data on the background, history, and visual character of the watershed and converting this into digital format; (3) developing digital standards required to compile the work of the different research teams; (4) developing an effective approach to graphically compiling, rendering, and animating multiple large-format DEM data; and (5) creating color-relief imagery from high-resolution DEM data. This work has been completed.

Future technical activities will focus on characterizing policy options with the developed DRIP and IMPLAN models and presenting them in a visual format for use in a planned sequence of stakeholder and policymaker negotiation workshops.

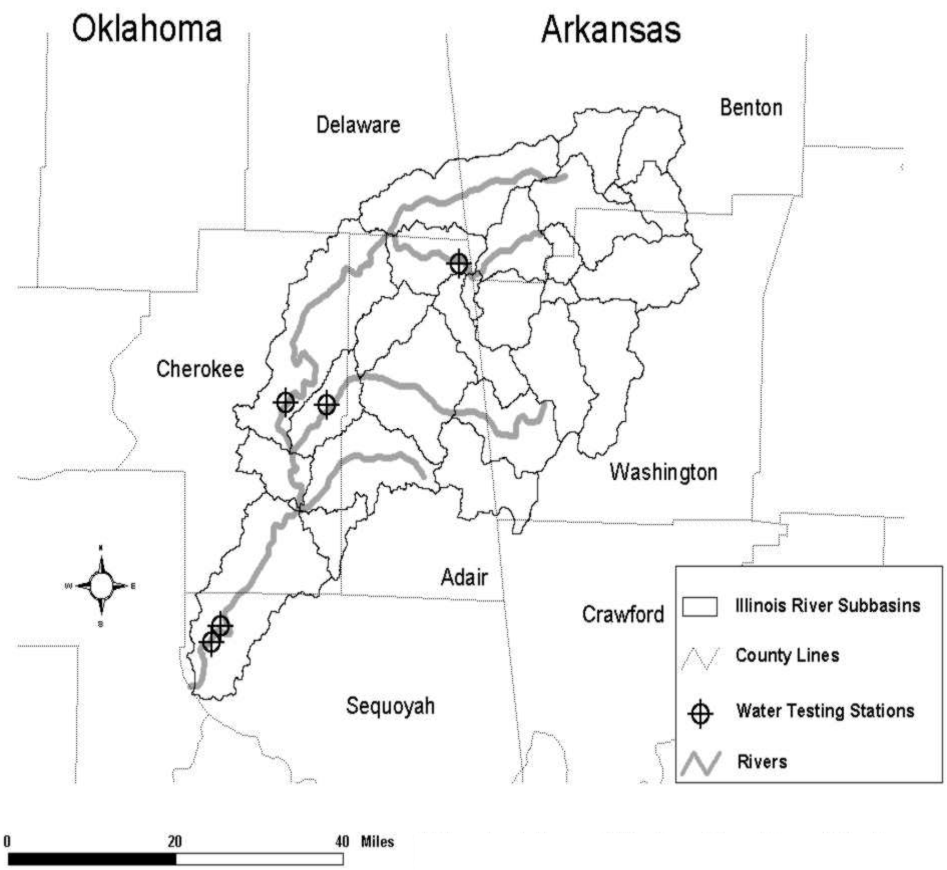


Figure 1. Illinois River water testing stations.

Balancing Risks of Flood Control and Ecological Preservation in Urban Watersheds

Vladimir Novotny, D. Clark, R. Griffin, A. Bartošová, and D. Booth
Institute for Urban Environmental Risk Management, Marquette University, Milwaukee, WI

This study employs an interdisciplinary approach to investigate community support for watershed management initiatives. Watershed professionals often address two consequences of urbanization. First, urban growth frequently exacerbates downstream flooding problems (magnitude, frequency, spatial scope) due to increased storm runoff. Second, urbanization also increases ecological risks as less tolerant species disappear due to loss of wetlands and diminished water quality. When assessing policy alternatives, watershed professionals must determine community support for flood control objectives vis á vis ecological risk reduction.

This research has the following specific objectives: (1) develop statistical flow, loading, and water quality models for flood risk assessment; (2) develop ecological risk assessment procedures to estimate ecological consequences of urbanization; (3) simulate flooding/ecological risk assessment for urbanization scenarios; (4) adapt a contingent valuation approach to spatially assess individual willingness to pay (WTP) from flood control and water quality improvements within urban watersheds; (5) examine the impact of drivers (spatial, demographic, attitudinal) of stated WTP for flood/ecological risk reduction; (6) determine temporal stability of WTP for flood/ecological risk reduction; and (7) derive communitywide benefit/cost estimates for watershed management alternatives.

A hydrologic model of flooding risk within a Milwaukee watershed was developed. The modified methodology uses data from an existing hydraulic model to delineate floodplain based on the flow of a specified recurrence interval. Regression analysis ties the flow to depth and floodplain width. Results then are incorporated into a geographic information system software package, permitting more precise evaluation of existing flood risks within the watershed. This methodology also allows flood risk changes from urbanization to be computed.

A model of ecological risk also has been developed. The information on habitat suitability and ecological risk due to chemical contamination is being analyzed with respect to overall biotic integrity of fish and macroinvertebrates. A habitat index has been used to assess the effect of habitat on an index of biotic integrity (IBI). All sites investigated show a decrease in IBI greater than the decrease in habitat index, or the level of habitat impairment, would indicate. This shows significant chemical impairment of water bodies. A simple software package was developed to facilitate calculation of ecological risks from hypothetical chemical contamination.

A telephone survey was developed, and the first of two waves was conducted in fall 1999/spring 2000 on 999 randomly selected adult residents of two Milwaukee watersheds. Respondents were provided with a description of a hypothetical referendum for a watershed project based on the hydrologic models. They stated their annual WTP for the next 20 years. Preliminary findings suggest that: (1) WTP is independent of the project scope (i.e., projects with more risk reduction are not more highly valued); (2) there is a relationship between WTP and sociodemographic characteristics of the respondent; (3) WTP is influenced by location within the watershed (e.g., upstream/downstream); and (4) attitudinal factors related to subjective norms and overall belief structures appear to influence WTP.

The stability of responses will be reviewed after the second survey wave. Benefit estimates will be computed for each watershed and compared with expected costs.

Impact of Social Systems on Ecology and Hydrology in Urban-Rural Watersheds: Integration for Restoration

***Steward T.A. Pickett*[1]*, J.M. Grove*[2]*, L.W. Band*[3]*, K.T. Belt*[4]*, G.S. Brush*[5]*, W.R. Burch, Jr.*[6]*, M.L. Cadenasso*[1]*, J.M. Carrera*[7]*, G.T. Fisher*[8]*, P.M. Groffman*[1]*, R.V. Pouyat*[4]*, and W.C. Zipperer*[4]**

[1]Institute of Ecosystem Studies, Millbrook, NY; [2]U.S. Department of Agriculture Forest Service, Burlington, VT; [3]University of North Carolina, Chapel Hill, NC; [4]U.S. Department of Agriculture Forest Service, Syracuse, NY; [5]Johns Hopkins University, Baltimore, MD; [6]Yale University, New Haven, CT; [7]Parks and People Foundation, Baltimore, MD; [8]U.S. Geological Survey, Baltimore, MD

This collaborative project, representing hydrologists, social scientists, plant ecologists, engineers, landscape ecologists, and outreach specialists, seeks to develop novel hydro-ecological models that integrate key social drivers of watershed function at various scales in Metropolitan Baltimore. In addition, it is sought to interact with stakeholders, managers, and decisionmakers to improve and test the utility of the model in the real world.

The project focuses on the 17,000-ha Gwynns Falls Watershed that extends from the suburban fringe to the densely built residential, and ultimately, industrial areas at the mouth of the stream. U.S. Geological Survey gauging stations, which are located at contrasting reaches of the stream, in representative but contrasting subcatchments of the stream, and in a reference forested watershed, provide the substrate for model development. The project is integrated by the patch dynamics approach, the human ecosystem framework, and hydrological models that take into account human and social capital as well as the more traditional inputs of built and natural capital.

The model is being developed to allow dynamic feedbacks between the four major realms of capital. The research project brings together specific data such as microclimate, soils and slope form, riparian and upland vegetation, social-ecological spatial patch pattern, and social structure and processes.

Testing the models will use, in part, paleoecological and historical data on infrastructure, land cover, human population, and social indicators. Projections will be based on contrasting land-use and economic scenarios. The models have an explicit spatial component that allows the role of biogeophysical and social heterogeneity on watershed function to be assessed.

The insights provided by recent additions to the knowledge base include: (1) the failure of land-use models to routinely include human decisionmaking; (2) the role of social heterogeneity in increasing ecological heterogeneity in the metropolis; (3) unexpected locations of environmental hazards in the watershed; (4) improved water quality downstream in the urban-suburban watershed, with expected low impairment in the forested reference watershed; (5) increased compositional and spatial heterogeneity in urban vegetated plots; and (6) promising utility of software being developed to support the integrated hydro-ecological models. Close interactions with the Patuxent Landscape Model is a feature of the project.

Index of Authors

United States
Environmental Protection Agency
(8701R)
Washington, DC 20460