PROCEEDINGS

1998 WATER AND WATERSHEDS PROGRAM REVIEW

28-29 January 1998
Corvallis, Oregon

Sponsored by the EPA/NSF Partnership for Environmental Research

NATIONAL SCIENCE FOUNDATION

ENVIRONMENTAL PROTECTION AGENCY

Cover Photo: Aerial photograph of the White Clay Creek watershed near the Stroud Water Research Center, Chester County, Pennsylvania. The photo, taken after a snowstorm, shows patches of forest (dark areas) interspersed among deforested meadow or cropland (white) areas. This region of southeastern Pennsylvania contains many of the study streams for Sweeney et al.'s study entitled "Streamside Reforestation: An Analysis of Ecological Benefits and Societal Perceptions" (see page 38). Photograph from Stroud Center archives; R.L. Vannote.

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Introduction

The U.S. Environmental Protection Agency / National Science Foundation (EPA/NSF) Water and Watersheds competition is one of three special extramural awards competitions supported by the EPA and the NSF under a partnership for environmental research initiated in 1994.

The competition emphasizes interdisciplinary research taking a systems approach to issues of water and watersheds. Its goal is 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 understanding of the structure, function, and dynamics of the terrestrial and aquatic ecosystems that comprise watersheds.

The 1995 Water and Watersheds competition reviewed 656 proposals requesting ~$335M and made 36 awards. In 1996, the competition announcement was narrowed to focus more on interdisciplinary research—as well as to limit the number of proposals. The 1996 competition reviewed 249 proposals requesting ~$168M and 12 awards were made. The agencies further narrowed the announcement in 1997 primarily in response to concerns that the competition had too low a success rate. Proposals were required to integrate physical, ecological and social science research and, for the first time, the investigators were encouraged to take a community-based approach. The 1997 competition, with an emphasis on urban/suburban research, reviewed 128 proposals requesting ~$77M and made 13 awards.

The abstracts in this volume are organized alphabetically, within three sections that correspond to the year of award. The most recent awards (FY97) are first. Many of these projects were just getting underway as this publication went to press and the abstracts indicate goals and plans. The FY96 cohort of projects appear next. These abstracts report early findings and plans for future years. The projects that were initiated with FY95 support are in the third section. These abstracts report results based on several years of research.

The competition is currently entering its fourth year, and the U.S. Department of Agriculture (USDA) has joined the two original agencies in supporting the effort. The theme for the fourth year competition is rehabilitation of watersheds. Program reviews such as this one will allow investigators to interact with one another, and to discuss progress and findings with EPA, NSF, USDA and other federal officials who are interested in the program.

Any opinions, findings, conclusions, or recommendations expressed in this report are those of the investigators that participated in the research and the Program Review meeting, and not necessarily those of the NSF or the EPA. For further information on the EPA/NSF Water and Watersheds competition please contact the Program Officers: Ms. Barbara Levinson, EPA, levinson.barbara@epamail.epa.gov or Dr. Penelope Firth, NSF, pfirth@nsf.gov.

Section 1.

Projects Initiated With Fiscal Year 1997 Support

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

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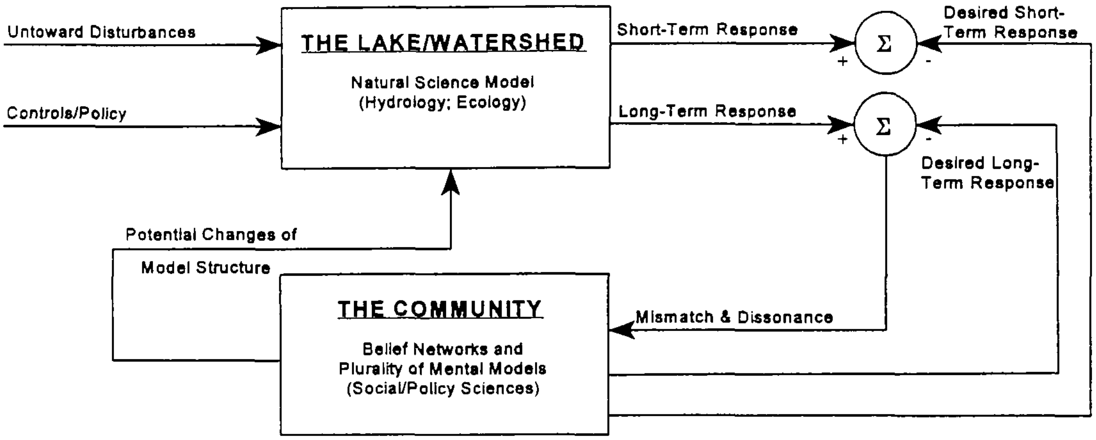

Figure 1. Schematic representation of the interaction between natural and social/policy science models in which the tasks are to identify: (a) on which critical, key unknowns in the natural science base may hinge the reachability of feared/desired futures; and (b) how community and stakeholder concerns for the future change in the light of changing information about the hydrological and ecological status of the lake and its watershed.

Watersheds surrounding metropolitan Atlanta are expected to experience substantial development during the next two decades. Indeed, Atlanta's continued rapid economic development could be constrained by problems of access to sufficient water supplies from the relatively small headwater catchments to its north. Within these watersheds lies Lake Lanier, which is used for hydroelectric power generation, water supply, flood protection, and most significantly, recreation.

The investigators are developing a new approach in which both community interests and a complex (mathematical) representation of the lake's ecosystem can be engaged in exploring how shorter term individual preferences can be reconciled with longer term community values regarding the maintenance of the integrity of an environmental system. The primary hypothesis is that citizens' value commitments are dependent upon scale (both in time and place) and that these scales have their counterparts in the range of time-constants typifying the behavior of the physical system: the short term, spanning 0-5 years; and the long term, more than 20-100 years. The secondary hypotheses are that: (1) radical shifts of behavior, as gauged by qualitatively different patterns of model outputs (such as populations of fish), may be a function of slowly evolving changes in the values of the model's coefficients (i.e., growth, mortality, and predation rates); and (2) longer term change, and hence maintenance of the integrity of a system, is primarily a function of such coefficient variations.

Adaptive community learning will be facilitated by working with small groups of stakeholders. The procedure will comprise several iterations around the cycle of eliciting community values, allowing their modification, encoding stakeholder concerns about the long-term future (as target features to be matched by the model's simulation results), identifying consensus on policy options and/or reconciling discord between longer and shorter term aspirations, and generating insight into the attainability of the target futures through the scientific model (see Figure 1). The model will be developed from past studies of Lanier and its watershed and will incorporate new material for description of the microbial food web and sediment biochemistry, the latter being supported by modest field and laboratory work. The model will be used principally within the computational framework of a sensitivity analysis employing Monte Carlo simulation.

In addition to developing and testing a prototype approach to facilitating adaptive community learning, with special reference to preserving the attainability of goals on an intergenerational time scale, this project will develop a new model for the dynamics of an ecosystem in a southeastern impoundment and policy guidance on options for maintaining the longer term integrity of such a system.

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

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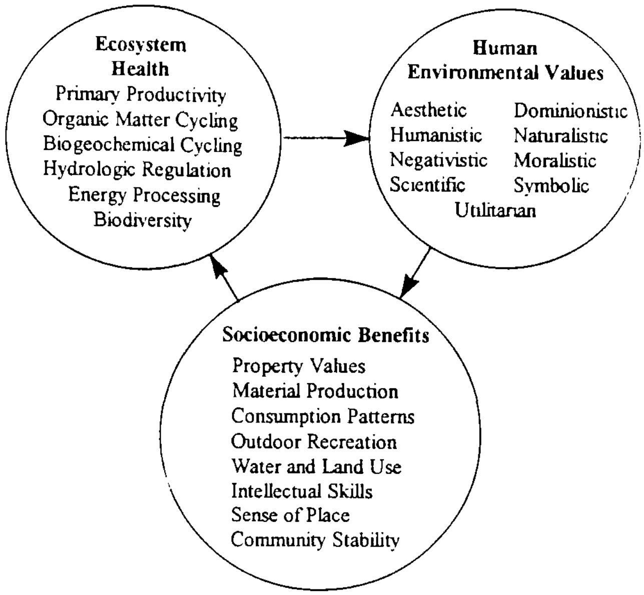

Figure 1. Hypothesized feedback loop linking ecosystem structure and function, environmental values, and socioeconomic benefits.

The goal of this project is to examine how ecological and social systems influence each other through either positive or negative feedbacks within watersheds. The central hypothesis is that the relative health and integrity of ecosystems cause, and in turn, are caused by enhanced human performance and productivity. Conversely, damaged and degraded ecosystems cause, and in turn, are caused by diminished human performance and productivity.

The current research will use observational techniques integrated by standard statistical methods to measure the quantifiable linkages between biophysical and social systems. This investigation also will lay the groundwork for a field experiment to test whether restoring a degraded watershed can significantly enhance social interactions in associated human communities. State-of-the-art analytical methods will be used to characterize approximately 30 sub-watersheds in terms of key hydrological, chemical, biological, economic, and social parameters. This large number of biophysical and social measures will be integrated within a quantitative context that allows us to test our predictions and to generate an overall index of watershed quality.

The first step has been to select study sites from among an initial set of more than 60 possible candidates. The investigators see objective selection of appropriate sites as crucial to the long-term success of this project. The final set of sub-watersheds need to fulfill several criteria: (1) relatively homogeneous land use or land cover in each; (2) all large enough to include a sufficient number of residents to yield robust statistics on social science surveys, even in areas having the minimum regional population density; (3) adequate in size to ensure year-round streamflow; (4) all sites within +/- 50 percent of the mean area; (5) representative of the entire range of development from rural to urban; and (6) covering the full spectrum of environmental quality from nearly pristine to badly degraded. Because these last two characteristics are not entirely correlated, a set of sites are being sought that includes representatives having: (1) a high level of development with good environmental quality and (2) low development with poor environmental quality as well as the more common converses of these two.

Every sub-watershed within our three river basins fulfilling criteria 1 through 4 have been delineated on 24,000 scale USGS topographic maps and all ambiguous boundaries clarified through field visits. Preliminary land cover and land use have been calculated for each sub-watershed, allowing them to be ranked as a test of criterion 5. Final land use characteristics will be derived from an existing detailed geographic information systems' database. Rapid assessments of water quality and biological characteristics are being conducted to evaluate criterion 6.

Also, we are in the process of designing and testing surveys to evaluate human attitudes, values, knowledge, and behavior towards nature and economic conditions within the watershed. The process of selecting sub-watershed study sites also has required us to begin examining in detail how to reconcile differences between physical watershed boundaries and political or other human social boundaries.

Social and Ecological Transferability of Integrated Ecological Assessment Models

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The coastal zone, near-shore waters and adjacent uplands, is heavily used for a variety of purposes—not all of which are compatible. In past years, urban and suburban development in the uplands have been accompanied by profound changes in ecosystems with declines in fish and shellfish harvests. However, people are reluctant to believe that what occurs in their backyards can affect the health of the sea. This project will develop a general integrated ecological assessment model for coastal watersheds. This model will be used to determine how the level of involvement with the model by managers and planners affects their acceptance of it as a useful management tool. Our project will determine how best to make the model relevant and useful to local citizens in their decisions regarding land use management in the coastal zone. Two interrelated issues will be addressed: (1) the ecological transferability of the model, the model's ability to capture the dynamics of a previously unconsidered ecosystem; and (2) the social transferability of the model, the willingness of local managers and planners to use the integrated planning model.

An existing watershed-loading model will be used, and an estuary model will be extended to include a new and socially important management endpoint—fish and shellfish. This new integrated assessment model will be used in a series of experiments designed to test simultaneously the ecological and social transferability of the model in a variety of new settings. Empirical relationships will be developed between predicted N-load and endpoint responses, using new field data and literature information. This project's research involves using replicated experiments to determine the effect of familiarity with and involvement in the model on its acceptance and usefulness by the planning community. The effect of four treatment conditions on model acceptance will be tested (see Figure 1): (1) explanation of the model by an "expert," (2) participation in a learning workshop ("Wkshp I"); (3) a learning workshop supplemented with intensive dialogue ("Wkshp II"); and (4) a learning workshop supplemented with a citizen field-data collection program ("Wkshp + Field").

There is an urgent need for an estuarine ecological model of broad application, incorporating components that are of direct concern to the public. It is not possible to build "from scratch" an integrated ecological model for each community using local researchers and local data. Most communities do not have the local researchers nor the data needed, and society cannot afford the money nor the time to fund *de novo* model development for each local case. Therefore, planners must rely on models developed elsewhere to be applied to their local situation. It is common knowledge, however, that people distrust policy recommendations for their community when they are based on data gathered elsewhere. One of the most interesting results will be to explain how much gain in model acceptance is achieved by differing levels of training and familiarity building. Conclusions will be drawn about whether the existing models provide information that community policymakers find useful and relevant. This research project is designed to benefit urban/suburban coastal communities interested in protecting estuarine ecosystems from nitrogen loading. Integrated ecological assessment models have the potential to improve the competence of local communities in making policy decisions. This research will result in an integrated ecological model of the consequences of coastal land use change on estuarine systems and, perhaps more importantly, better information on how to apply that model to new environmental and social settings.

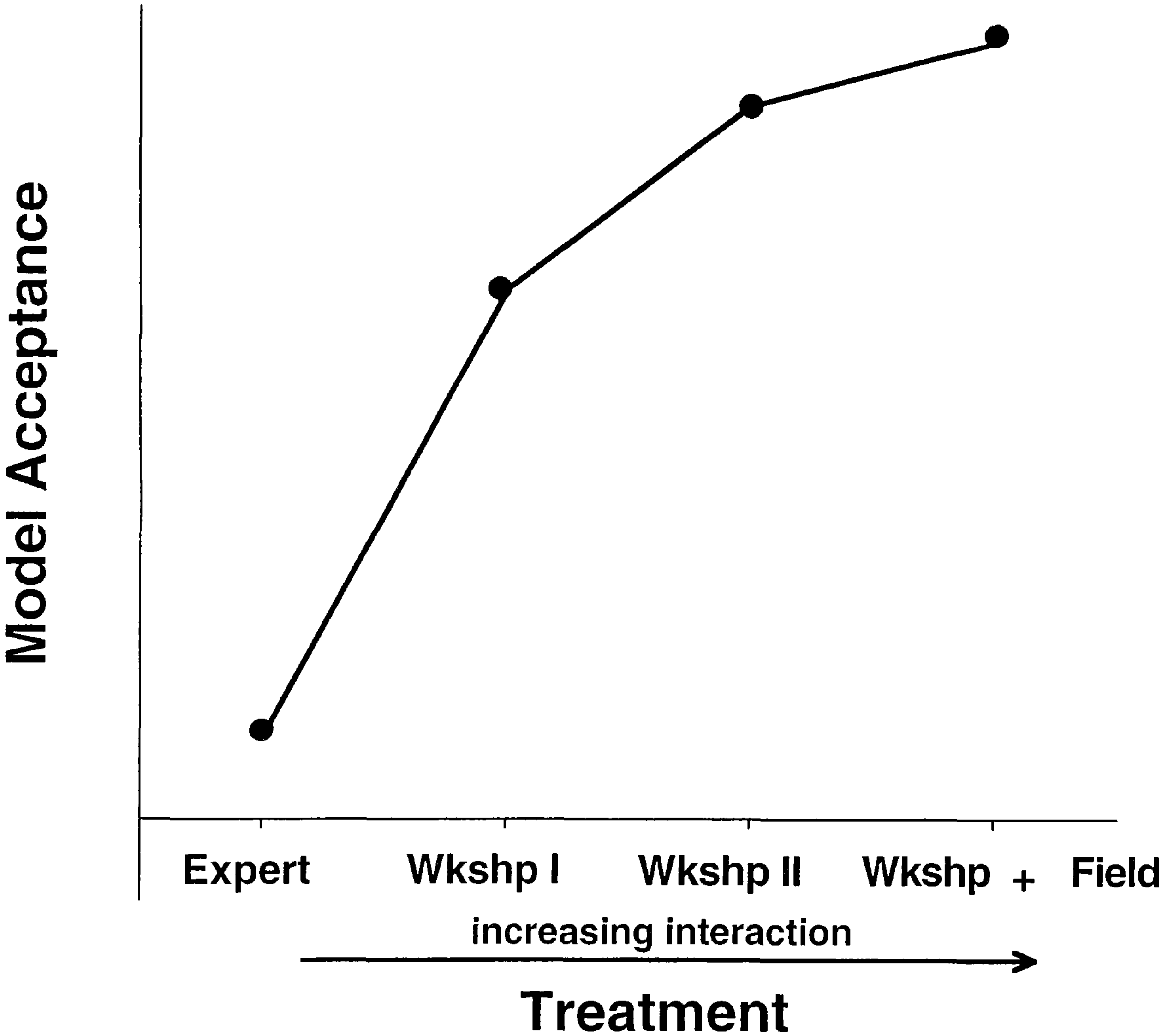

Figure 1. Hypothetical response of subjects to increasing intensity of interaction with the model. Dependent variable is the degree of acceptance of the model as a useful planning tool.

From Landscapes to Waterscapes: An Integrating Framework for Urbanizing Watersheds

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A generally adverse relationship between urbanization and water resources conditions is normally assumed. However, the variability of impacts from alternative landscape scenarios on water supply, flooding, and the ecological status of waters within a watershed subject to urbanization/suburbanization is not well understood. Approaches and methods for analyzing cause-and-effect relationships from a comprehensive perspective are not widely available.

Land settlements within urbanizing areas take place in a socioeconomic framework within which landowners attempt to maximize returns associated with land consistent with public policies on such issues as taxation, density of development, wastewater disposal, and drainage. These constraints have increasingly been applied on the basis of hydrologic units such as watersheds. However, watershed management has tended to consist of a collection of disparate measures that focus on specific aspects of development in relative isolation and sometimes without adequate evaluation of unintended side effects. For example, measures to protect surface waters from erosion and sedimentation may result in additional aquifer recharge and an increase in chemical content of runoff, which ultimately may affect not only use of groundwater but also use of the surface water into which the groundwater discharges. This situation creates the potential for ineffective management actions and wasted resources as individual control measures are implemented without evaluation of their interactions or cumulative effects. The lack of methodology for a comprehensive assessment of watershed management strategies is a major obstacle to assessment of policy effectiveness and adoption of a more holistic approach to watershed management.

The goal of this project is to develop procedures for integrated assessment of the hydrologic, ecological, and economic consequences of alternative landscape scenarios that occur during the urbanization/suburbanization processes. More specific objectives include: (1) development of an integrated hydrologic framework for assessing impacts of alternative land-scapes 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 economic conditions 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 will be employed to test the operation of the system of linked models to be developed. This study area is shown in Figure 1. This project will use a stakeholders' panel from the case study area to ensure relevancy to actual community watershed management.

The project will produce a set of linked models incorporated into a general methodology for holistic watershed assessment. Figure 2 illustrates the methodology that will be used as the basis for this assessment. The creation of this analytical capability will facilitate the development of policy likely to be effective in achieving social objectives by allowing an evaluation of consequences during policy development.

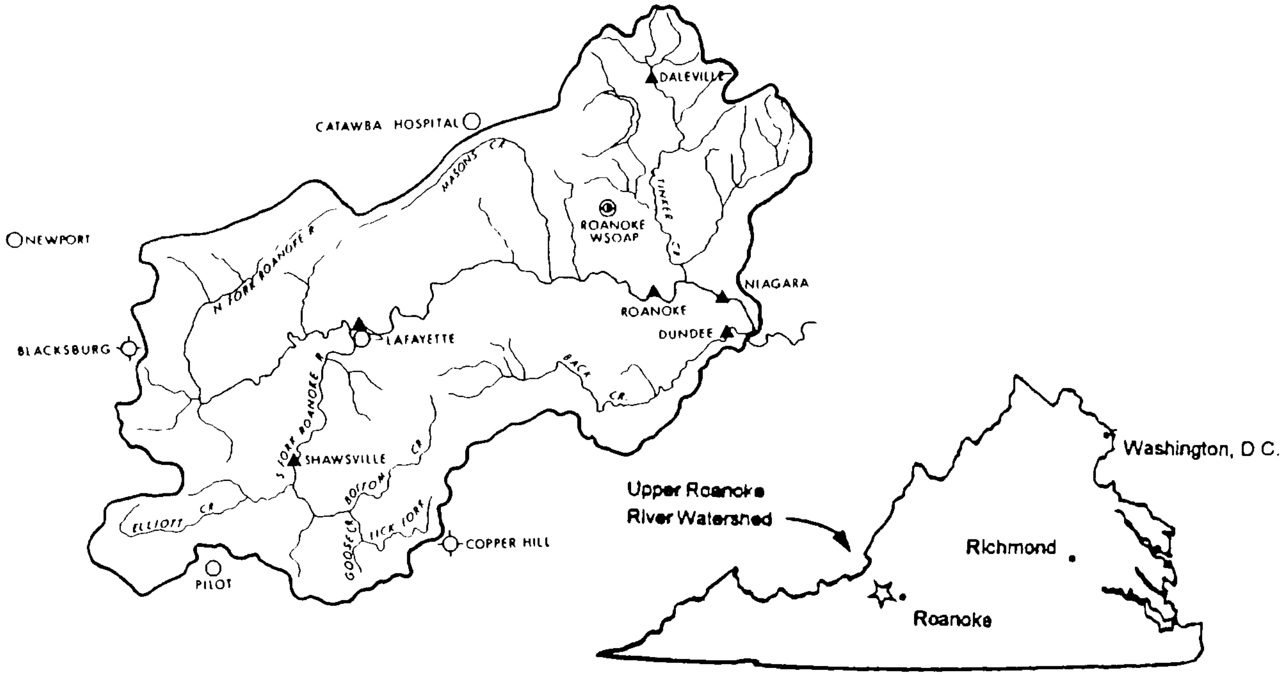

Figure 1. Upper Roanoke River watershed study area.

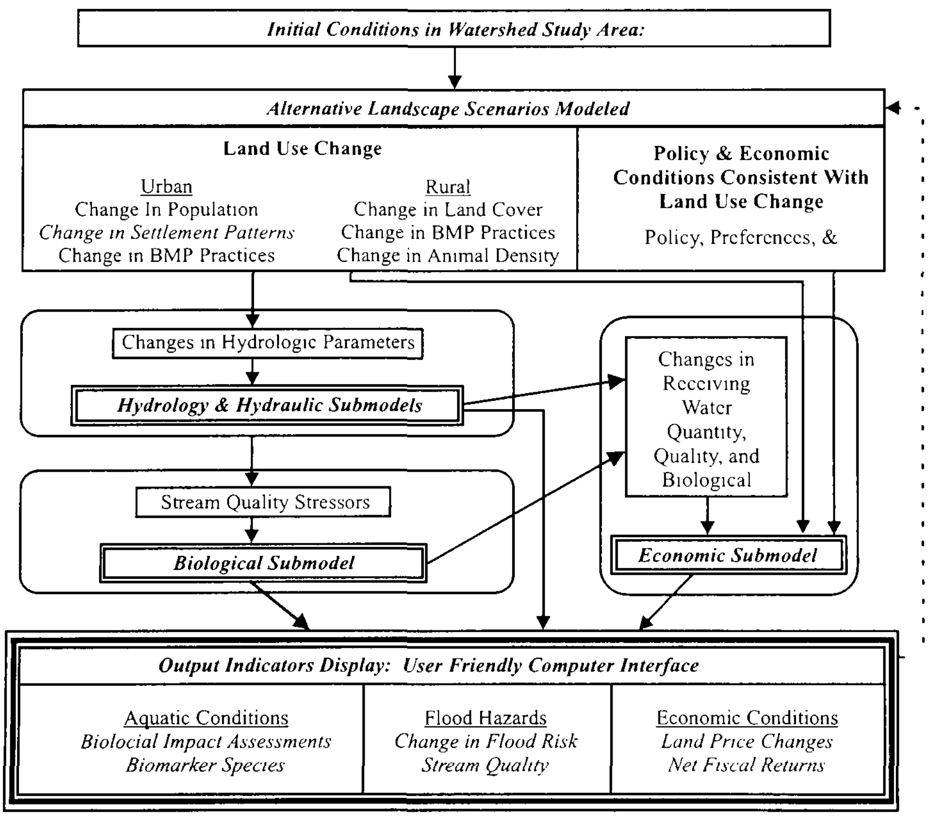

Figure 2. Study components and integration plan.

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

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Nutrient-enriched waters from the Mississippi River are one of the main causes of hypoxic zones in the Gulf of Mexico and adversely impact aquatic ecosystems within the basin. Nutrient loadings in the Mississippi River have been associated with the production of a substantial portion of the Nation's corn, soybean, and wheat, but the specifics of these links remain unclear. Our research will: (1) use a process model to predict agricultural discharges from two watersheds in the Upper Mississippi River basin (see Figure 1); (2) use observed and predicted runoff, sediment, and nutrient loadings to estimate the contribution of urban areas, wastewater treatment plants, and point sources to the total loading; (3) evaluate potential water quality benefits associated with the adoption of alternative management strategies on these watersheds; (4) develop regional-scale predictive models of ecosystem health, biodiversity, and sustainability by relating information on biota and ecosystem processes to current and potential landscape composition and structure; and (5) identify factors that affect the adoption of conservation production systems among landowners in the two watersheds. Our research focuses on the Lower Minnesota River watershed in eastern Minnesota and the Maquoketa River watershed in northeastern Iowa (see Figure 2). A spatial-process watershed modeling approach that incorporates a field scale model will be used for predicting daily hydrologic and water quality responses. Landsat Thematic Mapper data, Natural Resources Conservation Service's soils databases, published farming system information, topographic data, and historic climatic data will be used in conjunction with Geographic Information Systems (GIS) software to delineate watershed and hydrologic units to be used as inputs to the model. Available water quality data will be used to determine flow attributes associated with point discharges and nonagricultural activities.

Potential alternative farming systems will be developed based on interactions with stakeholders in each watershed. Process-model estimates will be made of potential reductions in environmental effects associated with the adoption of alternative farming systems. Data on macroinvertebrate communities in the study watersheds will be collected and analyzed in the laboratory. Statistical relationships between the habitat, biotic community structure, and land use activities will be developed and used to predict expected regional attainment for management plans. Finally, the project will evaluate socioeconomic factors that have influenced the success of past soil and water protection initiatives within the watersheds. Socioeconomic characteristics of the farm operator and the farm enterprise will be used to develop statistical models to predict the following: (1) adoption of specific soil and water conservation production systems; (2) agricultural productivity; and (3) propensities to adopt innovative conservation farming systems. A survey will interview 750 landowner-operators in each watershed. Socioeconomic, ecological, and water quality data will be analyzed by using a combination of parametric and nonparametric statistics. It is anticipated that factors affecting the adoption of conservation behaviors at the farm level will be identified. This will make it possible to implement more effective technology transfer programs within the region and provide a tool to assess the environmental benefits of adopting alternative management practices.

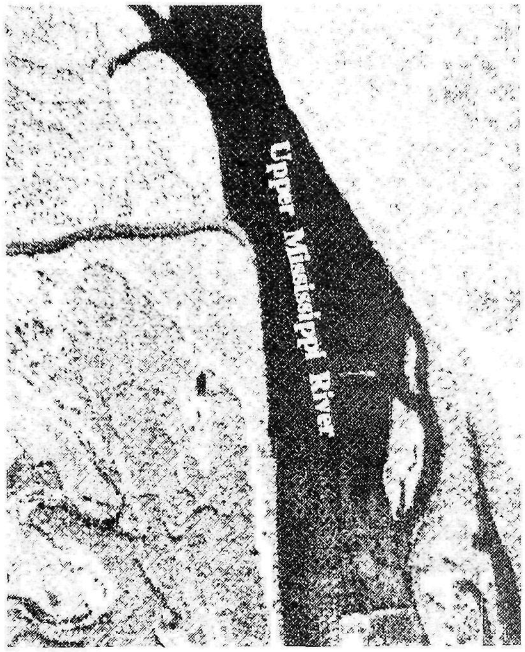

Figure 1. An infrared aerial photograph (acquired on September 12, 1989) showing movement of sediments from Maquoketa River watershed into Pool 13 of the Upper Mississippi River.

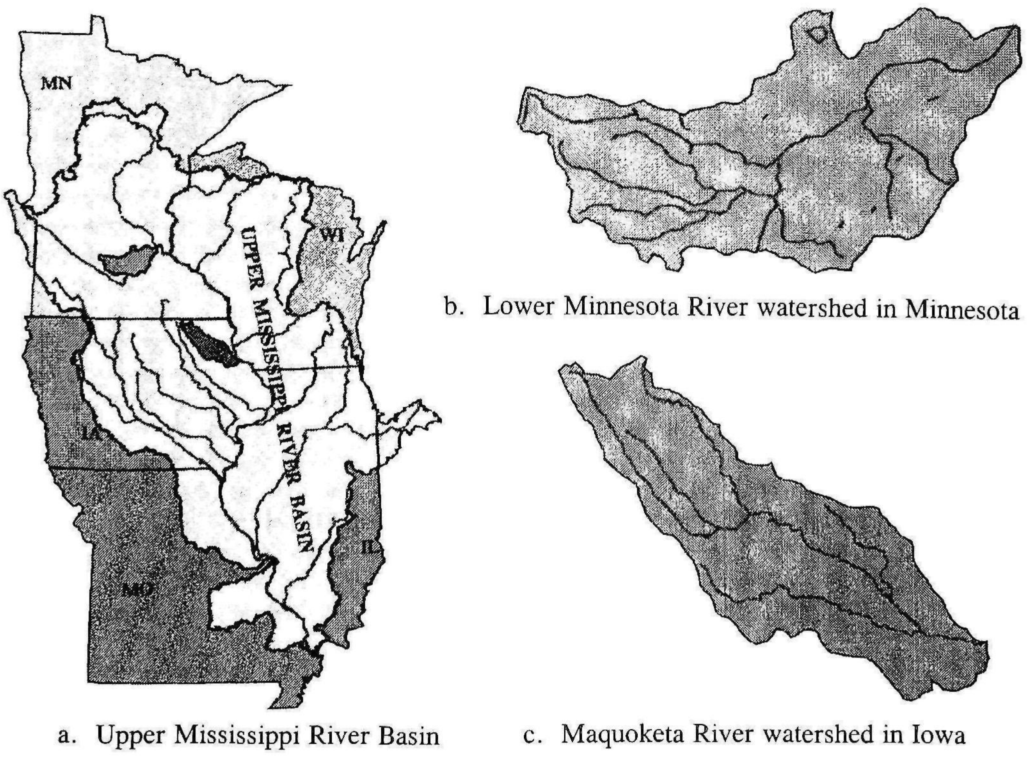

Figure 2. A map showing the location of Lower Minnesota River and Maquoketa River watersheds in the Upper Mississippi River basin.

Integrated Ecological-Economic Modeling of Watersheds and Estuaries at Multiple Scales

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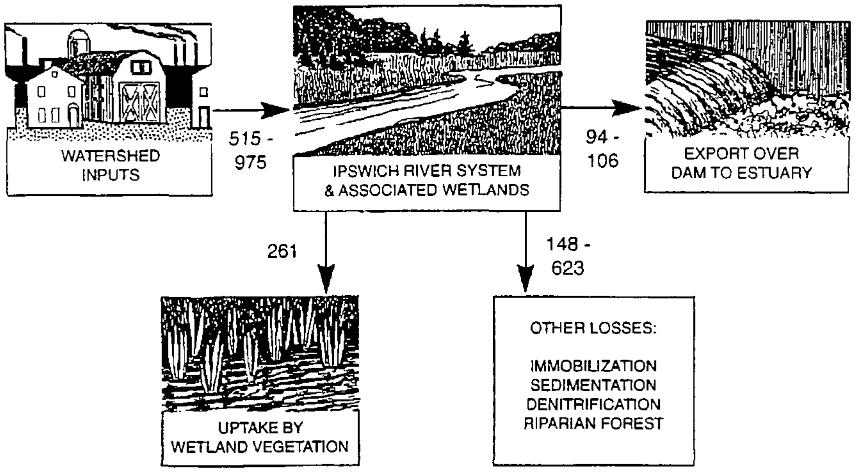

Figure 1. Annual budget of N loading, uptake, and export for the Ipswich River drainage basin (metric tonnes). Objectives of the research program are to develop spatially explicit models of water and nutrient transport and fate in the Ipswich River watershed.

The consequences of large-scale, long-term changes within watersheds on estuaries are poorly understood. Integrated assessments of ecological impacts of economic development in coastal watersheds will require interdisciplinary approaches. Ecological-economic models must be integrated into biogeochemical and landscape models to realistically assess human impacts on watersheds and estuaries. The objectives of this project are to: (1) integrate socioeconomic models with spatially explicit land use, biogeochemistry, and watershed hydrology models to provide comprehensive assessments of human activities on nutrient, sediment, and water fluxes in a ~ 500 km^2 coastal watershed; and (2) to develop aggregation schemes that will allow the linked models to be applied to other watersheds.

The Ipswich River watershed in the Boston metropolitan area will serve as the experimental watershed. Rapid economic and land use changes in this region, plus ongoing research and an extensive database, make the Ipswich River drainage basin particularly appropriate for this research project (see Figure 1).

To assess human impacts on watershed and estuarine dynamics, four types of models will be used: (1) socioeconomic models, (2) spatial land use change models, (3) terrestrial hydrologic models, and (4) stream hydrologic/biogeochemical models. A goal of our research is to develop a means of assessing the impacts of urbanization and land use change on watersheds and estuaries in general, not just a specific assessment for the Ipswich River. Pending successful completion of Ipswich River watershed modeling, aggregation schemes will be developed that will allow for applying our linked models to larger watersheds or watersheds with less intensive input data than ours. Aggregation procedures can ensure that our approach is transferable. Our approach will enable us to better assess human impacts on watersheds and to evaluate management strategies for minimizing or reversing watershed, riverine, and estuarine degradation.

The following scenarios will be evaluated following the development and linkage of models: (1) How do the magnitudes and temporal patterns of water, sediment, organic matter, and nutrient loadings differ among subcatchments with different land use patterns, and how are loadings processed within the river before being discharged to the coastal zone? (2) What effects do the spatial patterns of land use and river habitats have on magnitudes and temporal patterns of loadings to the mouth? How did historical land use and economic activities affect the magnitudes and temporal patterns of estuarine loadings? (3) What changes in watershed land use can be expected based on projected economic activity, and what will be the impact on water yield and material loadings?

Stakeholder involvement is an integral part of our research. Our research will be implemented with the involvement of three stakeholder groups in the Ipswich River watershed. Collaboration with these groups will facilitate the collection of data critical to parameterizing hydrologic and biogeochemical models of the watershed.

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

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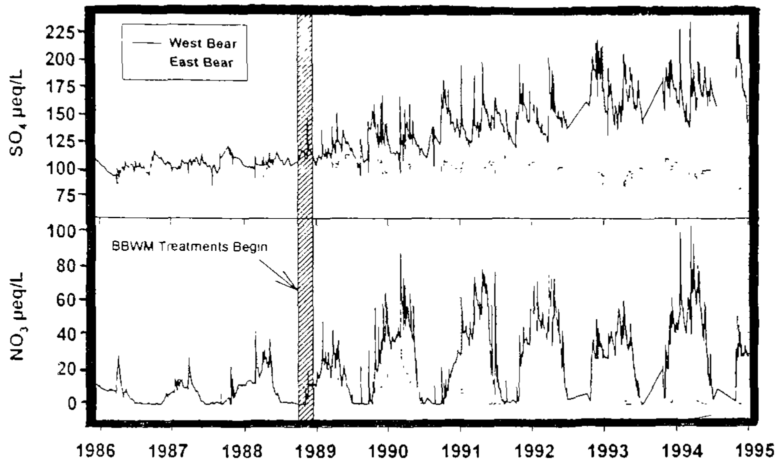

Figure 1. Bear Brook Watershed in Maine (BBWM) stream time series.

The possibility of negative impacts from acidic deposition on aquatic ecosystems was widely recognized in the United States less than 20 years ago. Methods to assess the status of aquatic systems have been available for only about 10 years, and the models to evaluate this assessment are still being modified and tested. In this project, a specific ecosystem response to experimental watershed acidification is being determined, and this knowledge is being scaled to a regional level to determine the extent of acidification and N-saturation in a sensitive subpopulation of high-elevation lakes. Concurrently, mechanisms are being developed to involve state, federal, and industry resource managers in the process of using these results in management and policy.

The project activities are hierarchical from site specific to regional. First, the indicators of, and model predictions for, acidification and N-saturation at the experimental site will be examined at the Bear Brook Watershed in Maine (BBWM). This site has had an 8-year experimental treatment of dry ammonium sulfate. The model of acidification of groundwater in catchments, and its nitrogen sequels, will predict acidification and responses as well as determine where BBWM is located on the response continuum. From new and ongoing data collection on soils, stream chemistry, and forest growth, the response indicators will be assessed at this site. Second, the site-intensive information will be scaled to the region using data from high elevation lakes in Maine and their watersheds. These lakes had the highest concentrations of nitrate of any known lake population in the northeastern United States in the 1980's. Their acidification status was similar to lakes in the Adirondacks. Resampling of these lakes will occur in 1997 and 1998 to determine lake-chemistry changes during the past decade. Using mechanisms defined at BBWM, parallels will be determined between Bear Brook and the high elevation lakes. Then the focus will be on transferring new information about changes in water quality and forest productivity to the state, federal, and industry contacts. A key component is the early and ongoing involvement of these stakeholders in a two-way communication process.

At BBWM, dry ammonium sulfate has been applied bimonthly since 1989 to the 10.2 ha. experimental catchment, with an adjacent 10.9 ha. catchment serving as an untreated reference. This experimental loading is 1,800 eq/ha/yr, vs. 600 eq/ha/yr ambient wet + dry N deposition. In the experimental watershed, nitrate concentrations increased from a volume-weighted mean of 26 µeq/L in 1989 to 78 µeq/L by 1996 (see Figure 1). The yearly maximum increased from 40 to 106 µeq/L. Nitrate concentrations in the reference stream decreased from an average of 23 to 3 µeq/L, and the yearly maximum decreased from 43 to 11 µeq/L, reflecting a regional decrease in nitrate concentrations and flux.

This information will be used by the EPA to meet the congressional mandate in the Clean Air Act Amendments of ascertaining trends in ecological response and determining the effectiveness of the Act in influencing these trends. Site-specific data from Bear Brook scaled to the regional high elevation lakes also will provide a template for the recognition and understanding of possible N-saturation and base cation depletion. This information will be evaluated for use in management and policy decisions by industry, and at the local, state, and federal levels.

Comprehensive Watershed Management: A Spatial Water Quality Assessment System

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Robert P. Brooks, Barry M. Evans, James M. Hamlett, Archie J. McDonnell, and Gary W. Petersen
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The geography of natural resources, land use, and human economic activity influence the nature and spatial distribution of water quality conditions and the health of many aquatic ecosystems. The goal of this project is to create an approach to achieve multiple goals for water quality improvement from both physical and biological viewpoints in river reaches that are subject to a variety of geographical, social, and economic factors. Basic to achieving this complex goal is the ability to answer two kinds of questions: (1) if we invest in pollution control at one location, where and to what degree will the stream quality goals be achieved? and (2) vice-versa, to attain particular quality standards for a given reach for a basin, what alternative strategies could be implemented under various stream-flow scenarios? Thus, integrated approaches to water quality improvement must be linked to available technological interventions, to spatial and temporal patterns of implementation and to social and economic dimensions of community decisionmaking.

This project is a collaboration between the Institute of Water Problems in the Bulgarian Academy of Sciences and the Pennsylvania State University, Environmental Resource Research Institute and Center for Integrated Regional Assessment, using the Yantra River Basin (see Figure 1) as a study site. This basin, the location of Bulgaria's first river basin planning council, is among the major Bulgarian contributors to Danube pollution as a result of its long history of industry and its farming and livestock production.

This work will bring together geographic information systems (GIS), water quality models, and decision-support software for simulating the impacts of community decisions about improving water quality. GIS will assist in the development of model input for estimating nonpoint source pollution where directly measured data are not available and will bring together such key variables contributing to water pollution and remediation as population centers, settlements, industry, soil types, land use, water use, stream hydrology, treatment facilities, and biochemical and aquatic indicator measures. GIS also will help decisionmakers visualize the impacts of alternative community decisions about priorities for pollution abatement.

This project's approach has been to link new and existing water quality model components in a holistic, and transferable, GIS-based water quality assessment system. Bulgarian colleagues will contribute important components of the research beyond empirical data for model calibration, including work with aquatic indicators, experience in modeling multireservoir hydrologic systems, multicriteria decision modeling, and interaction with local resource managers. The initial review of decision support software suggests that a basin managment system developed at the International Institute for Applied Systems Analysis (Austria) can be coupled with existing models used in the United States and other new approaches. This project will develop scenarios based on a finite combination of economic and climatic conditions, which are representative of past and future conditions in the basin.

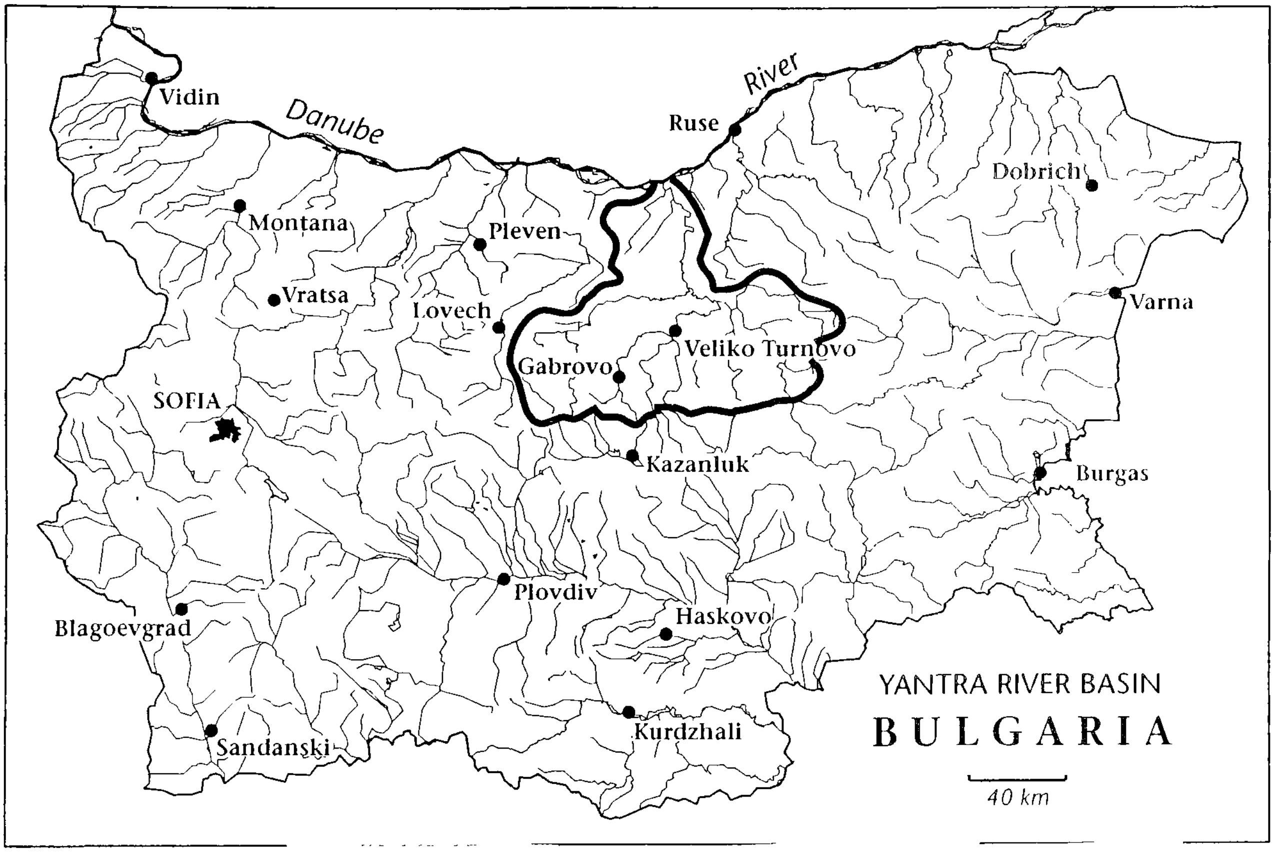

Figure 1. The Yantra River Basin, a Danube sub-basin in Bulgaria

Development and Implementation of Decision Support Systems for Predicting Economic and Ecologic Impacts of Alternative Land and Water Management Policies in Urbanizing Regions

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Community planning and environmental boards often evaluate proposed changes in land and water use. The aim of this research is to develop and then provide government agencies with an interactive computer-based technology for predicting the economic and ecological impacts of decisions on water and land use policies. To do this, this project must identify and quantify how various land use policies impact surface and ground-water quantity and quality, and how flows and pollutant concentrations affect aquatic and adjacent terrestrial systems. Also, the investigators must attempt to predict how changes in land and water use policies influence socioeconomic activities, local economic development, and tax revenues.

Our immediate goals are to improve the ability to predict the interdependent socioeconomic, terrestrial, hydrological, and ecological processes that define the dynamics of land use changes and their effects on water and associated biota. This capability will be incorporated into a data-driven, interactive, microcomputer-based decision support system (see Figure 1). This research is being conducted by a multidisciplinary team that includes a regional economist, three agricultural-environmental engineers, and an ecologist. Work is being conducted closely with town and county planners, and the methods will be tested on a local watershed. The approach and models being developed will be applicable to a variety of watersheds similar to those found in the Northeastern United States.

In the few weeks since this project began, work on developing the required surface groundwater simulation models for water quantity and quality has been conducted. This will be an expanded Interactive River-Aquifer Simulation (IRAS) model that has been developed steadily. To assess economic impacts of land and water use policies and to predict likely scenarios for future land use changes, this land use and land cover information is being gathered for the five-county economic region in which this study watershed is located. Data from the Census Bureau's Survey of Population and Housing for 1970, 1980, and 1990; the New York State Office of Real Property Services' tax assessment for every land parcel; and USGS' GIRAS files on land use and land cover are being obtained. The initial objectives include building a model that accounts for land converted to residential uses since 1970, and then using it to identify areas in the watershed having a high probability for future residential development under various economic growth scenarios. The structure of the ecological components of the simulation model are being developed by expanding a simple system relating macroinvertebrate and fish species to predicted habitat and water quality status. New quantitative information from the surface groundwater simulation model will permit much more sophisticated predictions on aquatic communities than were previously available.

This project's goal is to develop a model system that will simulate decision options, policy ramifications, and environmental enhancement strategies. The model should be valuable for uses such as designing the spatial distribution of conservation incentives, selecting requirements for development mitigation measures, comparing zoning and siting approaches, and planning reserves, greenways, and other forms of natural area designations.

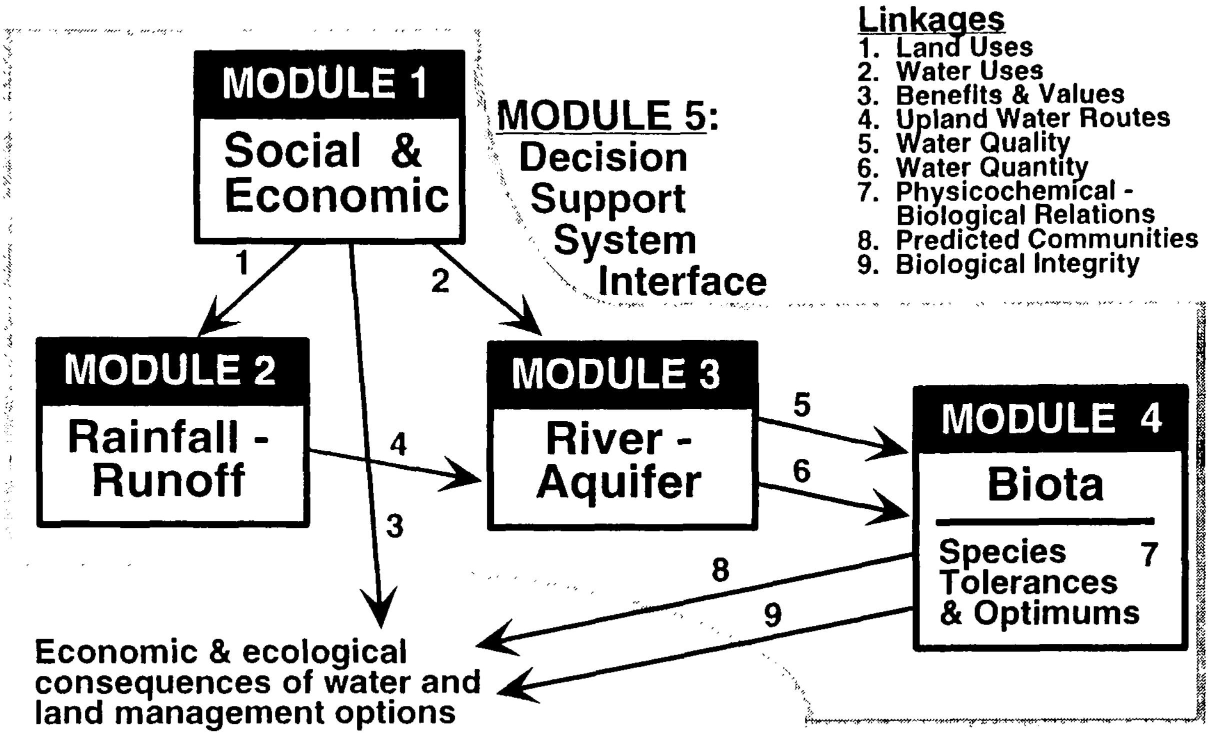

Figure 1. Decision support system modules and links.

Effects of Natural and Anthropogenic Processes on Tillamook Bay and Its Watershed: An Integrated Process Study and Land Use Perspective

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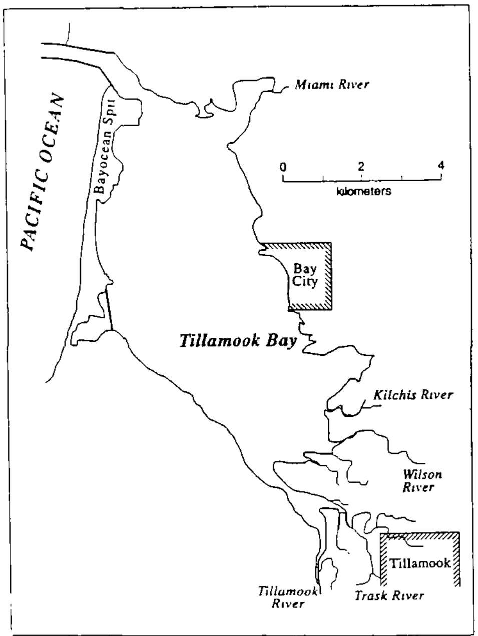

Figure 1. Tillamook Bay and its watershed.

Human activities can significantly alter the physical, chemical, and biological nature of aquatic environments. Furthermore, community perceptions of environmental hazards can lead to mitigative actions that may themselves have their own detrimental impacts on ecosystems. There is an interplay between social perceptions and societal decisions that can influence the physical environment, chemical cycles, and biological communities. An understanding of the problems associated with the interactions between social and natural systems requires a multidisciplinary approach.

This project is employing such techniques in addressing research problems associated with the interplay between natural and anthropogenic processes within the Tillamook Bay watershed. Tillamook Bay is a drowned-river estuary, formed initially about 9,000 years ago when rising sea level at the end of the Quaternary ice age inundated the lower reaches of the Trask, Wilson, Tillamook, Kilchis, and Miami Rivers, which currently drain into the bay (see Figure 1). The Bay is located in the Pacific Northwest, roughly 100 km west of Portland, Oregon, and approximately 80 km south of the Columbia River.

Land use practices vary significantly among the different riverine watersheds. The Trask runs through the urban center of Tillamook, whereas the Tillamook River to the south is heavily influenced by dairy farming activities. The northern-most three rivers experience progressively less urban and agricultural activities within their lower watersheds and increase in the relative proportion of forested lands. Within the framework of examining the relative influence of different watershed activities on processes occurring within the Tillamook basin, four specific hypotheses will be tested: (1) Land use practices have significantly altered the sedimentary budget of the Tillamook Bay watershed. (2) Carbon, nutrient, and trace metal cycles are significantly different among the five major river systems feeding the Tillamook estuary because of the different land use practices. (3) Differences in land use practices between the Tillamook and Kilchis River sub-basins have led to quantifiable differences in aquatic ecosystem health and biotic integrity in the riverine and stream environments. (4) Local knowledge of watershed activities and processes are influenced by many social factors that may result in perceptions quite different from scientific measures of sedimentation, nutrient cycles, and aquatic health.

The above hypotheses will be approached with field and analytical programs designed to yield information on spatial and temporal patterns within the watersheds. This project will attempt to explain the factors influencing watershed quality in such a way that plans can be developed to enable residents of the five river basins to improve the environmental quality of Tillamook Bay and the basin in which they live.

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

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The Illinois River, one of the most scenic rivers in Oklahoma, has been the center of political controversy about private property rights and environmental protection for more than 25 years. The Illinois River has provided multiple social benefits to the citizens of Oklahoma through its use for recreation, water and power supply, flood control, and nutrient removal. Yet, the inability of different interests to reach agreement on how to protect the Illinois River watershed has placed its hydrologic resources at increased risk of long-term degradation. With the absence of a unique environmental issue or feature to catalyze political support for policy change, the Illinois River basin exemplifies the challenge to sustainable river basin management.

This 3-year interdisciplinary research project demonstrates how different environmental and social values held by river basin stakeholders can be identified and compared so that more effective environmental protection strategies can be determined and adopted by local land and water use interests and state agencies. The investigators will develop and test an integrated impact assessment management protocol for the Illinois River watershed by linking together the ecological, economic, hydrological, social, and political aspects of the watershed in an interdisciplinary approach that provides a more realistic framework for calculating, communicating, and negotiating environmental risks and competing social values (see Figure 1). In the first 2 years of the project, the research team will: (1) identify stakeholder views on the Illinois River basin; (2) determine the economic effects of alternative land and water uses for three study sites in the river basin; (3) calculate the ecological risks associated with different intensities of resource use; (4) develop hydrologic models using Geographic Information Systems (GIS) that incorporate water quality aspects of alternative land use practices; and (5) develop computer-generated imagery of each of the three sites that will enable stakeholders to visualize more easily the implications of different management options for the river basin's resources. At the same time, members of the research team will be investigating stakeholders' perspectives of natural, economic, and sociopolitical impacts through interviews and focus group sessions. These groups will include technical experts, lay stakeholders, and policymakers. Background data will be drawn from the investigators' prior studies of the Illinois River watershed, its carrying capacity, and comprehensive land use plans.

In the third year of the project, stakeholder groups will be engaged in a policy dialogue and a test of the effectiveness of integrated computer models to facilitate the risk communication of complex environmental management issues. Visual simulations developed from GIS-based hydrological models will be shown to stakeholders in conjunction with focus group sessions to ascertain management preferences and the overall legitimacy of negotiated agreements. Negotiation workshops will be held to develop a consensus about land use practices that afford an adequate level of protection to the basin. The entire process will be tested to determine the degree to which the process is viewed by experts and lay stakeholders as efficient, effective, and legitimate, and therefore acceptable.

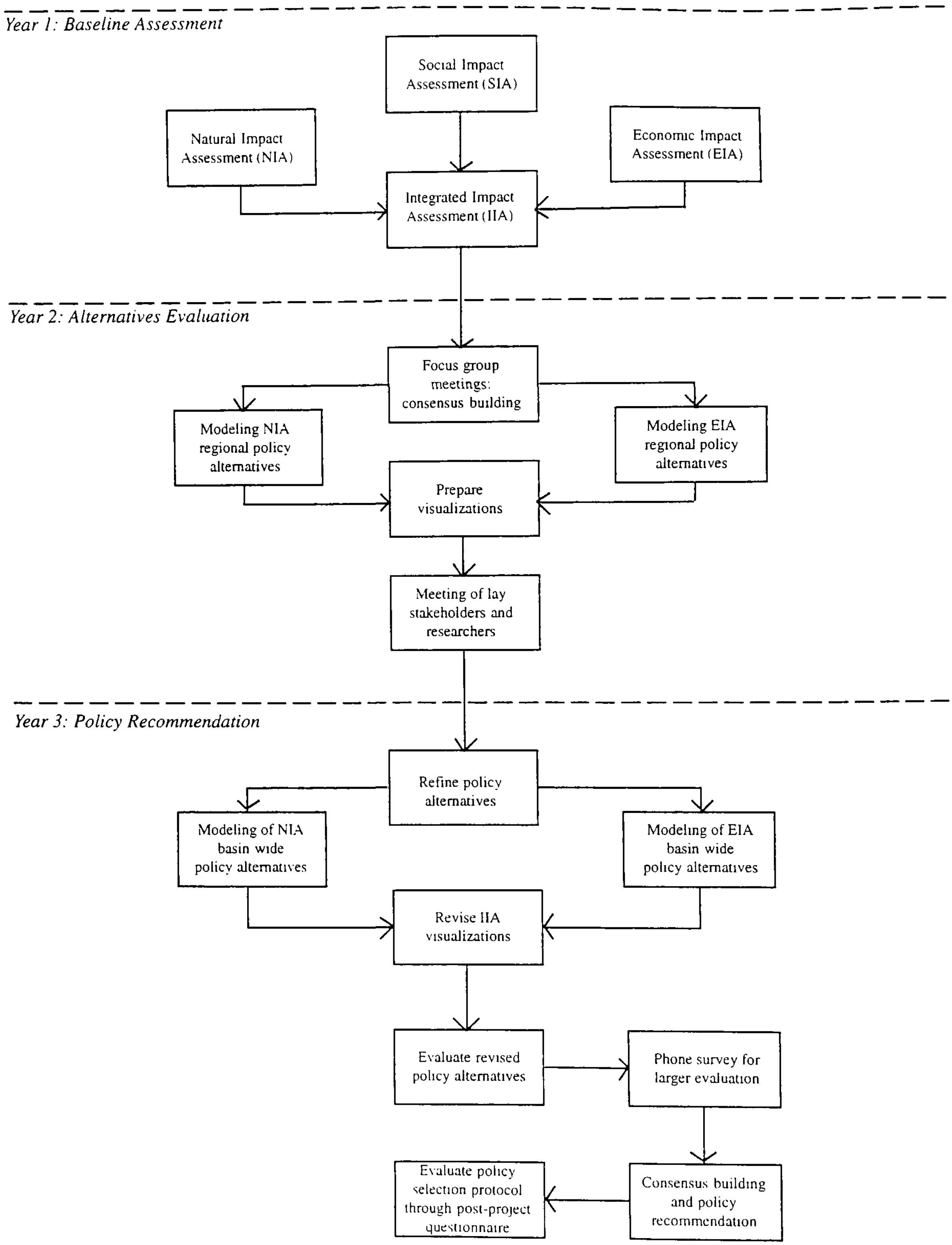

Figure 1. Illinois River Project: Research Plan. Ecological risks, stakeholder values, and river basins: testing management alternatives for the Illinois River.

Risk-Based Urban Watershed Management: Integration of Water Quality and Flood Control Objectives

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Figure 1. The Milwaukee River is being restored. The picture shows a site that was previously an urban reservoir with very poor water quality. The dam that has created the reservoir is being removed, contaminated exposed sediments are either removed or capped and vegetated, stream banks are being reinforced by bioengineering, and the channel is restored to provide a natural habitat to fish, including migrating salmon from Lake Michigan.

Urbanization is known to increase flooding potential and to impair the ecological integrity of water bodies. In the past, however, most urban drainage projects focused almost solely on flood protection and were conveyance oriented. This project will develop and test methodology for watershed management in urban and urbanizing watersheds. Management is based on quantitative risk assessment of urbanization to the watershed ecosystem, including people residing in the watershed and affected by the receiving water body and biota residing in receiving water bodies. An evaluation of the flood and ecological risks will help to set priorities for management, find an optimum solution considering both risks, and provide necessary information to agencies for funding decisions.

The objectives of this project are to: (1) develop statistical flow, loading, and water quality models applicable to risk assessment; (2) develop objective and quantitative risk assessment procedures for estimating ecological risks of stormwater and subsurface discharges from urban and suburban watersheds; (3) develop a methodology for the assessment of flood control and water quality benefits and resolving conflicts between flood control and ecological preservation-restoration objectives; (4) develop benefit/cost models for urban watershed management to optimize both flood control and receiving system ecological integrity; (5) research innovative financing of urban watershed management, identify key players, and assess the willingness to pay for different types of benefits; and (6) examine homeowners' risk/benefit perceptions, values, effective responses to the risk, subjective norms, sociocultural backgrounds, and use of communication in the willingness to pay for these different types of benefits.

Figure 1 shows the concept of optimization of flooding and ecological risks in watershed management. Ecological risk assessment quantitatively enumerates the hazards of pollution discharges and physical alteration of urban water bodies and their hydrology/hydraulics to the biota residing in the water body and riparian ecosystems. A similar notion is applied to flood risk that denotes a probability of damage to the water body itself, to properties in the flood plain, and hazards to human health and well being.

Presently, no ecological standards are available for urban drainage and water body restoration projects, and most projects are driven by flood protection objectives, leading to conveyance-oriented modification of the urban (suburban) water bodies. Conveyance solutions (such as channel lining and straightening) have adverse ecological consequences and commonly are economically inefficient. Today, such projects and solutions may not be acceptable. Incorporating ecological integrity objectives may lead to storage-oriented approaches and restoration of ecological integrity of urban receiving water bodies.

The methodologies developed in this project will be tested on two pilot watersheds in Milwaukee County. One watershed is fully urbanized and is found in the City of Milwaukee. The other pilot watershed is in a suburban part of the County that is undergoing rapid urbanization.

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

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Policymakers, planners, and managers need to understand the biophysical and social processes controlling water yield and quality as well as aquatic biodiversity in human-dominated landscapes. This requires an integrated watershed model, which can address three types of social interventions for ameliorating water quality: Type 1—reducing point sources of pollution at the "end of the pipe;" Type 2—regulating land use to reduce nonpoint inputs; and Type 3—modifying sociocultural processes within different types of land uses to minimize the polluting behavior of individuals, groups, and institutions. Types 2 and 3 are underutilized.

This research, to be initiated in late 1997, will develop a model to test whether the sociocultural factors involved in Types 2 and 3 control water quality, watershed dynamics, and stream biota of watersheds that extend across urban through rural land uses. Specifically, the model will test to what degree sociocultural factors affect water quality, watershed dynamics, and stream biota indirectly by modifying ecological processes, or directly by modifying people's actions. Indirect sociocultural effects include clearing, planting, or managing forest patches that can affect the extent, distribution, and structure of vegetation cover. Direct sociocultural effects on ecological processes include inputs of solids and nutrients from dumping or runoff from fertilizers and pesticides. The research will be conducted in the 17,150 ha Gywnns Falls watershed in the Baltimore region of the Chesapeake Bay drainage.

An integrated approach is needed for two reasons. First, the U.S. EPA has mandated a 40 percent reduction in nitrogen loading to the Chesapeake Bay. Controlling point sources of pollution (Type 1) has not met this mandate. Second, forest conversion and suburbanization are proceeding rapidly (Type 2), leaving few options to mitigate water quality. Thus, a model of the interaction between the ecological and physical patterns and processes in the landscape with sociocultural patterns and processes (Type 3) is a potential decisionmaking tool to identify and evaluate social and ecological interventions for improving water quality in the Chesapeake region.

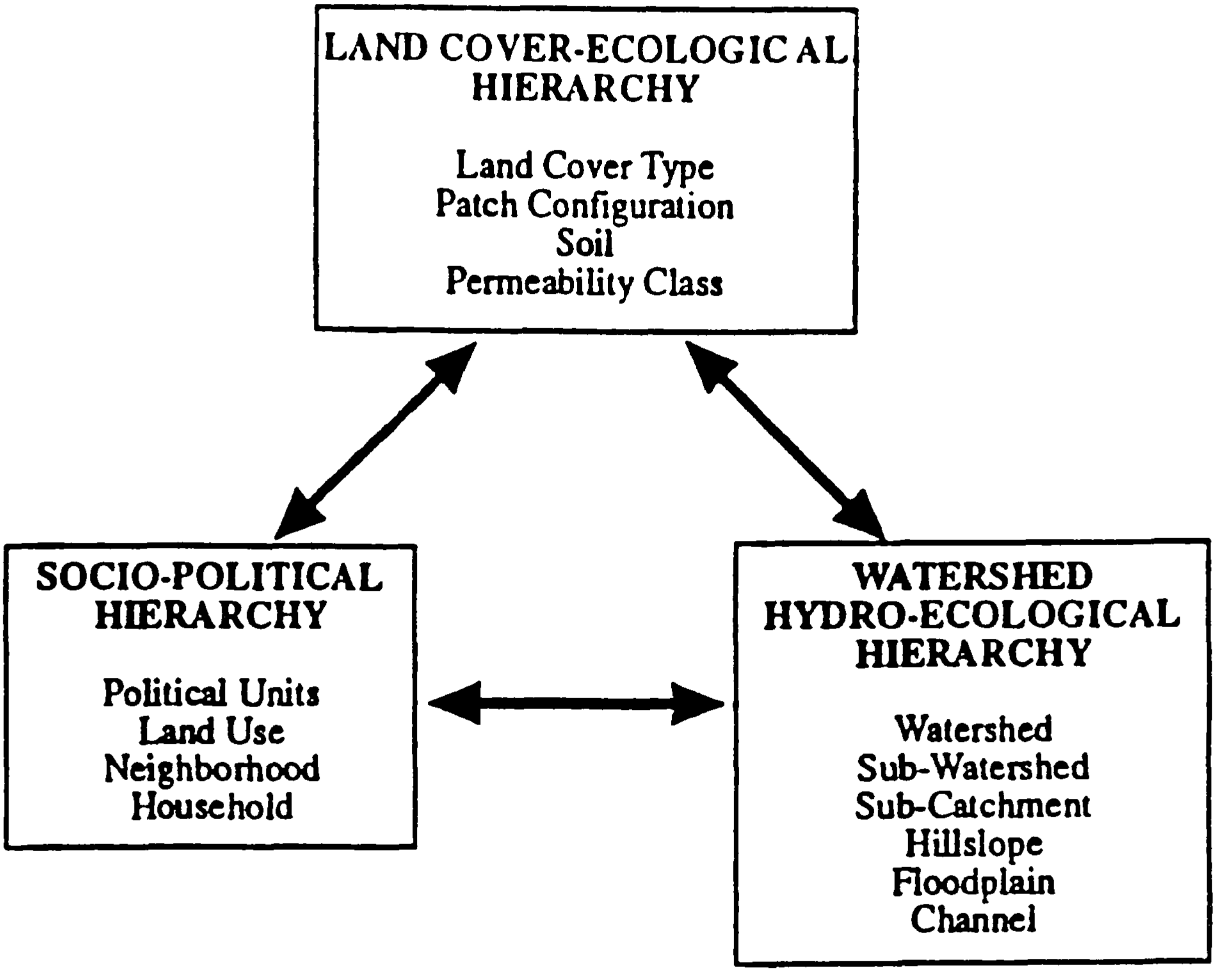

Figure 1. The three hierarchies of patch or land units to be integrated in the proposed research. Sociopolitical units are those defined by political or administrative entities. Watershed hydroecological units are those delimited by decomposing large watersheds into smaller units that contribute runoff. The land cover-ecological hierarchy describes the specific surface features that govern the flow rate and pathway of runoff and the degree of saturation.

Section 2.

Projects Initiated With Fiscal Year 1996 Support

Strategic Renewal of Large Floodplain Rivers: A Preliminary Status Report

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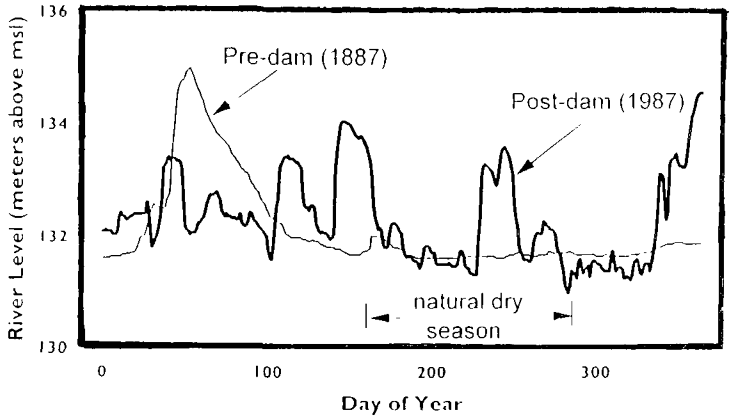

Figure 1. Effects of Illinois River dams.

This project is investigating the potential for selective restoration of the hydrology and ecology of floodplains. Interrelated ecological, hydrologic, and economic models are being developed to compare the effects of current floodplain management versus ecosystem-based alternatives. Specific objectives are: (1) to estimate thresholds at which floodplain restoration measures can have significant impacts; (2) to identify combinations of structural changes and floodplain restoration efforts that enhance sustainability; and (3) to identify institutional obstacles to policies that might otherwise balance the costs and benefits of floodplain restoration. Our project uses the LaGrange Reach of the Illinois River as a study site. Figure 1 illustrates the impact that current river management has had on river and floodplain hydrology.

The hydrology of the Illinois River varies on time scales of days, seasons, and decades. The role of variability is being examined at each of these time scales on the ecological processes in the floodplain and the resulting economic activities. Ways to increase the overall economic value of the river using ecological and hydrologic restoration are being sought.

Project hydrologists are combining one- and two-dimensional hydraulic models to compute flow fluctuations in three critical time scales: (1) short-term changes related to navigation needs, (2) seasonal patterns, and (3) long-term extremes (both floods and droughts). For selected restoration sites, intensive modeling using the two-dimensional model will allow prediction of lateral-flow velocities and sedimentation processes that influence biotic regimes. To date, the one-dimensional model has been run under selected high flow conditions to test its sensitivity and to simulate the removal of levees. The analysis will be extended to low flow conditions. The model results appear highly sensitive to Manning's roughness coefficient.

Project ecologists are creating dynamic models of floodplain vegetation, for both forested and nonforested regions. A critical feature of the models has been to incorporate daily hydrological variation rather than the average annual conditions used in existing floodplain forest models. These dynamic ecosystem simulators interact with complex water regimes provided by the hydraulic model and, in turn, generate input for static habitat suitability models for floodplain animal species. More than a century of river-stage records, floodplain forest descriptions from early 19th century surveyor notes, and information from present-day vegetation surveys have been used to calibrate the forest model. The model has demonstrated that hydrological variation at long time scales is necessary to maintain floodplain forest diversity. The next steps include incorporating the nonforest vegetation model and linking the dynamic models to habitat suitability.

Project economists are developing a model to estimate the impacts of restoration on the local economy. This includes collecting, organizing, and assessing data of the various economic elements (e.g., farm production budgets, crop insurance, recreation values, flood damage records and estimates, transportation values, institutional influences, etc.). A limited land use allocation model has been developed and used to assess how agricultural land use might change as levee heights are reduced. Agricultural land use values will be supplemented with survey data on recreational values to permit a more complete analysis of social values associated with floodplain land uses. This project has emphasized improving the information flows between disciplines and model components, perhaps through expanded use of geographic information systems.

Integrating Modeling and Management of Agriculturally Impacted Watersheds: Issues of Spatial and Temporal Scale

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Scientists and managers concerned with watershed management are faced with a dilemma: Scientists are developing models that explicitly address cumulative effects, large spatial scales, and longer timeframes, but societal policy shifts are forcing managers to make decisions on an increasingly more local basis. Effective implementation of watershed management principles requires models that resolve this dilemma (e.g., models that incorporate knowledge about effects at longer temporal scales and larger spatial scales into more localized decisionmaking). The goals of this project are to develop a more quantitative understanding of the implications that this dilemma poses to aquatic science and watershed management and to develop solutions for resolving the dilemma.

This project focuses on the Minnesota River basin, which occupies much of southern Minnesota. The basin presents great opportunities for integrative research to advance watershed science as well as contribute to solving a major environmental problem. The basin drains almost 40,000 km^2, including 34,000 km^2 of intensively farmed land, and it is considered one of the most polluted rivers in the country. High concentrations of nitrogen, phosphorus, pesticides, bacteria, and sediment, mostly from diffuse sources, cause degraded conditions throughout the river and many of its tributaries. In turn, the river acts as a major source for these pollutants to the Mississippi River, into which it flows at the Twin Cities.

A state-initiated program, the Minnesota River Assessment Program, studied water quality in the basin and set improvement objectives during the period of 1989-1993. This program led to a phase in which comprehensive basin plans are being developed and implemented. These plans include Best Management Practices (BMPs) for farm management, wildlife and habitat protection, sewage treatment facilities, riparian zone and wetland restoration, and pesticide/nutrient management. However, these plans rest on an incomplete knowledge base. Barriers to implementation include incomplete knowledge about sources and the effectiveness of proposed BMPs. This project is addressing these needs with one overarching objective: to improve the understanding of how biophysical and socioeconomic variables interact in agricultural watersheds of varying scales, landscape conditions, and land use management practices to affect the export of nutrients and their impacts on instream biological communities, and in turn, to assess the role of knowledge about those effects in decisionmaking processes on local level land use.

We are conducting the research in three coordinated phases, respectively dealing with landscape processes, aquatic processes, and socioeconomic issues. Biophysical phases of the project encompass spatial scales ranging from the whole drainage basin to several scales of watersheds. In particular, we are evaluating: (1) ways to account for scale effects in hydrologic and nutrient transport modeling within watersheds; (2) the effectiveness of agro-ecosystems as complementary landscape units (to watersheds) for analysis of nutrient export from the land (see Figure 1); (3) the scales at which aquatic ecosystems process and retain nutrients and how they influence rates of stream recovery when land management practices are improved; and (4) ways to identify priorities for controlling diffuse sources of sediments and phosphorus based on technical, social, and economic feasibility. All of these are critical for the protection and enhancement of aquatic ecosystems by integrated watershed management.

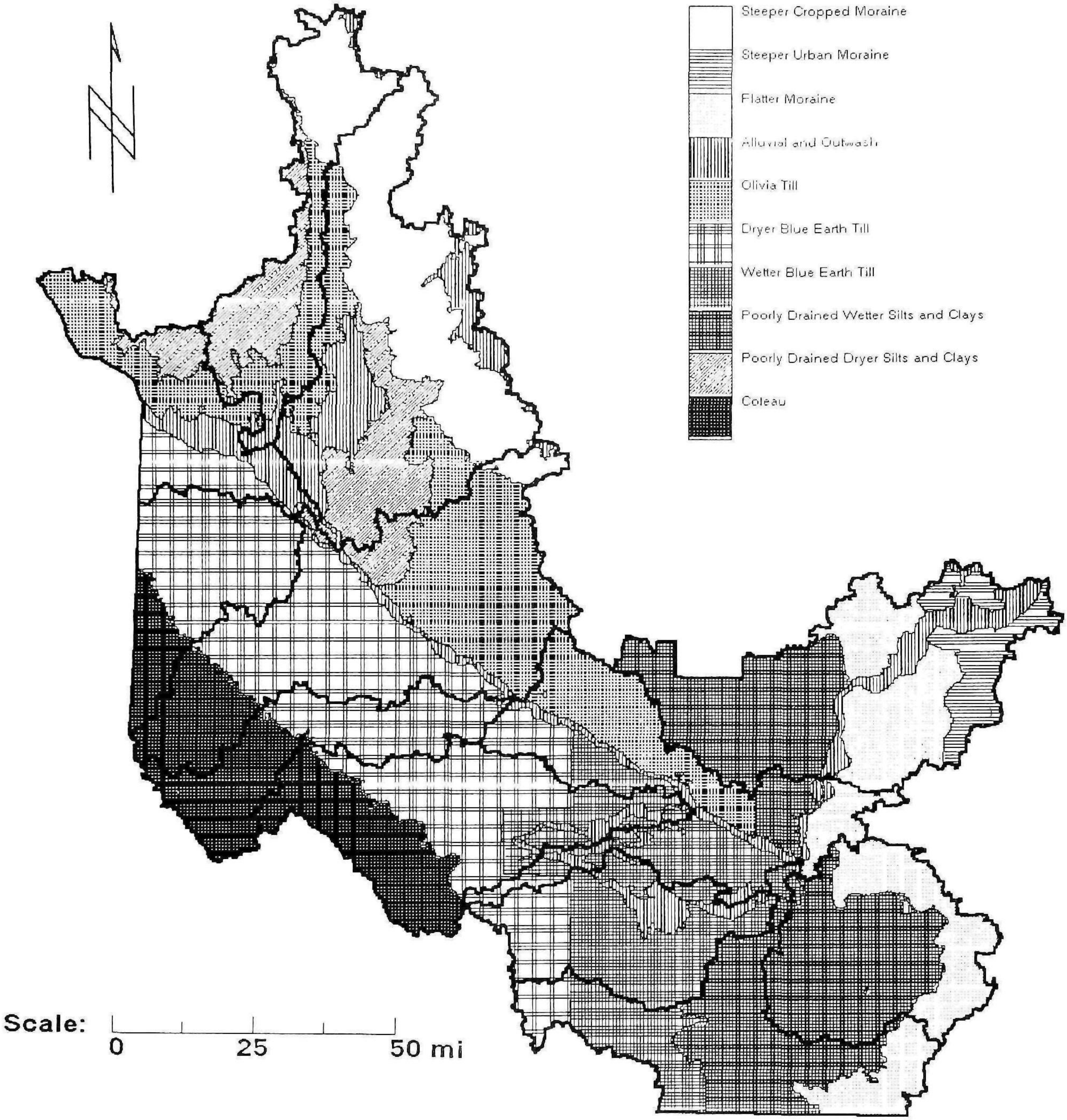

Figure 1. Map of Minnesota River Basin delineating its 12 major watersheds and 10 agro-ecoregions.

Urban Stream Rehabilitation in the Pacific Northwest: Physical, Biological, and Social Considerations

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University of Washington, Seattle, WA

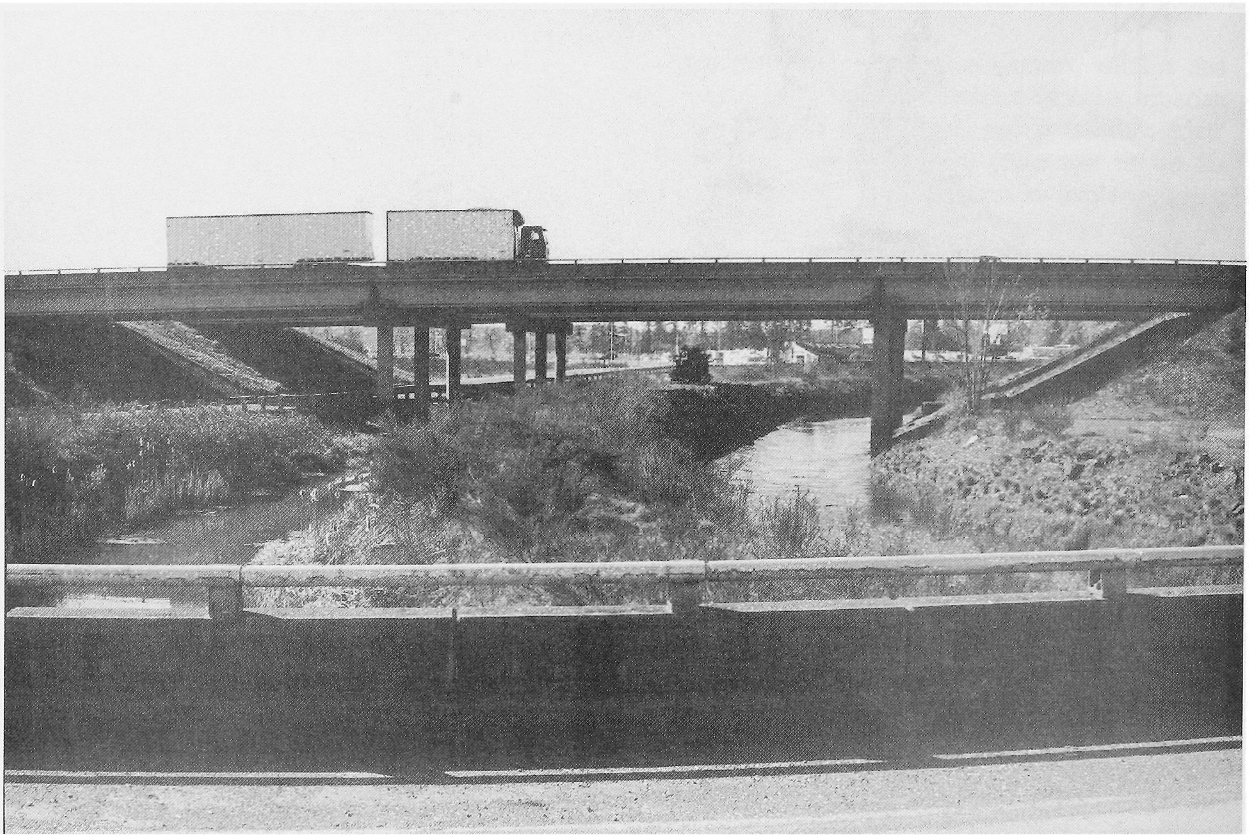

Figure 1. McAllister Creek, Thurston County, WA.

Society is eager to rehabilitate urban streams and to limit future damage as new areas are urbanized. Any framework for rehabilitation or protection must be grounded in understanding the specific factors responsible for degradation, their consequences, and the causal pathways linking them to human activities. With an improved understanding of what determines stream condition in urban areas, we can better evaluate prospective rehabilitation candidates; define realistic rehabilitation goals; guide the design of successful rehabilitation projects; and limit damage to high-quality aquatic systems through improved planning, design, construction, and management in urban areas.

One of the goals of this project is to document the consequences of urban development on the physical and biological condition of urban streams and to demonstrate specific rehabilitation strategies likely to restore valued properties of those systems (see Figure 1). Another goal is to develop successful rehabilitation methods for urban areas and to test public attitudes and preferences for rehabilitation measures. The questions for this project are framed in a process-based, watershed context: How do landscape processes translate to patterns in channel form and process, and how does urbanization affect spatial and temporal pattern of landscape processes? Since April 1997, we have accomplished several important tasks: (1) selected sites for examining processes, elemental changes, and cultural contexts of stream degradation, benthic macroinvertebrates, channel forms, bed sediments, and cultural landscapes—we have considered 18 sites that span a gradient from low to high urbanization; (2) evaluated visual preferences for rehabilitation design and human behaviors exhibited toward urban riparian areas and rehabilitation designs; and (3) assessed rehabilitation project costs and outcomes. These efforts are being expanded as we continue the development of our project.

Influences of Forest Fragmentation on Watershed Functions in Northern Vietnam—Preliminary Field Results

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It is likely that the atmospheric and hydrologic effects of deforestation depend on the degree of fragmentation of the remaining forest. As fragment size is reduced, a greater fraction of the remaining forest is in close proximity to a forest edge, where humidity, air temperature, and wind speed may enhance the transpiration rate. Forest clearing and subsequent land use can have major effects on soil hydrologic properties, including hydraulic conductivity. A fragmented landscape will translate into high spatial variability in the saturated hydraulic conductivity of the soil known as Ks. As a result, overland flow may be less likely to reach the stream channel or to attain velocities capable of initiating erosion or transporting sediment as far as the stream channel. Together, fragmentation effects on evaporation and overland flow can alter the hydrologic process differently than monolithic clearing. Thus far, one of several planned intensive field experiments has been conducted to investigate edge effects on transpiration. During the first experiment, a transect was instrumented, crossing both upwind and downwind forest fragment edges. Along the transect, four recording microclimate stations were created. Also, two arrays of Granier-type sap flow sensors were installed, monitoring 10 trees near the forest edge and 5 trees in the interior of the patch. Preliminary analysis of the sap flow measurements indicate significantly higher transpiration in near-edge trees as compared with trees of the same species located in the patch interior.

To scale up the hydrologic effects from a single forest fragment to a larger area, knowledge of the larger area's land cover is needed. Preliminary analysis of the research area's landscape suggested that the relatively homogeneous land cover, dominated by forest, present in 1952 has become much more heterogeneous and fragmented over time. To test this hypothesis, 1995 Landsat TM imagery was acquired, classified, and compared with a 1952 air photo interpretation. Because of the different resolutions of the two data sets, intensive field work was carried out to adequately ground truth the Landsat TM image. More than 200 ground truth points were collected as randomly as possible. A method was devised for using differential global positioning systems or GPS (+/- 7 meter accuracy), and the satellite imagery was registered to the field data with a resulting root mean square or RMS error of 0.74 pixels (22.2 meters). A "supervised classification" (whereby the image analyst "supervises" the process by choosing the information categories on classes desired and then selecting training areas that represent each category) of the imagery resulted in seven land cover classes. Two accuracy assessments of the classification were done. The first showed 79 percent of 155 check points correctly classified without attempting to account for GPS surveying and registration error. The second attempted to account for GPS surveying and registration error and resulted in 95 percent of the check points being correctly classified. A comparison of the Landsat TM classification with the 1952 air photo interpretation suggests that the research area's land cover is more fragmented and heterogeneous than in 1952. Today, trees still make up a relatively large part of the land cover (27 percent), but it is significantly more fragmented than in 1952 and the average tree cover fragment size is two-thirds of a hectare as compared with the air photo in 1952.

Preliminary socioeconomic research results indicate that the local community manages the fragmented landscape for different types of bamboo. The land cover analysis also corroborates this. The largest land cover type is dominated by bamboo (32 percent), and the average fragment size is 2 hectares.

Future efforts will include continued field work to investigate edge effects on transpiration in dry and wet seasons, further ecological surveys to determine the major tree species that compose the vegetative cover, and additional socioeconomic studies to determine factors that cause and maintain forest fragmentation.

Figure 1. Forest fragment where we established four recording microclimate stations, Ban Tat, Vietnam.

Geochemical, Biological and Economic Effects of Arsenic and Other Oxyanions on a Mining Impacted Watershed

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University of Nevada, Reno, NV
Ron Hershey and Lambis Papellis
Desert Research Institute, Reno, NV
Susan Anderson
University of California at Davis-Bodega Marine Laboratory, Davis, CA

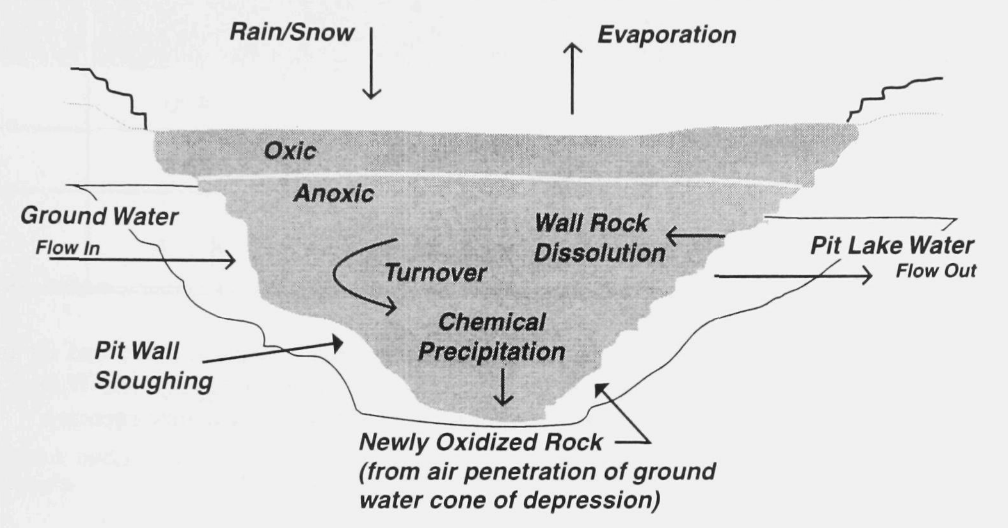

Figure 1. Processes affecting pit lake chemistry.

More than one-half of the annual production of gold is mined in the Humboldt River Basin, between Elko and Winnemucca, Nevada. More than 15 major precious metals mines are located in this watershed, including the Nation's two largest mines, which together produce more than 5 million ounces of gold per year. The expansion of precious metals mining in the past 15 years has been made possible, in part, by relatively new techniques of cyanide extraction that have allowed profitable extraction of gold at very low concentrations. This expansion of mining has introduced environmental problems that are poorly understood, both in terms of their immediate environmental impact and in our ability to predict long-term changes that may occur as mines begin to close. Many of these large mines penetrate the groundwater table. The required pumping of large amounts of water significantly impacts the groundwater systems. Arsenic (As) is often associated with gold deposits, and release of As in soils and surface waters has become an increasing concern.

This research is focusing on the geochemical, biological, and economic impacts of As released during mining in the Humboldt River watershed in northern Nevada. The objectives are to examine four aspects of precious metals mining: (1) studies on the evolution of precious metals pit lakes, (2) long-term drainage from cyanidization heaps, (3) biological effects of arsenic and antimony, and (4) economic effects of long-term alteration of the watershed.

The pit lake studies are using a variety of geochemical models (see Figure 1) to develop a predictive understanding of an existing 106 meter deep pit lake in Yerington. The water quality in the pit lake appears to be significantly affected by dissolution of wall rock because the equilibrium models underpredict the contaminant concentrations in the lake. Trace metals are particularly difficult to model. Initial laboratory studies on leached heap material show a large array of constituents being released from the rock. As expected, As concentrations in the drainage water are controlled by sorption to the heap material. Development of mathematical models are considering both equilibrium dissolution effects for heap drainage water quality and chemical reactions on the heap material.

Biological research on the effects of arsenite on water flea (*Ceriodaphnia*) indicate that brood sizes are decreased from 9.4 +/- 1.8 to 1.5 +/- 1.1 individuals when two generations are exposed to arsenite at 1.5 mg/L. These multigenerational studies indicate that arsenite may cause long-term genetic damage at sublethal doses.

Studies on the economic impacts of mining on the Humboldt River system have been initiated using five focus groups with interests in the Humboldt River watershed. Groups consisting of representatives of the mining industry, the agricultural industry, the conservation community, and the government have provided views on the potential impacts. Water quantity issues, rather than water quality, appear to be a dominant concern, and the focus groups have reflected strongly held views of water usage in the watershed.

Effectiveness of Regulatory Incentives for Sediment Pollution Prevention: Evaluation Through Policy Analysis and Biomonitoring

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	Minimum Disturbed Area Requiring Erosion Plan	# Field Staff	Total Area (Miles ^{2})	# Active Projects
Orange County	0.5 Acres	3	400	~60
Wake County	1.0 Acres	13	858	~500
District 4* (16 Counties)	1.0 Acres	5	8,116	~1000

* District 4 oversees all construction projects in all 16 counties without a Local Erosion and Sediment Control Program. It covers all governmental construction in the District 4 area, including Orange and Wake Counties. So, a single stream can have adjacent construction sites administered by different regulatory agencies.

Figure 1. Characteristics of the regulatory jurisdictions studied.

A critical problem in American rivers and streams is sedimentation. Sedimentation degrades water quality, alters habitat for fish and macroinvertebrates, limits the ecosystem functions and services, and reduces the aesthetic and economic value of rivers and streams. Many regulations and policy incentives have been devised to control sediment pollution of our rivers. Yet, there has rarely been an attempt to reconnect the policies with the ecology of the rivers. That is the goal of this research. The overall objective is to study the effectiveness of different policy incentives in the reduction of the ecological risks and consequences of sedimentation. The aim is to create more effective management strategies to provide environmentally sustainable social and economic development in U.S. watersheds. This work will integrate the social and regulatory theory behind sediment ordinances and policies as well as the resultant ecological impacts of sedimentation on the rivers and streams. This project's goal is to discover which policies and regulations really work to enhance stream biota and ecosystem health and the reasons why they are or are not effective.

A comparative watershed approach is being used to contrast the ecological effects of different intensities of sediment control standards and enforcement. Similar watersheds are being selected from three political jurisdictions that differ in the stringency of their sediment and erosion control requirements, their staffing, and enforcement (see Figure 1). Field biomonitoring data, water chemistry, and leaf litter decomposition rates are being used to document changes in stream ecosystems above and below construction projects under these different regulatory regimes.

North Carolina has one of the strongest state laws in the Nation for erosion and sedimentation control, and at least 38 of its county and municipal governments have enacted even more stringent control ordinances. The differences among these regulatory regimes, applied to similar types of socioeconomic activities (e.g., commercial and housing construction, road building) on otherwise similar watersheds, provide opportunities to draw broader inferences on a comparative basis. An unusually detailed evaluation of the North Carolina erosion and sedimentation program and a close working relationship with the North Carolina Division of Land Quality provide substantial baseline and supporting information for this research. This project focuses on the regulations governing controls on sedimentation into rivers and streams to determine their effectiveness and ecological consequences. A direct comparison of differences in the programs' regulatory stringency with their ecological outcomes in the streams will expose what actually results in the protection of stream ecosystems. This will determine the actual effectiveness of these regulations in maintaining stream ecosystem health, functioning, and biodiversity. In the end, the answer to the question, "What really works?" will become clear.

Watershed Protection in Agricultural Environments: Integrated Social, Geomorphological, and Ecological Research To Support Ecosystem-Based Stream Management

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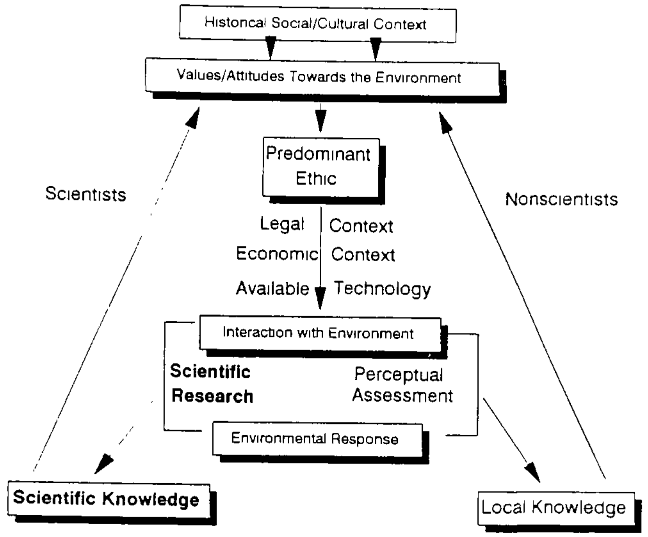

Figure 1. Conceptual model of interaction between scientists and nonscientists in the social negotiations of community-based resource management.

The overall goals of this project are to provide an improved understanding of the roles of scientists and scientific information in community-based environmental decisionmaking (see Figure 1) and to advance knowledge of the connections between stream geomorphology and aquatic ecology in human-modified agricultural stream systems. The proposed project has a four-pronged research design: (1) historical analysis of the attitudes and values of rural stakeholders toward water and watersheds in the agricultural Midwest, (2) social analysis of the mechanisms that facilitate and impede infusion of new scientific knowledge into local decisions about stream management in agricultural watersheds, (3) GIS- and field-based analysis of interrelations between geomorphological and ecological dynamics of human-modified agricultural stream systems at the watershed and reach scales, and (4) dissemination of scientific information from the geomorphological and ecological research to farmers and other local stakeholders.

First-year data collection activities have concentrated mainly on the social component of the project. Fifty-seven in-depth, open-ended interviews have been conducted with drainage district commissioners, farmers, and associated stakeholders in the rural communities of East Central Illinois. The interviews have focused on three issues: (1) farmer and stakeholder perception of watersheds as an agricultural, cultural, and aesthetic resource; (2) current usage and maintenance of watersheds; and (3) perceived best and relevant strategies for future usage and maintenance. Preliminary findings indicate that farmers are a surprisingly heterogeneous group in outlook and perspective and that important commonalities can be identified. Farmers value streams not only for the purpose of land drainage, but also perceive themselves as fundamental stewards of the land. Future work will explore the interplay of these contrasting values. Additional open-ended interviews will be conducted after scientific/technical information is imparted to farmers and stakeholders to gauge their responses.

Work on the geomorphological component of the project has emphasized the development of a georeferenced grid of control points for digitizing stream-channel traces and for analyzing changes in these traces through time. Preliminary analysis indicates that over the last several decades, humans have been the dominant agents of geomorphic change in the fluvial systems of East Central Illinois. Field activities have involved the selection, preparation, and mapping of seven study sites for detailed investigations of the fluvial dynamics of human-modified agricultural streams. During the next year, geomorphological research will focus on GIS analysis of stream-channel change and on data collection at the field sites.

A fish-species data matrix containing critical habitat and life history information for Illinois fish species is under development. The matrix will be used to assist in interpreting habitat fisheries relationships from field data and will provide a means of specifying critical habitat conditions when management programs are being developed. A systematic fisheries collection program has been initiated at the field sites in coordination with geomorphic data collection activities. Preliminary sampling suggests that fish-species diversity is tied strongly to physical habitat diversity.

Towards an Integrated Regional Model of River Basins of the Western Pacific Rim

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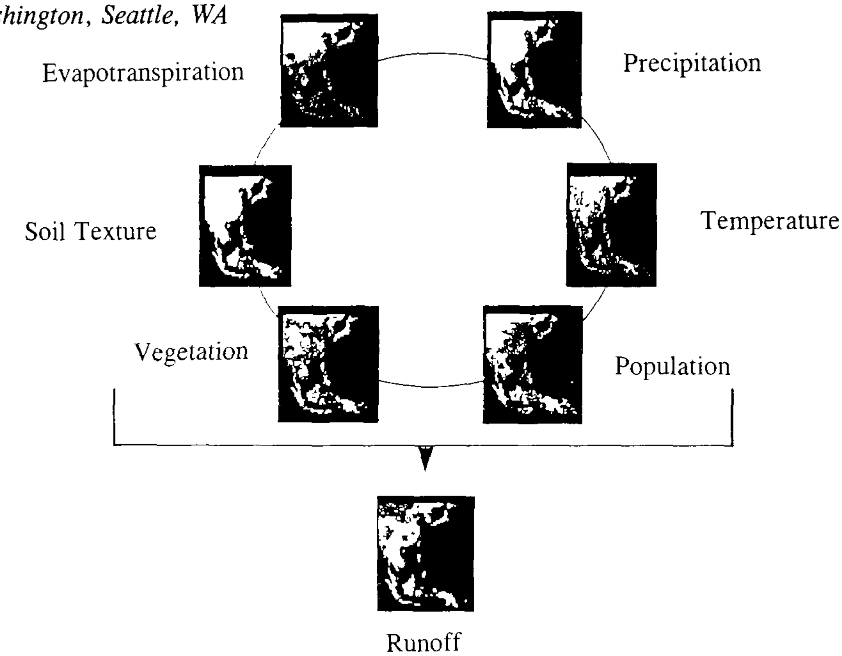

Figure 1. Schematic of integrated regional model for the Western Pacific Rim.

The extraordinary pace of development and population growth along the Western Pacific Rim has placed dramatically increasing pressure on river basins and their downstream coastal ecosystems. Although decisions about the usage and allocation of water resources are generally made according to economic and political criteria, the sound management and optimization, and hence sustainable use of these resources, will require increasingly sophisticated information on the functioning of the biophysical systems and how they are affected by socioeconomic and political institutions. To address these issues, the investigators are building an "integrated regional model" of the river basins of the Pacific Rim, with a focus on Southeast Asia. The model has the objective of coupling hydrological pathways and biogeochemical indicators with the interactions and effects of human impact to describe how materials are mobilized and transported from the land surface to the coastal zone. The project is addressing two interrelated questions: (1) The science question is, "What are the effects of changing land use (and climate) on the mobilization of water and its dissolved and particulate load from the land surface into the coastal zone at local to regional scales?" (2) The practical question is, "How is information and training in a geographically and politically diverse region mobilized and focused on the problem?"

The project approach is to link large scale attributes of drainage basins to fundamental biogeochemical processes and fluxes through rivers via a regional-scale routing model (see Figure 1). This approach is derived from the extensive experience of this group on the Amazon River. To address the inherent space and time scaling assumptions that must be made, the investigators have developed a "drainage basin element" model (DBE), expressed within the modeling environment of a global biogeochemical model. Each DBE is georeferenced within a drainage network and linked to databases of basin characteristics (e.g., elevation, soil texture, and vegetation types). The immediate requirements are to translate precipitation into runoff with a water balance model for each DBE in a manner that allows estimates of residence time and flow through each element (to "mobilize" the chemistry). Selection of the size and temporal resolution of each DBE is a "scaling" problem, where tradeoffs must be made between expectations and data availability.

The current expression of the model for the region is 1 degree (about 100 km), based on readily available data sets and summed to a monthly composite. At this scale, the hydrographs of such rivers as the Mekong and Yangtze are readily reproduced. However, it is not possible to resolve the dynamics of, for example, the myriad small rivers of the coastal areas so typical of the region, nor to address the typical scales of land use and cover change. Hence, the next phase of the work will be to establish the model for 1 km elements, taking advantage of newly available data. An integral part of this project will be to establish a network of cooperating institutions across the region, including science, policy, and economic organizations. Based on preliminary feedback, this project will contribute to useable assessments of water resources along the Pacific Rim.

An Integrated Approach To Assessing Water Management Options in a Major Watershed: Extending a Hydrodynamic-Water Quality Model To Include Biological and Politico-Economic Components

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The primary objective of this project is to develop and demonstrate an integrated methodology for assessing management alternatives for watersheds that support aquatic species at risk. Such a methodology requires an interrelated set of deterministic and statistical models designed to characterize quantitatively the responses of sensitive species to hydrodynamic, water quality, and ecological influences within riverine and estuarine reaches of the watershed under various management alternatives. Alternatives may include restoration of riparian habitat, regulation of stream flows, curtailment or rescheduling of diversions, and control of point and nonpoint sources of pollution. The project links not only hydrologic, water quality, sedimentation, and fishery models, but also the impacts of various management alternatives on urban and agricultural water supplies. Finally, the conditions under which such modeling capability can produce consensus on the perceived impacts and feasibility of various management alternatives in situations of political conflict will be assessed. The models are being developed for the Sacramento River from Shasta Dam through the Sacramento-San Joaquin Delta, with the principal fisheries being the winter run chinook salmon, striped bass, and Delta smelt.

In the 12 months since funding began, the project has focused on: (1) developing the hydrologic and water quality (i.e., temperature, salinity, and toxic particle) models for 1984, 1992, and 1993; (2) integrating models of particle and fish movement into the hydro model, and then estimating winter run and striped bass survival; (3) continuing long-standing work on the Clear Lake and Cache Creek watersheds, particularly with respect to sedimentation and mercury; (4) gathering the data to build the models relating water quantity and quality to urban and agricultural water use; and (5) conducting a mail survey of approximately 1,300 policy participants in Bay-Delta-Central Valley water policy.

The number of water years was increased from three to six to include a wider variety of flow and temperature conditions. Project members also have obtained additional support to study mercury contamination and urban water management in the context of this research.

Modeling Effects of Alternative Landscape Design and Management on Water Quality and Biodiversity in Midwest Agricultural Watersheds

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Serious concerns exist about ecological degradation from modern agriculture. An integrated, multidisciplinary approach linking multiple purposes of watershed could inform and improve our management of agricultural watersheds and water resources. The goal of this project is to develop alternative future landscape design and management scenarios and to evaluate their effects on agricultural production, water quality, and native biodiversity in watersheds characteristic of the midwestern United States.

This project involves the following: (1) iterative design of alternative future landscape and management scenarios; (2) development of computer models to estimate effects of landscape change on agricultural production, water quality, and biodiversity (i.e., aquatic organisms, terrestrial vertebrates, plants); and (3) a farm planning exercise to incorporate input from local farmers and decisionmakers and to explore how human attitudes as well as practical and economic constraints are translated into land use and management decisions and the spatial implications of these decisions at the watershed scale. This project is focusing on two agricultural watersheds (5,130 and 8,790 ha) in central Iowa. Databases exist on land cover, avian biodiversity, and aquatic biodiversity for these watersheds as a result of the USEPA/USDA Midwest Agrichemical Surface/Subsurface Transport and Effects Research (MASTER) program.

For each watershed, 3 alternative scenarios for 25 years into the future are being developed using a normative expert informed design process (see Figure 1). The scenarios reflect a set of alternative national priorities with an emphasis on: (1) production of agricultural commodities such as corn, soybeans, and livestock; (2) conservation of native biodiversity and associated ecosystem functions; (3) improvements in water quality; and (4) a compromise among all three. Digital maps of each scenario may incorporate the effects of heterogeneous implementation of each watershed design to reflect situations in which farmers and/or landowners may decide not to participate in programs designed to achieve improvements in water quality and biodiversity. Therefore, the manner in which patterns of implementation may influence the success of these efforts can then be evaluated. Digital coverages among scenarios can also be recombined to evaluate effects on ecological and reorganized model results.

Existing spatially explicit computer models for terrestrial vertebrates (multiple species and individual species populations) are being adapted for the present watersheds. Parallel models for terrestrial vertebrates will crossvalidate results. New models for plant biodiversity (particularly in wetlands) are being developed from existing databases in central Iowa and southern Minnesota. Currently, only rudimentary accounting models are being developed for agricultural production and water quality.

This project is pioneering a landscape design approach for agricultural watersheds based on a normative process using experts. Evaluation efforts will contribute to the development and comparison of spatially explicit computer models for individual versus multiple species for a variety of taxa. The longer term significance lies in the ability of the project to inform landowners and policymakers (for example, those crafting Farm Bill 2000) of effects of land use and management choices on water resources, ecosystem function, and human social systems in the Western Corn Belt Region.

The next steps for this project will involve the completion of digital maps of future scenarios as well as the construction and parameterization of computer models.

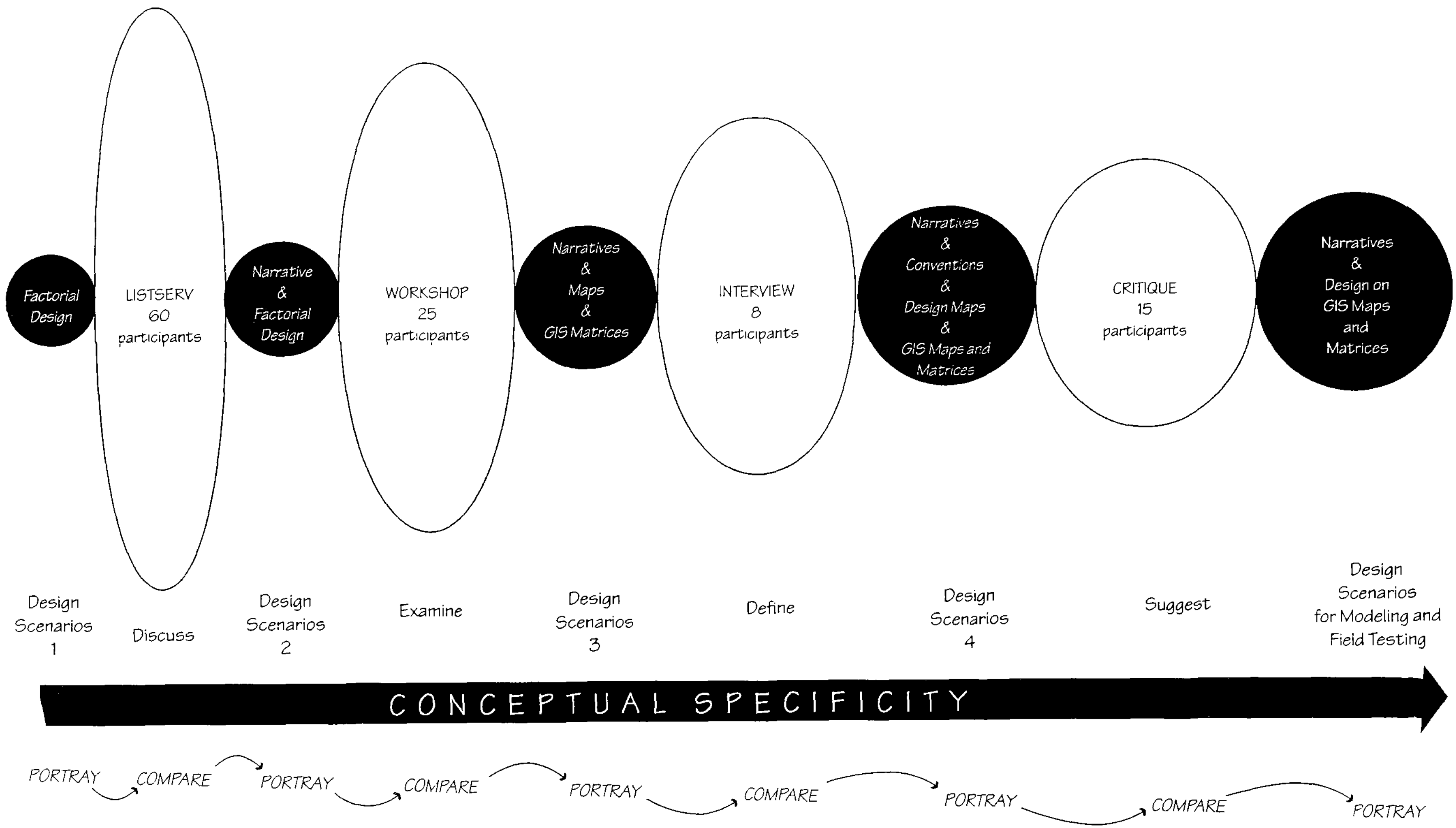

Figure 1. Agricultural watersheds—A normative, expert design process.

Streamside Reforestation: An Analysis of Ecological Benefits and Societal Perceptions

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Streamside forests are recommended as a land use practice to protect aquatic ecosystems from nonpoint source pollution. To date, the scientific basis for the benefits of these forest buffers has stressed their role in removing watershed inputs of nutrients, sediments, and toxic contaminants. In this project, forests along small streams in the Piedmont region of Eastern North America are viewed as the primary regulators of stream width. Preliminary measurements indicate that small forested streams are consistently wider than contiguous meadow reaches. The alteration of stream width that results from deforestation profoundly influences the stream ecosystem, both locally and in downstream rivers and estuaries, through effects on habitat and water quality.

Public policies to restore streamside forests will require documentation of ecological benefits and an understanding of societal factors affecting their implementation. The principal goals of this project are to: (1) understand the relationship between forest buffers, stream width, and the condition of stream ecosystems; (2) develop databases concerning stream organisms and their activities that can guide the development of policies concerning restoration of streamside forests; and (3) identify and quantify social and economic issues affecting streamside forest restoration.

This project includes four interrelated components: (1) field measurements in 15-18 different streams to ensure general applicability of results; (2) supplemental experiments in controlled model streams; (3) mathematical modeling to assess watershed-wide water quality implications; and (4) interviews and surveys to assess landowner attitudes and land use practices. The ultimate goal is to bring both the natural and social science components into focus for policymakers and regulatory agencies.

Field work began in March 1997. Longitudinal profiles and detailed cross-sectional measurements have been performed on 18 stream reaches (i.e., paired meadow-woodland reaches on 9 streams) to estimate the geomorphological characteristics of each stream reach (e.g., slope, cross-sectional area, width, depth, sinuosity, pool and riffle characteristics, floodplain height and width, and habitat heterogeneity). Preliminary results indicate that woodland reaches are 1.6 to 3.4 times wider than meadow reaches. Community metabolism studies have been conducted on 5 streams (10 reaches) using open-system measurements of dissolved oxygen change. Macroinvertebrate communities in the riffle and pool sections of 9 streams (18 reaches) were sampled quantitatively in March, May, July, and November of 1997. Fish community analysis was performed by electroshocking studies of 6 streams (12 reaches; 3-4 passes per reach) in the fall, including length and weight analysis of individual fish of each species. Degradation/decomposition studies of natural organic matter (i.e., humic substances, amino acids, carbohydrates, and total dissolved organic carbon) and pesticides (i.e., atrazine, dursban, linuron, and methoxychlor) in meadow and forest reaches was initiated in 1997. Preliminary studies involving bromide and chloride releases in 5 streams (10 reaches) have been completed in 1997 in preparation for nitrogen and phosphorus spiraling work.

In the anthropological work, investigators developed, pretested, and refined an interview protocol and objective statements describing streamside forests. Target watersheds and streams in central and southeastern Pennsylvania, and northern Delaware and Maryland were randomly selected, and the interview process with landowners was started in 1997 (see Figure 1).

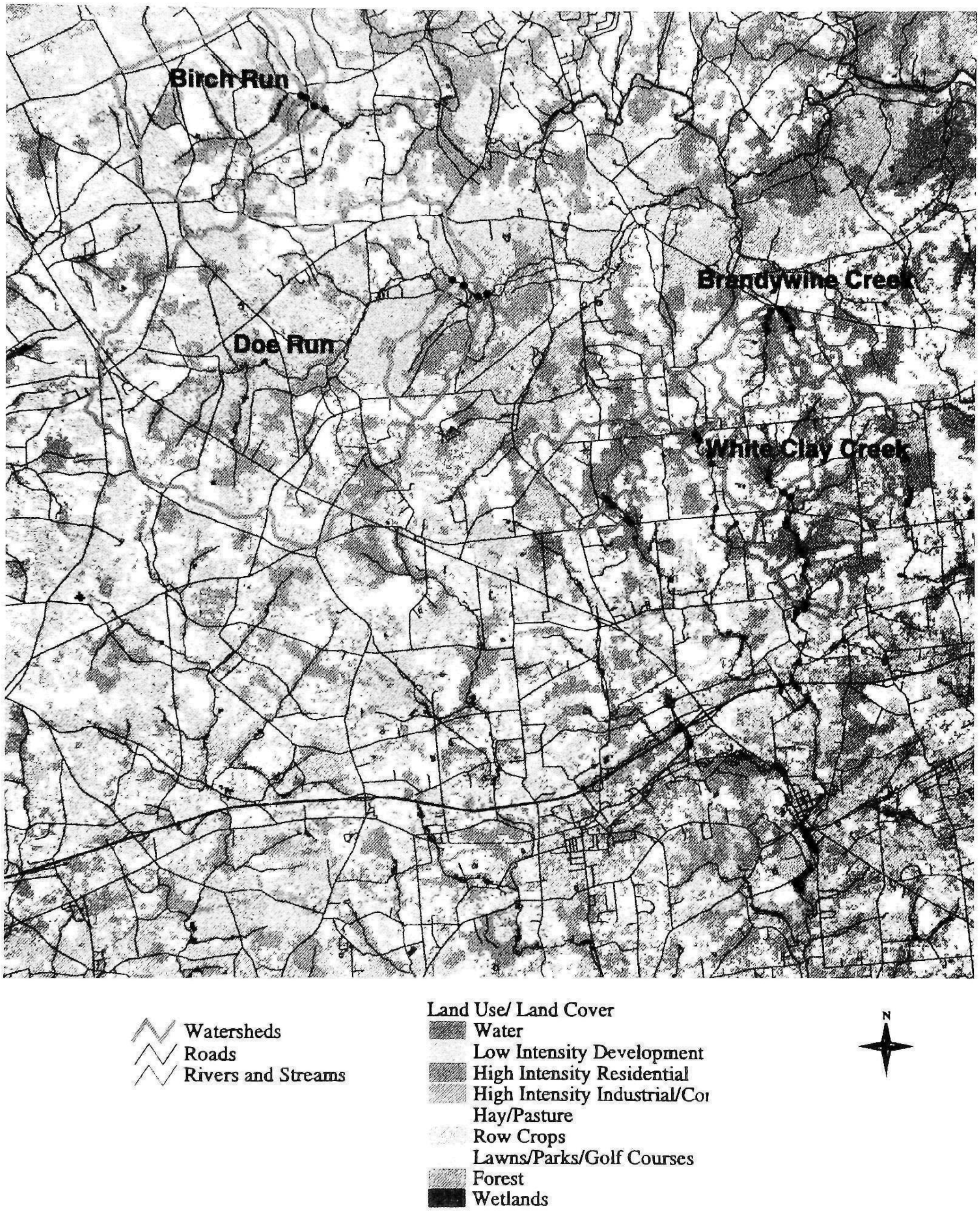

Figure 1. Contemporary land use map near rural Chester County, Pennsylvania, showing the location of study streams (blue lines) and their watersheds (red boundaries) where stream ecosystem structure and function are being evaluated in response to the presence/absence of a streamside forest. Each dot represents either the upstream or downstream limit of a given reach of stream; each study stream has two experimental reaches—one forested, one deforested. Map was derived from EPA Region III's 30 m Landsat Thematic Mapper Land Cover Data Set Version 3alb by Cully Hession, Linda Misiura, Maeve McBride, Academy of Natural Sciences of Philadelphia.

Integrated Urban Watershed Analysis: The Los Angeles Basin and Coastal Environment

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This project is investigating the processes that control water availability and quality in a major urban watershed—the Los Angeles basin in southern California (see Figure 1). The study consists of a synthesis of data and models that bear on numerous aspects of the water resource problem, including: regional meteorology and climatology; basin hydrology, vegetation and land use; human water consumption and disposition; runoff sources of sediments, toxics and nutrients; air pollutant transport, transformation and surface deposition; downstream wetlands ecology and impacts; and coastal water circulation, biogeochemistry, and sediments. This project consists of a broad synthesis of observational data—*in situ* measurements, remotely sensed data, and local geographical information—and model simulations of material flow, deposition, transformation, and bioassimilation.

Regional simulations of storms over the Los Angeles basin were carried out with the MM5 mesoscale dynamics model. This project focuses on a record rainfall event that occurred in 1993. Model calculations of precipitation compare favorably with meteorological observations. The corollary aspects of extreme regional drought are under investigation through a tree ring analysis, which correlates moisture availability with seasonal growth rates and wood density. A 500-year reconstruction indicates an extended period of severe drought in southern California in the late 1500's, within the epoch of the "Little Ice Age."

A coastal ocean model for the Los Angeles watershed is close to completion. To provide realistic large scale forcing of the circulation, the model incorporates a nesting of spatial scales from that of the Pacific basin, to the California Bight, to Santa Monica Bay. Moreover, initial results were obtained from a biogeochemistry code that is being integrated with the coastal dynamics model to study the "red tides." The coastal modeling also is being connected with the runoff component of the project, for which a GIS-based analysis has been developed to quantify the chemical composition (nutrients, toxics) in key regional Los Angeles outflows. The runoff model is being calibrated using streams in the region, particularly those heavily impacted by urbanization. The runoff component uses a comprehensive hydrological database and modeling system developed for several of the Los Angeles watersheds.

New research was conducted on the response of vegetation in a major southland estuary to anthropogenic nitrogen and phosphorus. Measurements taken along an upstream-to-downstream transect through the Newport Bay estuary indicate that macroalgae efficiently scavenge nutrients from the freshwater inflow. The levels of nitrogen in the salt marsh sediments were quite low, however, and the nitrogen/phosphorus ratios in these sediments were unusually low.

An analysis of the contribution of airborne particulates to the southern California coastal ocean surface microlayer showed that the concentrations of a suite of trace metals (i.e., Cd, Cu, Ni, Pb, Zn, Cr, Mn, Fe, and Ag) are more strongly correlated with a planktonic source than with either an aerosol or bulk water source. The plankton appear to bioconcentrate these metals effectively, although the mechanism by which this occurs remains uncertain. Hence, the situation of southern California is quite different from that in the Great Lakes, where the trace metal composition of the surface layer, bulk water, and aerosols are strongly correlated. In other work, a novel analysis of DDT in offshore sediments succeeded in separating the contributions due to sewage outflows and to industrial dumping. The sewage source is identified through a close relationship that exists between DDT and another class of stable organic compounds used in detergents. Thus, coastal regions with heavy industrial DDT pollution have been identified, which will help in formulating remediation schemes.

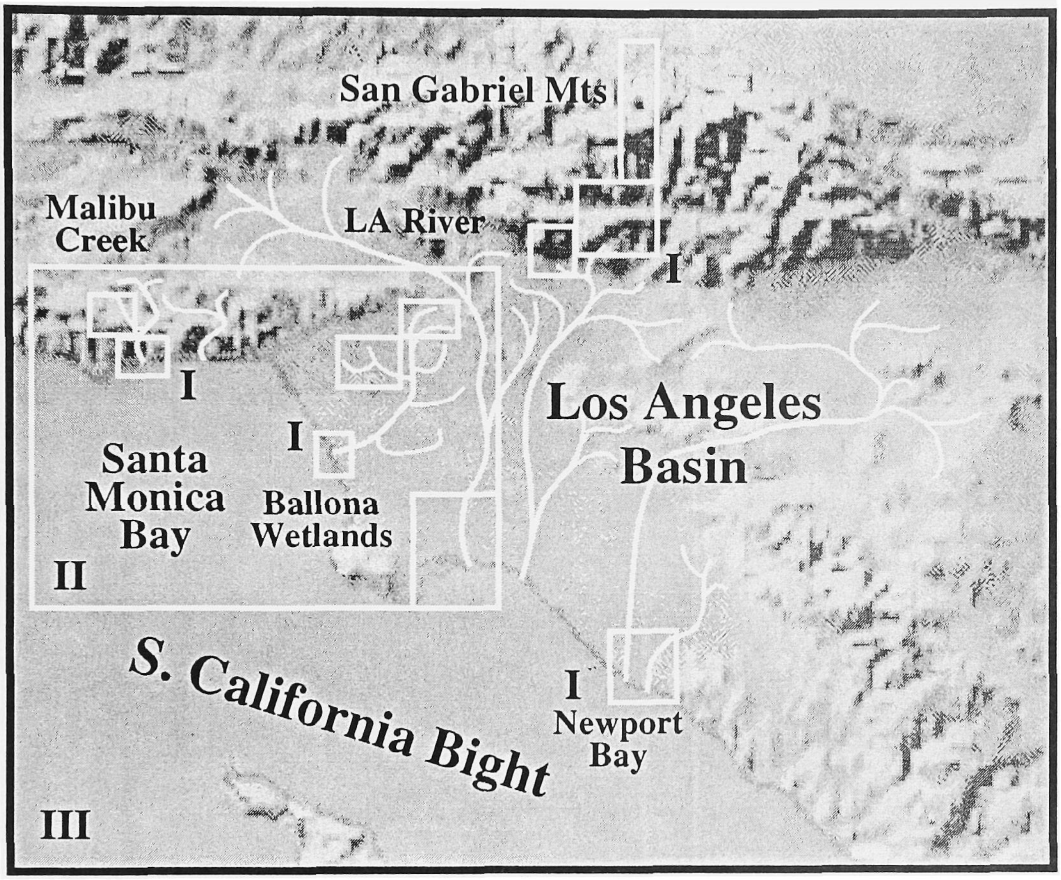

Figure 1. Los Angeles Regional Watershed.

Section 3.

Projects Initiated With Fiscal Year 1995 Support

Development and Application of Spectroscopic Probes for Measurement of Microbial Activity in Aquatic Ecosystems

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The microbial degradation of organic matter is a key part of carbon cycling in aquatic systems. Bacteria are responsible for a high organic-carbon turnover in water and sediments, hydrolyzing organic macromolecules to smaller pieces that can be remineralized and interconverting organic structures through a variety of reactions. Measuring the net degradative capabilities of a complex community of microorganisms is a major challenge in understanding the dynamics of carbon cycling because we lack the means to measure accurately the rates at which bacteria hydrolyze large macromolecules to smaller pieces, which can be further transformed or remineralized. In this project, we are developing a new generation of spectroscopic probes that can be used to measure extracellular enzymatic hydrolysis rates of organic macromolecules in the water column and sediments. This approach is based on efficient intramolecular energy transfer between donor and acceptor fluorophores covalently attached to single macromolecules, so hydrolysis rates can be measured using simple fluorescence techniques. For this study, the fluorophores are covalently linked to polysaccharides, which comprise a significant proportion of total organic matter. The sensitivity of these probes should permit measurement of hydrolysis rates at picomolar levels; ease of analysis means that a large number of samples can be surveyed rapidly.

Two different polysaccharides as well as lower molecular weight oligo-saccharides with different sets of fluorophores have been covalently labeled to determine optimal probe characteristics and coupling strategies. Based on initial laboratory investigations, we are focusing on two fluorophore pairs. Laboratory investigations demonstrate that the double-labeled probes exhibit fluorescence energy transfer. Donor quantum yield is significantly higher in single-labeled as compared to double-labeled probes. Field tests of these probes are being conducted; the addition of fluorescein/Texas Red-xylan to porewater from Delaware Bay sediments demonstrated an increase in the ratios of donor to acceptor emission with incubation time (see left side of Figure 1). Concurrent measurements using gel permeation chromatography showed changes in substrate molecular weight (hydrolysis of xylan; see right side of Figure 1) consistent with the fluorescence measurements. Changes in fluorescence characteristics were observable on much shorter time scales than changes in substrate chromatography; the fluorescence analyses also required much less time than chromatographic analyses ($<$ 4 min. vs. $>$ 1 hr). Our technique already allows us to screen rapidly large numbers of samples to evaluate enzymatic activity and select samples for further investigation.

This project focuses on using purified enzymes to calibrate the fluorescence responses of the double-labeled probes in the laboratory. The synthesis of several new double-labeled probes of different chemical structures are being planned to test for a wider range of enzyme activities. This expanded suite of probes will then be used to make larger scale field measurements of enzyme activities in the water column and sediments. Preliminary studies have indicated that we may find distinct differences in relative activities of specific enzymes in sediment pore waters as compared to the water column, and an expanded suite of probes will enable us to investigate this possibility in detail. These fluorescent-labeled probes will provide the means of making rapid, high-resolution measurements of specific enzymatic activities with minimal disturbance to the naturally complex microbial community, providing a more realistic picture of the transformations that actually take place.

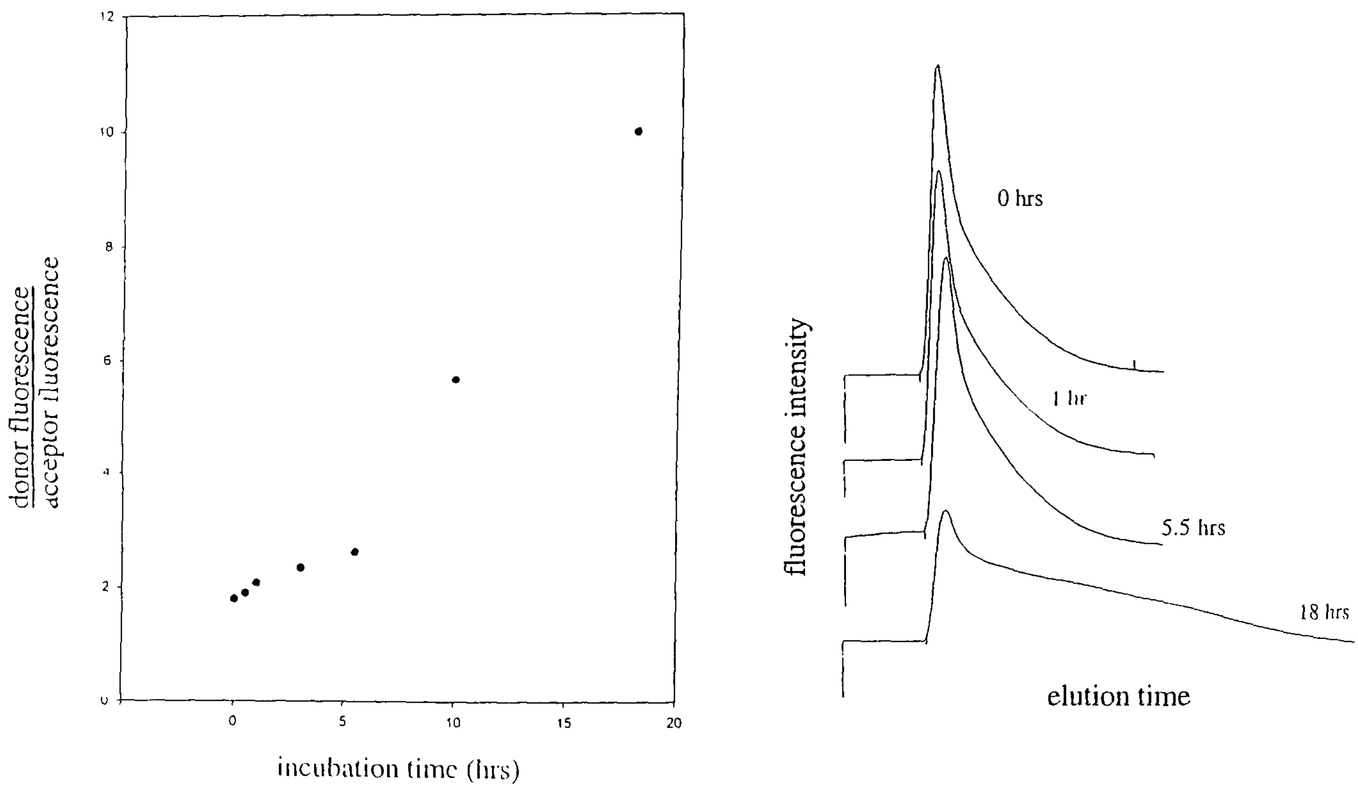

Figure 1. Incubation of double-labeled probe (FLA/TR-xylan) in sediment porewaters from Delaware Bay. Left side shows increase in ratio of donor fluorescence relative to acceptor fluorescence as the probe is progressively hydrolyzed during incubation. Right side shows corresponding gel permeation chromatograms of the probe. Times listed next to each chromatogram are the incubation times of each sample; the x-axis shows chromatogram elution time. Longer elution times (movement to the right) correspond to lower molecular weights. Changes in substrate molecular weight (hydrolysis of xylan) are consistent with the flluorescence measurements. Note that changes in fluorescence characteristics were observable on much shorter time scales than changes in substrate chromatography.

Watersheds and Wetlands: Large Scale Disturbances and Small Scale Responses

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As pressures for development increase and more wetlands are permitted for modification or destruction, our understanding of the watershed-level impacts of these activities remains poor. In addition, although wetland restorations usually try to provide a replacement that looks and operates like a natural wetland, the complexity of these systems may limit success. The goals of this project are to: (1) assess characteristics of natural reference wetlands and created wetlands, by watershed, disturbance, and hydrogeomorphic (HGM) category, to determine improved design characteristics for created wetlands implemented for mitigation purposes; (2) assess succession in reference wetlands using seed banks and soil dating; (3) assess characteristics of created wetlands of different ages to begin determining successional pathways; (4) compare created wetlands with the reference sites to see if the created wetlands are successful in any sense; and (5) use disturbance theory to evaluate the impacts of the surrounding landscape on both reference and created wetlands and their successional trajectories.

The Penn State Cooperative Wetlands Center (CWC) has been assessing wetland structure and function by classifying a wetlands' position within the watershed (e.g., headwater) and by its source of water (e.g., groundwater). Research indicates that surrounding disturbance impacts wetland function so that events occurring at the watershed scale will likely be revealed by changes in function at the wetland scale. The CWC is studying 63 reference wetlands by measuring soil characteristics, sedimentation rates, hydrology, basin morphometry, plant community composition, biomass and production, seed banks, macroinvertebrates, and wildlife habitat. The investigators have found that soil characteristics, sedimentation rates, hydrology, and plant communities all are predictable (to some degree) based on position and sourcewater for the wetland.

This project involves studying 12 created wetlands and looking at the same parameters. Our research found that created wetlands are not at all like natural wetlands in Pennsylvania. They have different physical structure, different soils, markedly different hydrology, and different plant communities. A preliminary time series analysis shows that created sites are not converging in structure or function towards natural wetlands.

In addition, this project is considering the historic use of each of several watersheds to determine if past land use practices resulted in any discernable changes in wetland plant communities. A subset of the reference wetlands is being examined by sampling the soil column and dating soil layers using Cs^{137}. Once the soil layers are dated, the seeds in the seed bank will then be germinated or otherwise identified to develop a plant community history. A comparison of land use changes since the 1930's for a 1 km radius around each site will be made to see if land use has been reflected in the seed bank (i.e., the plant community). To date, successful dating of the soil layers has been accomplished, and the process of collecting seed bank samples is under way.

Our findings are helping to develop data on wetland function by HGM subclass. HGM will soon be the primary wetland classification and assessment protocol within the United States, and we will be able to provide real data towards assessing functions. Also, we are adding to basic ecological knowledge on succession by looking at historic seed banks in reference wetlands and at chronological sequences in created wetlands. This will help to define permit expectations and requirements as well as aid in streamlining an already contentious mitigation process. We are just now beginning to explore the impacts of watershed-level activities on individual wetland function. This data will allow for a better understanding of large scale decisions on site-specific processes.

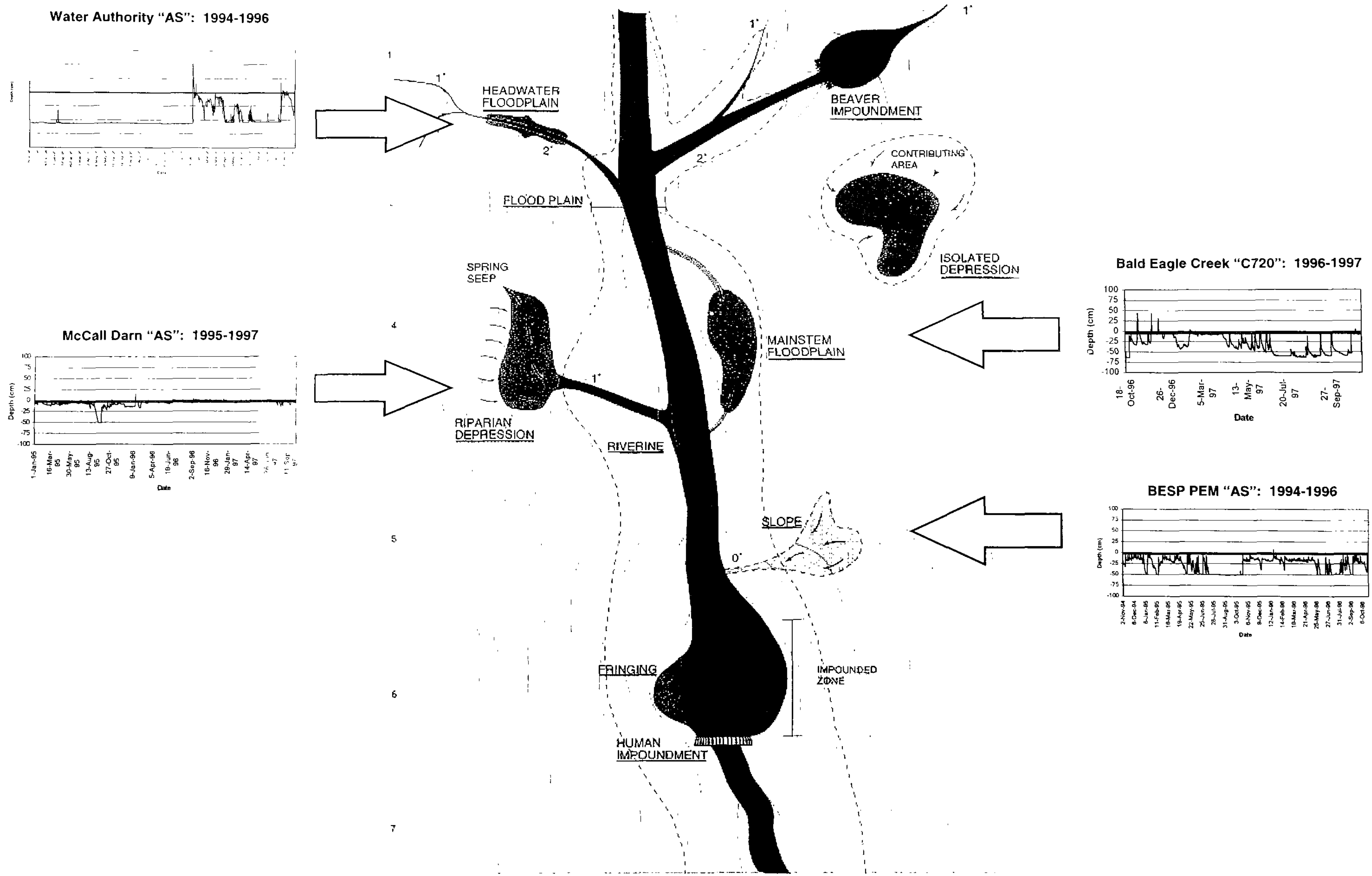

Figure 1. Examples of wetland hydrographs by HGM subclass.

Integrated Ecological Economic Modeling and Valuation of Watersheds

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This integrated modeling effort is intended to provide tools to manage water quality and ecosystem responses by synthesizing data from intensive experimental studies on small scales and using dynamic models to extrapolate that information to large drainage basins. A grid-cell, process-based model developed for the 2,500 km^2 Patuxent River watershed in Maryland integrates information over areas of spatial, temporal, and complexity scales. A unit model calculates stocks and flows for water, nutrients, plants, and animal populations within each cell, and cells are linked to simulate water and material fluxes across the landscape (see Figure 1). An economic submodel estimates land development patterns and effects on human decisions from site characteristics, ecosystem properties, and regulatory paradigms. Patterns of development are used in the ecological model to estimate effects of human activities. The software we have developed links geo-referenced and other databases to the model for input and calibration. We have developed methods and tools to simplify and partially automate model calibration and result analysis.

Preliminary model runs show good agreement with measured data for components of the model at several scales and for several years. Streamflow in the hydrologic submodule was compared with 2 years of gage data after the initial calibration year. The model predicted overall surface and groundwater flow across the watershed generally within 10 percent of daily values, although some large flood peaks deviated to a larger extent from measured values. Several sub-watersheds were used to test model behavior at smaller spatial extents (23 km^2 to 940 km^2). This modular approach to calibration worked well for the hydrologic component, with little fine tuning required when switching scales. Forest biomass calculated by the model matched boundary conditions established from calibration data. Temporal and spatial calibration data on annual increments to forest biomass were developed using species-specific tree ring records and spatial distributions in the watershed. Seasonal and longitudinal dynamic records for phosphorus and nitrogen concentrations in the river were compiled from numerous sources for calibration. Unit model estimates were constrained to boundary conditions for nutrients and deposited matter.

The investigators developed methods to examine the effect of spatial pattern of land use on ecological indicators developed from model variables. Preliminary results from an adaptation of the hydrologic model for a suburban watershed suggest that sensitivity to land use proportions and spatial pattern decrease sharply above 60 percent high-density residential and commercial uses. Stream buffers in particular lose the ability to mitigate storm peak flows at this level of development. These effects will be tested in the full landscape model.

Scenarios are being developed to investigate the implications of changing land management policies on both the ecological and economic components of the system. These include: (1) clustered vs. sprawl for agricultural and urban areas development; (2) implementation of nutrient and water management practices for agricultural and urban areas; (3) development with varying proportions of forest, agricultural, and urban uses; and (4) spatial arrangement of land uses. Dynamic models examine the numerous competing effects of human and naturally imposed variation to suggest potential long-term impacts to system function and resiliency. Model results can help guide land use policy and help to develop goals for ecosystem quality indicators.

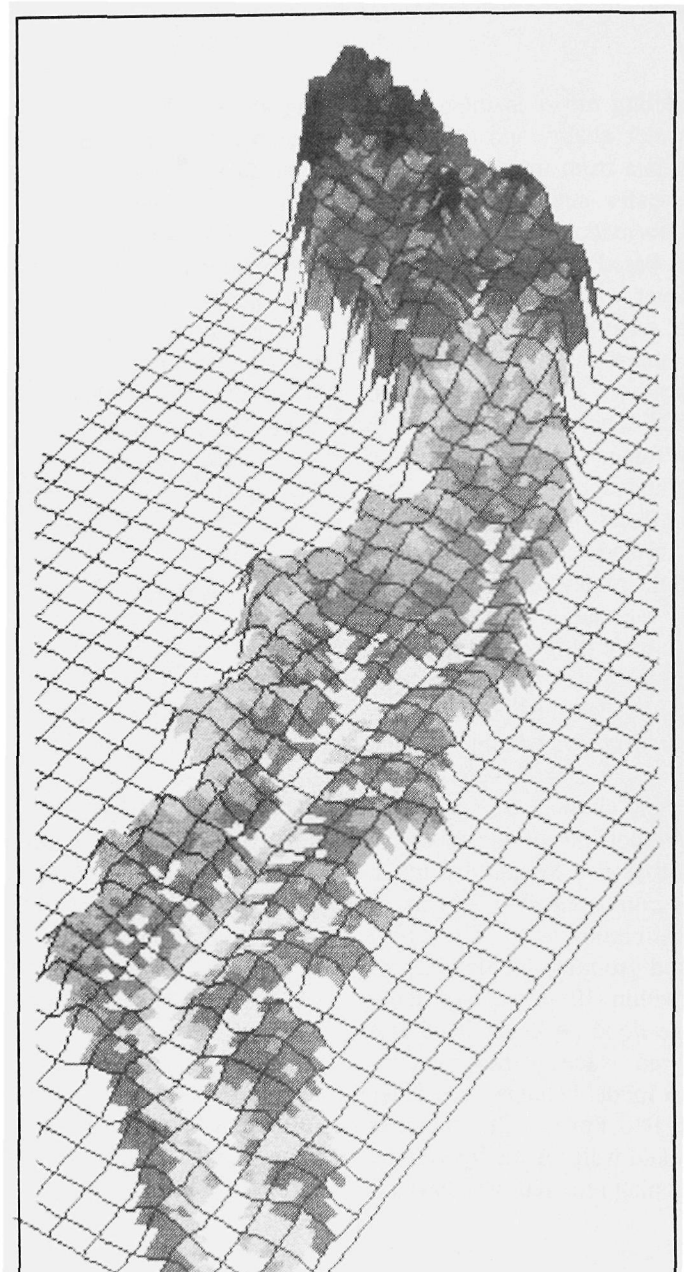

Figure 1. Elevation of the Patuxent Watershed. Grid cells shown are 3 km. Model grid cells range from 0.2-1 km.

Oyster Reefs as Structural and Functional Components of Tidal Creeks: An Ongoing Ecosystem Experiment

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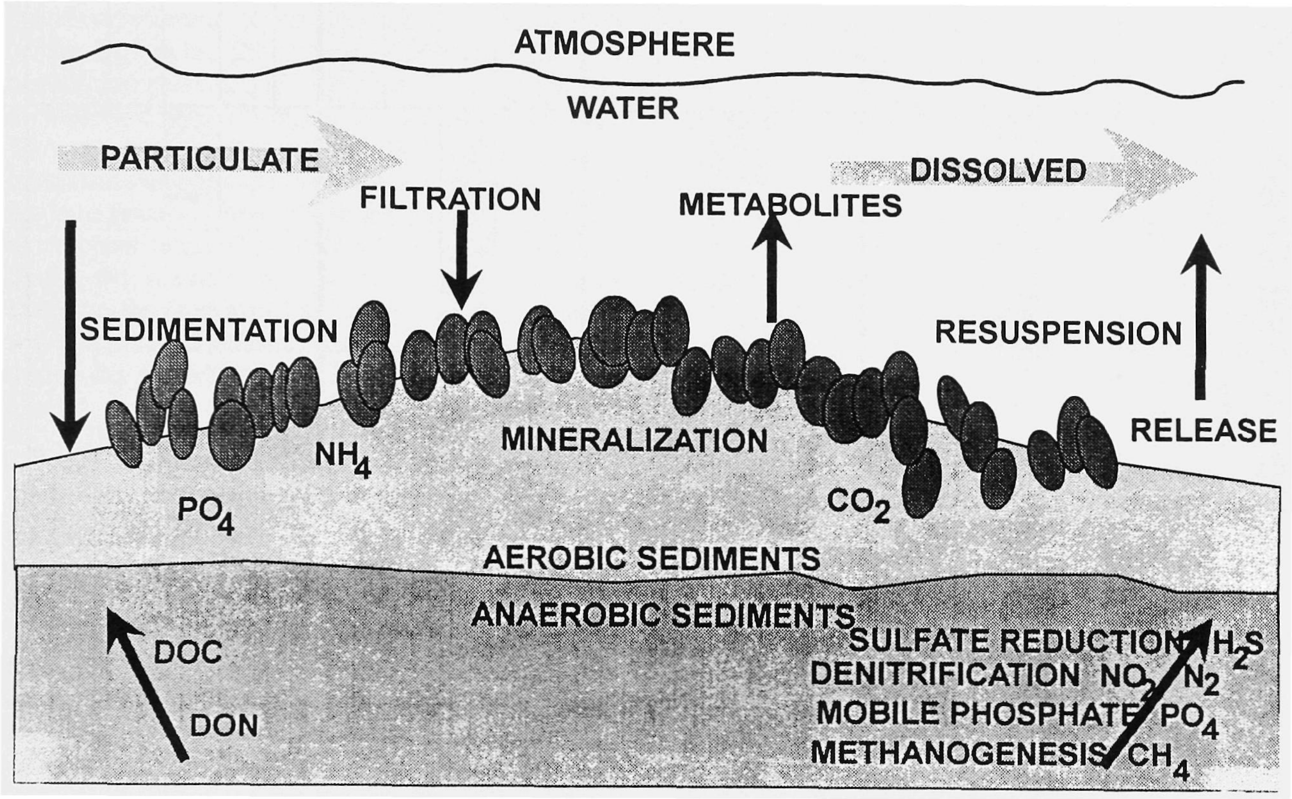

Figure 1. Ecological processes coupling oyster reefs to tidal creek waters.

Shallow tidal estuaries are highly productive and ecologically diverse systems because the complexity of the physical environment generates a multitude of habitats. These estuaries are threatened by environmental changes such as pollution, overharvesting of fisheries, and sea level rise. The investigators in this project are conducting an ecosystem-level experiment to examine the structural and functional role of oyster reefs in tidal creeks (see Figure 1). Eight similar tidal creeks were chosen to standardize for oyster dry body biomass to creek water volume at full bank conditions. Each creek has been topographically and bathymetrically surveyed, and these data have been used to determine area and volume relationships for each creek basin.

Preliminary findings from the first, premanipulation year include: (1) less mature creeks with upland interfaces have lower nutrient concentrations than more mature creeks nearer the ocean; (2) oyster growth appears to be negatively correlated with distance from the creek mouth; (3) grazing by bivalves and microzooplankton is important in controlling phytoplankton year round; (4) nutrient limitation effects are only found during the late fall to early spring period (see Figure 2); (5) tide pools within creeks accumulate nutrients and serve as refuges for nekton; and (6) differences in nekton assemblages among creeks appear to be determined by creek geomorphological and flow pattern variations.

In the manipulation year, which begins in March 1998, oyster reefs will be removed from four creeks, and their structure and function will be compared to four manipulated creeks for 1 year. The replicated experimental design will further the basic understanding of the role of oyster reefs in sustaining the ecosystems that they dominate.

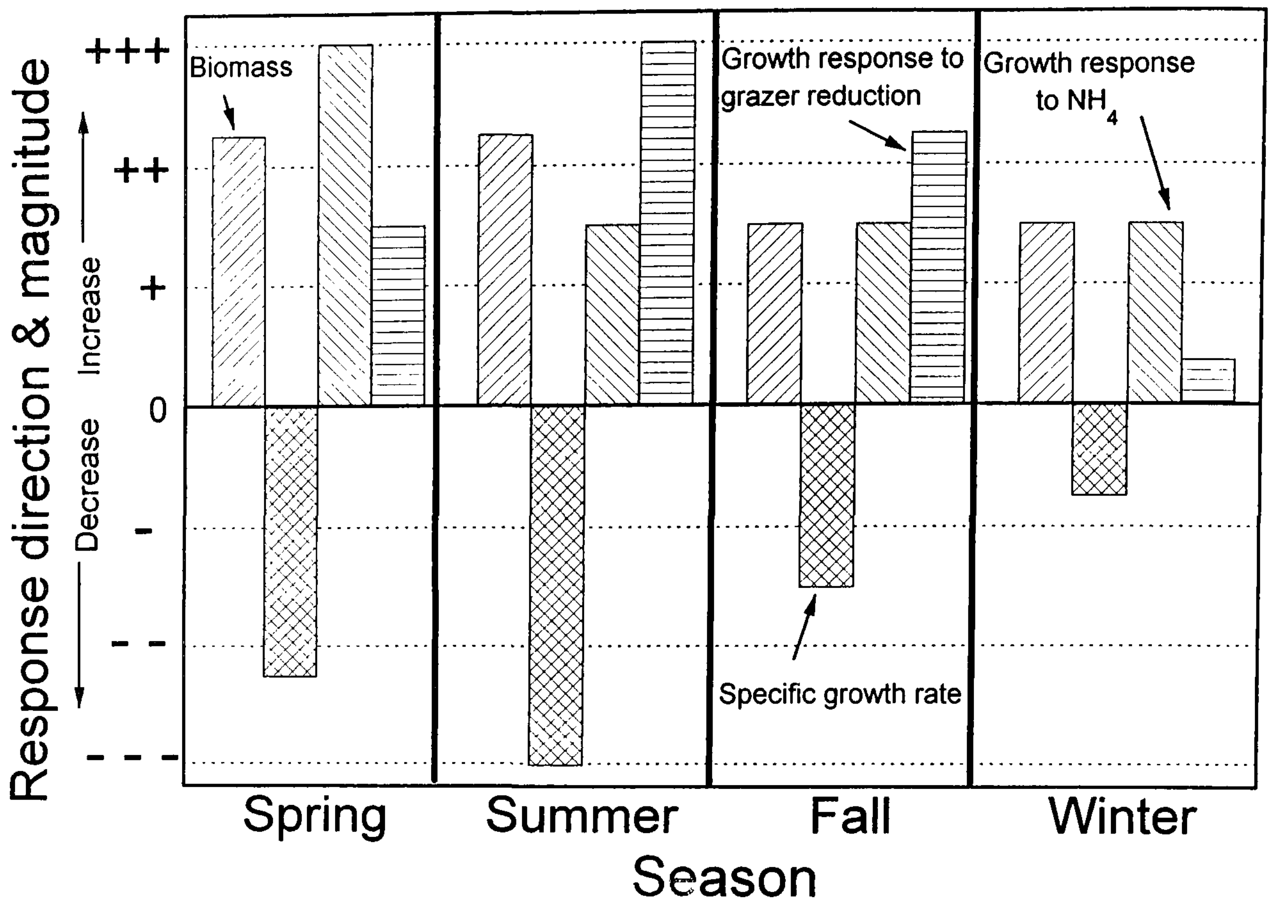

Figure 2. Predicted phytoplankton responses in creeks without oyster reefs compared to creeks with oyster reefs.

Tracing the Fate of Nitrogen Inputs From Watersheds to Estuaries

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This project's goal is to illuminate the trophic pathways by which river-borne dissolved inorganic nitrogen is incorporated into and processed by food webs in the upper, tidal freshwater-oligohaline reaches of coastal plain estuaries. Specific research goals include determining: (1) the key species in pelagic and benthic food webs; (2) the strength of linkages between benthic and pelagic food webs; and (3) the importance of watershed nitrogen inputs to consumer organisms. To meet these goals, we conducted the first whole-ecosystem stable isotope tracer amendment to be carried out in an estuary. First, ^{15}N-enriched nitrate was added to the upper reach of the Parker River, Massachusetts, during the summer of 1996 and, through intensive sampling, the progress of the isotopic label through the water column, organisms, and sediments was tracked during the amendment and for several months thereafter.

Three major sources of organic matter fuel the consumers of the upper Parker River estuary: (1) mostly microscopic pelagic (water column) producers, (2) benthic (sedimentary) primary producers, and (3) detritus derived predominantly from the tidal freshwater marsh (see Figure 1). The pelagic diatom, *Actinocyclus normanii*, was identified as a critical determinant of the fate of watershed-derived nitrogen in the Parker River estuary during the summer period when biological activity reaches its maximum. A bloom of this single-celled alga rapidly assimilated watershed-derived nitrate entering the upper estuary and was the primary vector of this nitrogen to benthic and pelagic food webs. Among those species feeding directly on the diatom, or on an herbivorous intermediary, up to one-half of their assimilated nitrogen was derived from this source, and thus from new nitrogen entering from the watershed. On the basis of ^{15}N tracer incorporation, 25-50 percent of the dietary nitrogen assimilated by planktivorous fishes, such as juvenile alewife and white perch, was derived originally from *A. normanii* by way of their copepod food. Surprisingly, we found that the tracer was rapidly assimilated by major crustacean benthos (i.e., mud crabs, amphipods, and grass shrimp), indicating an unexpectedly strong linkage of pelagic primary production with benthic secondary production. It is estimated that 20-40 percent of their assimilated nitrogen derived from the pelagic diatom. *A. normanii* was incorporated into surficial sediments, providing both a food reserve for benthos, and a probable nitrogen source for locally important benthic primary producers that fed small, productive intertidal fauna. Other species were largely uncoupled from *A. normanii* and depended more on unlabeled food sources, derived most likely from freshwater marsh detritus. Abundant benthic-feeding fishes (e.g., white sucker, mummichog) assimilated the tracer minimally by feeding primarily in a detritally based food web.

This project is among the first to measure directly the relative trophic importance of *in situ* primary producers and detrital organic matter in an intact ecosystem, and it is the first to do so by using a stable isotope tracer in an estuary. The research has made a major contribution to understanding the fate of watershed-derived nitrogen in the critical zone where rivers interface with estuaries, a region that has received relatively little study despite its potential to control nutrient transformation and transport from uplands to coastal waters.

Trophic Pathways of Nitrogen Flow in the Upper Parker River Estuary

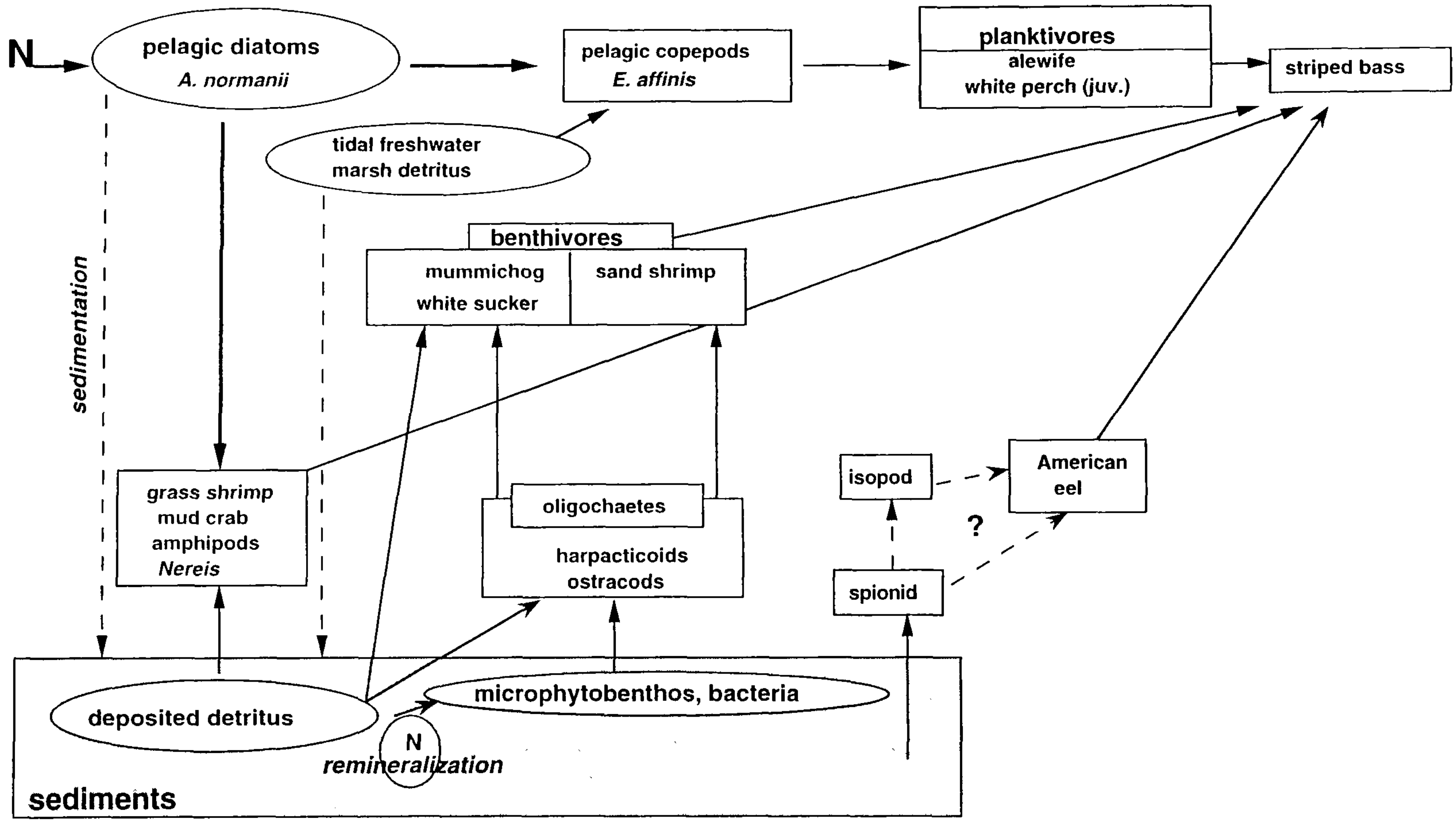

Figure 1. Conceptual model of nitrogen flow through biota of the upper Parker River estuary, showing trophic linkages supported by isotopic evidence, feeding ecology, and habitat use.

Probing the Relationship Between Fulvic Acid Aggregation, Metal Ion Complexation, and the Binding of Organic Compounds

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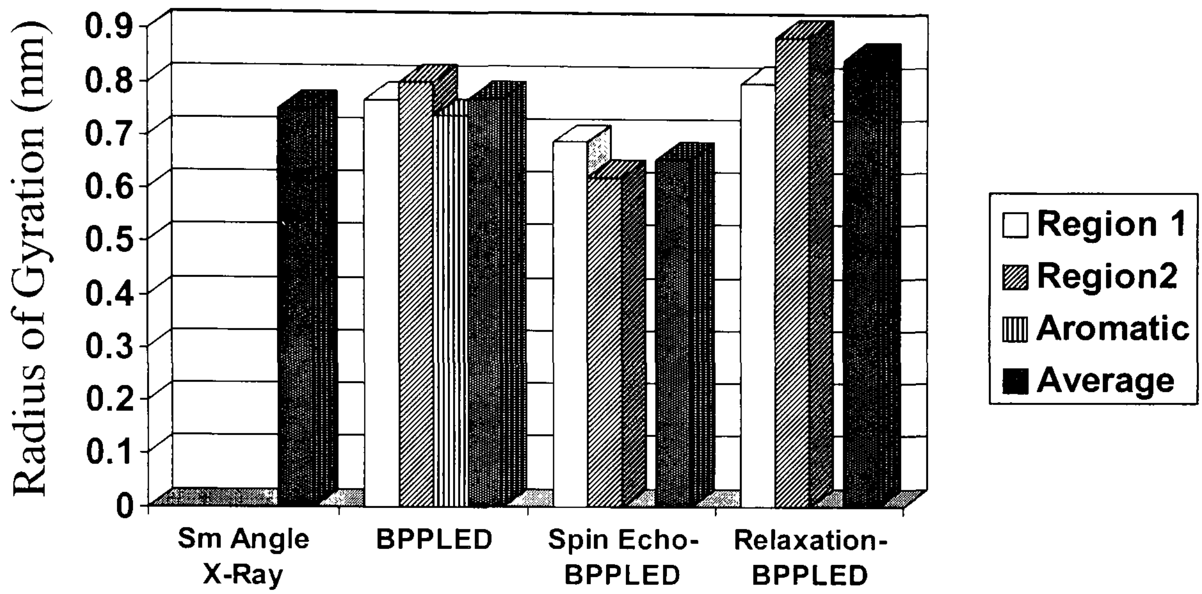

Figure 1. This figure shows the results of NMR experiments for the analysis of the average molecular size of fulvic acid solutions. These results are compared with the reported radius of gyration for this sample using small-angle X-ray scattering. Region 1 refers to the portion of the proton NMR spectrum containing CH_3, CH_2, and CH groups adjacent to aromatic, carbonyl and carboxyl groups. The standard NMR experiment, the Bipolar Pulse Pair Longitudinal Encode-decode pulse sequence (BPPLED), produces a radius of gyration that is the average over all fulvic acid molecules and is directly comparable to the small-angle X-ray scattering results. We have used two spectral editing methods based on spin-spin coupling (spin echo) and T_1 relaxation to modify the standard BPPLED experiment to detect fractions of the sample that are either lower or higher in molecular weight than the average. All three NMR experiments are being used to see how the average size of each fration changes as a result of cadmium complexation.

Soluble organic acids (humic substances) leach into ground and surface waters from soil and plant organic matter. Humics play a key role in water quality because they are the major constituents of dissolved organic carbon and they are important in controlling the bioavailability and transport of toxic metals and organic pollution. The goal of this project is to develop a better understanding of the physical and chemical properties of natural aquatic organic materials such as fulvic acids. Our approach makes use of the high specificity of nuclear magnetic resonance spectroscopy (NMR). NMR provides information about the local chemical environment of a molecule or chemical group. For example, binding constants of NMR active metal ions (such as cadmium) can be measured by monitoring the concentration-dependence of the NMR chemical shift. In addition, the NMR chemical shift also yields information about the local chemical environment of the metal. In this way, it is possible to determine which functional groups (such as carboxylate or amine) form the complex.

NMR relaxation measurements and detailed molecular mechanic calculations also are being used to further elucidate the nature of the metal-fulvic acid complex. One interesting facet of this project is the relationship between metal complexation and fulvic acid aggregation. NMR experiments have been modified for the measurement of diffusion coefficients to make them more specific for different classes of compounds. In this way, the extent to which metal ion complexation induces aggregation in a fulvic acid sample can be examined. The high specificity of NMR can provide additional information about the fulvic acid aggregates when compared with that provided by other analytical methods, which could be used for this purpose, such as small angle X-ray scattering and dynamic light scattering. The ultimate goal of this project is to use NMR and specially labeled compounds to examine the extent of metal binding to a fulvic acid solution, how metal ion binding affects the aggregation of the fulvic acid sample, and how metal-induced aggregation affects the binding of organic pollutants by the fulvic acid aggregates. The molecular level specificity of our analytical methods will increase our knowledge of the molecular-level behavior of aquatic fulvic acids. This information will be useful to develop a better understanding of how the chemistry of fulvic acids contributes to the availability and transport of pollutants in aquatic ecosystems.

Diffusional Rate Limitations in Heterogeneous Porous Media: Model Structure, Scale, and Geologic Characterization

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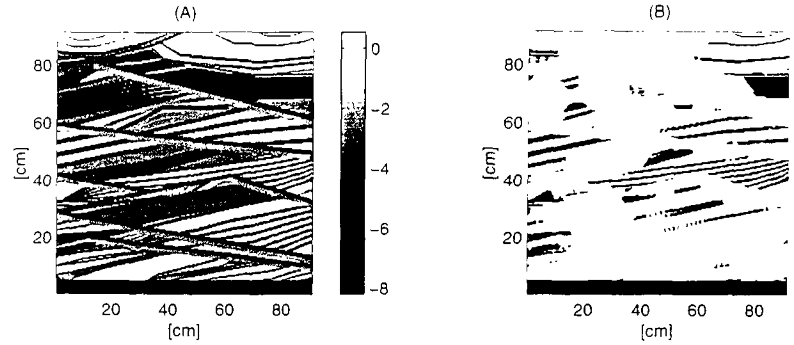

Figure 1. Regions of low groundwater velocity within a point bar deposit. (A) Natural log of the hydraulic conductivity (cm/s) for a vertical section. (B) Regions of low velocity (dominant flow direction is left to right): mean velocity magnitude=4.7×10^{-4}cm/s; dark regions are those with velocity magnitudes less than 4.8×10^{-5}cm/s.

The goal of this project is to enhance our ability to predict the transport and fate of hazardous chemicals in subsurface waters by increasing our understanding of the nature and significance of diffusion during transport in saturated, heterogeneous porous media. The objective is to develop the understanding and tools necessary to evaluate and predict the relative importance of diffusion, or diffusion-like processes, over a range of spatial scales (from grains to regionals). The approach rests on a program of numerical experimentation and analysis examining: (1) the mathematics of multiscale diffusional rate limitations on sorption; (2) the interactions between geologic structure, heterogeneity, upscaling, and real and apparent transport process representation in mathematical models; and (3) physically based aggregation schemes that are consistent with different model formulations of transport processes and multiscale diffusional rate limitations. The investigators are using both random-field models and a very fine-scale, quasideterministic, numerical model to represent spatial heterogeneity and uncertainty.

The researchers have developed and applied a model to analyze a set of laboratory column experiments conducted to determine the rate at which trichloroethylene (TCE) can be removed from natural soils. A wide range of diffusional time scales for the TCE sorption-desorption process, spanning up to 15 orders of magnitude, has been found. To investigate the effects of a distribution of contaminant sorption time scales in macroscopically homogeneous aquifers, the temporal moments of a contaminant pulse were examined. A distribution of sorption time scales was found to not affect the first two temporal moments, but can affect strongly and even dominate the third moment. In extending the analysis to heterogeneous aquifers, the statistics of the arrival times of a contaminant are being examined after transport through a hydraulic conductivity field. Preliminary results suggest that we will be able to distinguish among scenarios in which: (1) the heterogeneity of the aquifer controls the spread of arrival times, while sorption can be treated as an equilibrium process; (2) the kinetic sorption controls the spread of arrival times, and the aquifer can be treated as macroscopically homogeneous; and (3) both heterogeneity and kinetic sorption contribute significantly to the spread of arrival times.

Pure advection through spatially heterogeneous groundwater velocity fields itself can lead to skewed breakthrough curves. In addition, velocities in some regions of a heterogeneous velocity field may be so low that solute transport is dominated by diffusion, even though the mean velocity is relatively high. To investigate the nature of low-velocity regions, the investigators began by exploring simple geometries such as spherical inclusions. Subsequently, this project has examined simulated flow through a highly resolved representation of a point-bar deposit. Preliminary results show that regions of very low velocity do exist, and that the spatial structure of these regions is complex and a strong function of the conductivity heterogeneity as well as of the mean head gradient (see Figure 1).

The results from this research will contribute to a fundamental understanding of the impact of diffusionally rate-limited sorption and diffusionally controlled slow release from zones of low velocity on transport, with applications to contaminant remediation design, site characterization, and the interpretation of field monitoring and laboratory experimental data.

Continuing work is focused on exploring heterogeneity-kinetic sorption interactions in different heterogeneous settings; characterizing low-velocity regions and their relationship to geologic structure and flow as well as transport boundary conditions; and exploring the roles of aggregation, upscaling, model formulation, and spatial structure in predictive modeling of transport.

Integrating Planning, Forecasting, and Watershed Level Ecological Risk Assessment Techniques: A Test in the Eastern Cornbelt Plains Ecoregion

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The objectives of this research are: (1) to test the relationships between biological conditions of streams and the nature and distribution of human activities on the watershed; (2) to demonstrate methods for linking physical models of urban and agricultural impacts on runoff volume and runoff quality; (3) to define the relationships between physical model forecasts and the biological conditions of streams; and (4) to integrate all of the findings into an expert system to be used by planners.

During the past year, we have been working simultaneously in three areas: (1) assembly of a comprehensive regional database and testing of watershed scale relationships between biological measures of water quality and watershed characteristics; (2) testing the impacts of different scale soils data on our predictive models of hydrologic response; and (3) finalizing methodologies and data for preparing and analyzing riparian zone and detailed watershed data aimed at testing models at larger scales.

The USEPA RF3 stream Geographic Information System (GIS) files were used as the basis to divide the 4 Eastern Cornbelt Plains region into two distinct sets of watersheds—25 coarse scale watersheds and 137 fine scale watersheds. For the region as a whole, Landsat imagery was used to define the major land use categories. A number of other data were compiled using the same geographic base, including the IBI (Index of Biologic Integrity), the major dependent variable in our regional scale analyses. The data were collected at 522 locations throughout the watersheds.

At this regional scale, a number of empirical relationships between the IBI as a measure of biological quality and some proxy variables for point and nonpoint water pollution stresseshave been tested. More detailed modeling at the watershed scale has proceeded by testing the impact of soils data at two scales on the results of our sediment model. A test of the model behavior using two soils data at two different scales has been completed. Finally, work at the riparian zone level has led to a strategy for extracting relatively detailed vegetation-type assemblages and patterns in the riparian zone using Landsat imagery. A new set of techniques will be used in the coming year to derive the most detailed data sets and to test empirical models at this scale against our regional scale and watershed scale empirical and physical models.

A set of empirical models for the Eastern Cornbelt Plains Ecoregion has been defined, which explains significant amount of the variation in IBI levels across watersheds. Table 1 compares the results for the larger scale (more detailed) and smaller scale watersheds.

The significant variables are the percentages of dense urban settlement, and several measures of watershed condition and location, including stream order, substrate type, and pool and riffle run quality. Adding an estimate of chemical stressors using STORET data produced significant improvement in model results. IBI levels also are strongly influenced by upstream and downstream IBI.

Model runs made for the Big Darby Creek basin with the two alternative sources of soils data lead to different conclusions concerning scale changes. The predicted annual flow, sediment, and nitrate losses for the analysis with conventional tillage and no subsurface drainage are presented in Table 2. There is no significant difference between the mean annual flow and sediment values predicted by using data of finer vs. coarser resolution. However, the mean annual nitrate loss prediction based on the two soils databases are significantly different due to the approximately 10 percent difference in the loss for 1992. There are considerable differences in the flow, sediment, and nitrate prediction for individual map units of fine vs. coarse resolution (not presented). The results suggest that coarser resolution data can be used to model hydrological responses at a watershed scale but should not be used at a field scale, or if the goal is to predict responses for short time periods. It should be noted that in this study, the model was not calibrated and the results only provide an indicator of the relative responses associated with different agricultural practices and soil characteristics. It is probable that sediment losses are underpredicted and some of the model input variables need to be adjusted.

Table 1. Regression models for mean IBI at the watershed scale.

	Coarse Watersheds (25)	Fine Watersheds (137)	Significant Independent Variables
R^2 Values	.384	.409	Dense urban; substrate; stream order; Pool/Riffle
R^2 Values	.494	.525	Adding chemical conditions based on ranking of segment by STORET readings
R^2 Values	.694	.703	Adding upstream and downstream IBI to account for spatial autocorrelation

Table 2. Comparison of annual flow depths, sediment losses, and nitrate losses for conventional tillage without subsurface drainage.

Year	Precipitation (mm)	Flow Depth (mm)		Sediment Loss (ton/ha)		Nitrate Loss (kg/ha)	
		STATSGO	MUIR	STATSGO	MUIR	STATSGO	MUIR
1991	718	197	198	3.0	2.8	9.3	9.3
1992	792	211	226	3.7	3.9	16.2	17.8
1993	931	264	270	3.7	3.8	9.9	10.2
1994	696	155	160	3.9	3.9	6.9	6.8
1995	937	317	318	6.8	6.9	10.7	11.0
Mean	815	229	235	4.2	4.3	10.6	11.0

Development of Geomorphological Artificial Neural Networks (GANNs) for Modeling Watershed Runoff

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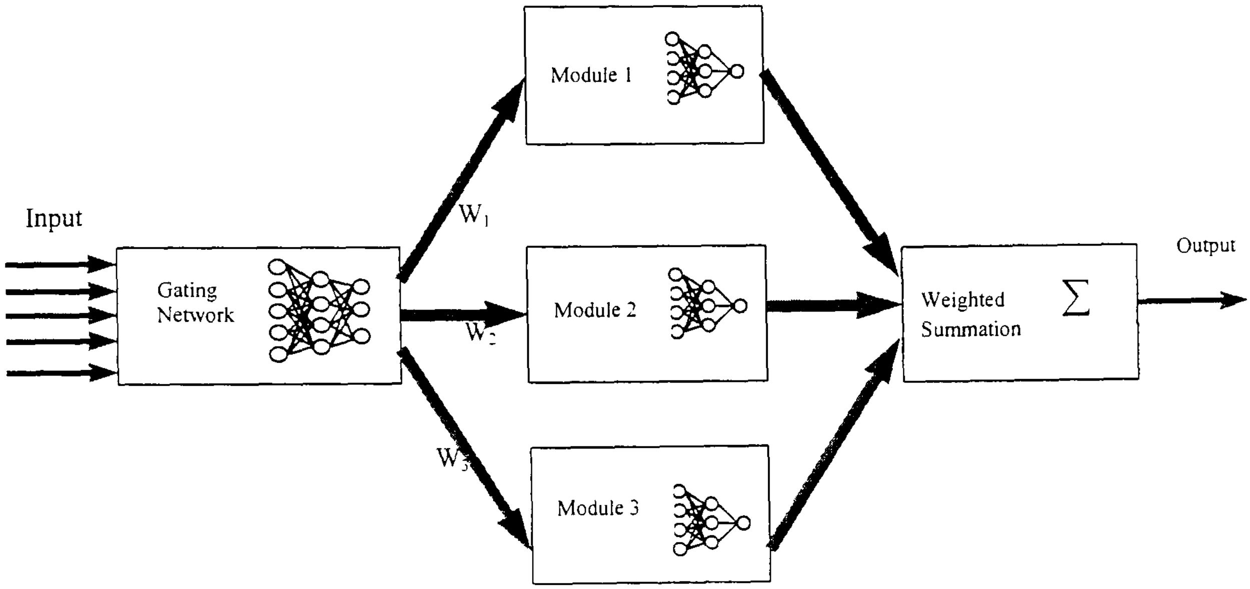

Figure 1. A schematic of modular artificial neural network.

Predicting streamflow is a fundamental component of a wide range of watershed-modeling efforts. In this project, geomorphological artificial neural network techniques have been applied to predict watershed response to precipitation and temperature. These networks can be used to resolve watersheds at different spatial and temporal scales through a massively interconnected network of processing units. System architecture is determined by the topology of the watershed. Network development is characterized through an iterative training procedure. Model calibration involves the selection of the optimal values of connection strengths and processing-unit thresholds, so that the network best reproduces historical streamflow records for the watershed. This requires a large number of training examples, in terms of historical precipitation and streamflow records for a watershed. Once network training has been accomplished, it can be used to forecast streamflows for the watershed based on rainfall and temperature inputs. The model preserves some geomorphological and probabilistic characteristics of watershed response as represented by historical records. Data from several Kansas watersheds are being used to test the performance of the model. To avoid problems associated with over-training, an additional cross-validation data set has been used to determine optimal training and network architecture. The data set is partitioned into three portions: (1) a training set, (2) a cross-validation data set, and (3) a testing data set. Historic records have been used to determine the time lags for watershed response to precipitation and have been incorporated in our modeling effort. A cross-correlation analysis between the average monthly precipitation and watershed runoff revealed that the past 3 months of rainfall data would have a significant impact on the runoff for some Kansas watersheds.

Singular neural networks predict average streamflow characteristics satisfactorily, but they have not been successful in predicting high and low runoff events. A number of singular networks were arranged in a layered structure to form a modular network, and stream discharges were partitioned into three classes, each using a singular network (see Figure 1). Each singular network or module covered a particular range of the dataset, and a final module assigned weights to the prediction of the individual modules. Each module was developed based on the data in a class, but the final network was based on the entire training dataset. This kind of network resulted in an improved prediction of streamflows for three Kansas watersheds. Inclusion of rainfall and temperature from previous months allows the model to better represent watershed conditions.

The preliminary success of modular networks suggests that different rules are required to represent extreme and average events. The architecture of the modular network can be adapted to represent a stream network and includes the geomorphology of a watershed. Future efforts are planned to extend our applications of geomorphological artificial neural networks and consider the influence of spatial and temporal resolution on watershed-runoff computations.

Physicochemical Mechanisms Governing Virus Filtration

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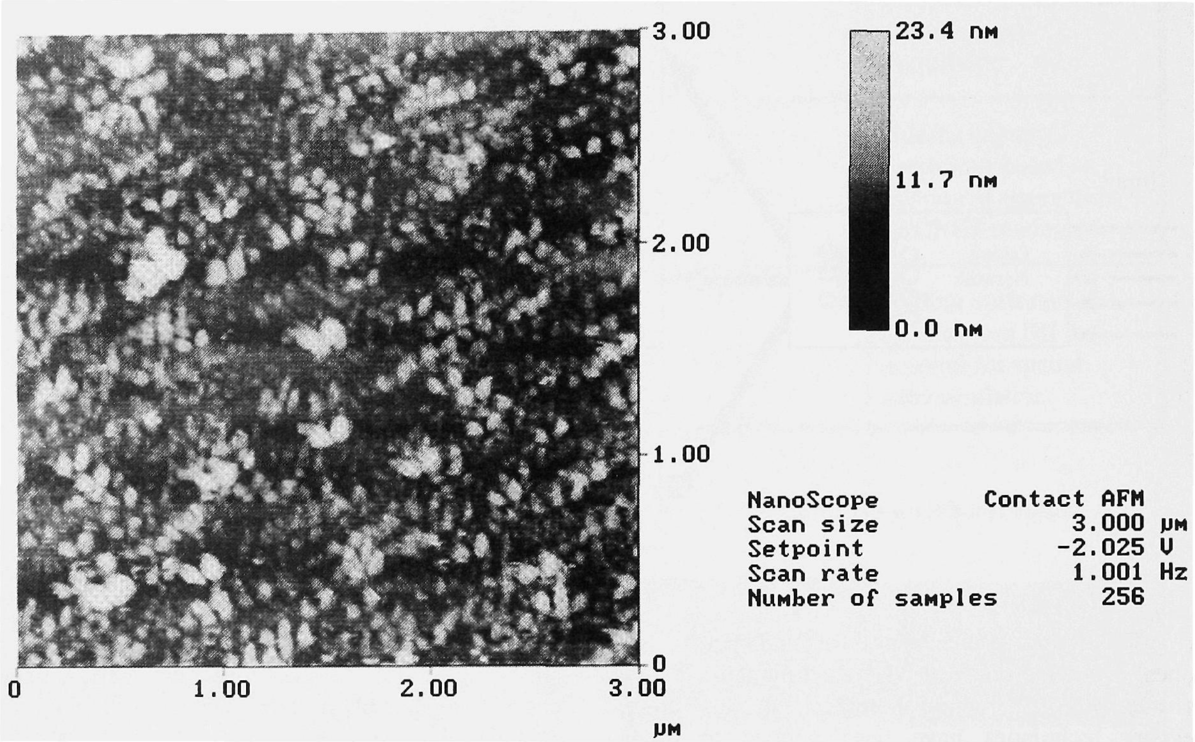

Figure 1. Atomic force microscope image of Norwalk virus particles absorbed to a mica surface. This adsorption experiment was conducted in an aqueous solution at pH 5 and 100mM NaCl. Under these conditions, the virus is positively charged and the mica is negatively charged. Consequently, there is no electrostatic barrier to virus adsorption.

The use of reclaimed sewage for groundwater recharge raises a number of important human health issues. Foremost among these is the possibility that human enteric viruses present in the reclaimed sewage may be transported to production wells and, ultimately, end up in a water distribution system. Laboratory-scale experiments are being conducted that are aimed at identifying the geochemical features of a recharge basin influencing the removal of viruses from groundwater by physicochemical filtration (see Figure 1). Initial experiments of this project examined the influence of water pH on the surface charge of recombinant Norwalk virus-like particles and their filtration rates in packed beds of quartz sand. Many outbreaks of gastroenteritis in the United States are caused by waterborne or foodborne transmission of Norwalk virus. The initial results from this project suggested that pore water pH may be the most important factor in determining the capacity of groundwater systems to provide natural disinfection by physicochemical filtration.

Further experiments have used a total of four different viruses, including three coliphage (a somatic phage, and two different male-specific phages) and Norwalk virus particles generated using a baculovirus expression system. In all cases, we found that pore water chemistry dramatically influences the removal of these viruses in packed beds of quartz sand. When the filtration results are combined with microelectrophoresis measurements of the viruses' surface electrical potential, the results are generally consistent with the predictions of classical theory—that is, electrostatic interactions between the viruses and quartz sand ultimately determine a filter's ability to remove viruses from water.

Watershed Impacts on Sediment Pollution History and the Viability of the Zooplankton Egg Bank

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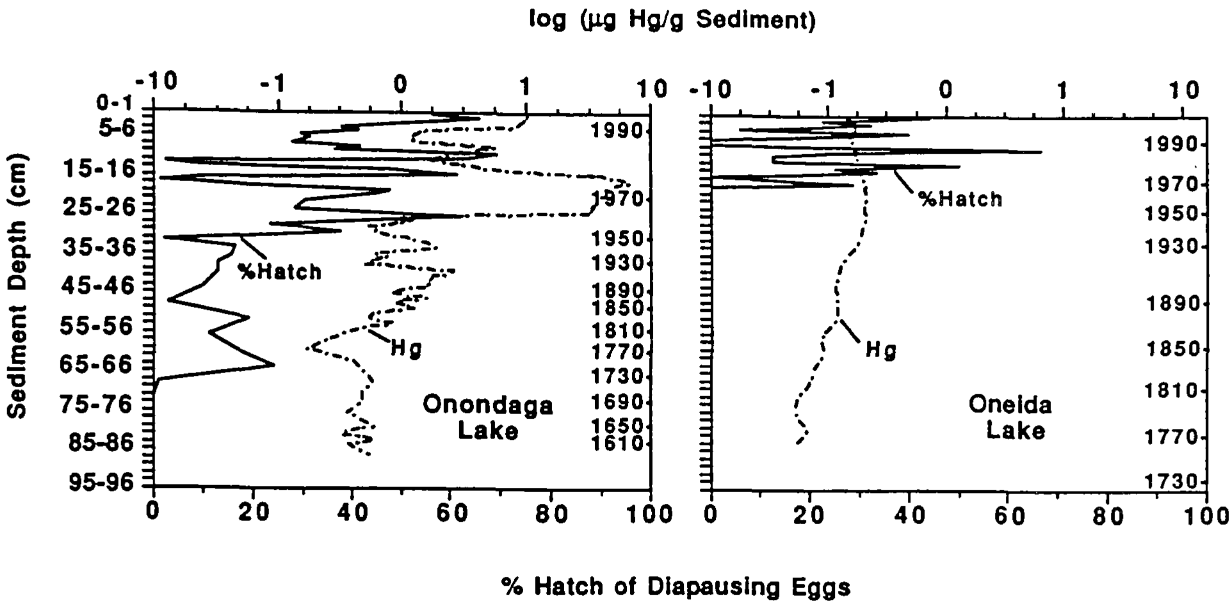

Figure 1. Comparison of the mercury concentrations (logarithmic scale) and hatching success of zooplankton diapausing eggs in the sediments of two lakes in central New York State. Oneida Lake has only received metals from atmospheric deposition on the watershed. Onondaga Lake has experienced direct inputs from industry effluent. Sediment dates determined by 210-Pb analysis. Note that analysis of hatching success in Oneida Lake is only partially complete.

The zooplankton community of lakes and its response to environmental change may be substantially impacted by the diversity, viability, and population dynamics of long-lived diapausing eggs buried in lake sediments. The history of environmental change in lakes is manifested in the pollutants that enter their watersheds and are transported to the lake, where they ultimately accumulate in the sediments.

This project is investigating the impact of this pollution on diapausing egg viability. The two major sources of heavy metals in lake sediments in the Northeastern United States are: (1) direct inputs of industrial effluent to the watershed or lake and (2) atmospheric inputs that are deposited within the watershed and wash into the lake. Replicate sediment cores taken at two lakes in central New York State reflect their distinct histories of industrial impacts. In both lakes, cores were sectioned, dated by 210-Pb, and analyzed for concentrations of metals, including lead (Pb) and mercury (Hg). In both lakes, fluxes of these metals to the sediments increased from 1850 to the mid-to-late 1900's. The increase was initially due to atmospheric deposition to the watersheds, but in Onondaga Lake, major inputs from chemical and steel industries on the shore occurred during the 1960's, 1970's, and 1980's.

Sediment enrichment factors (modern metal deposition/metal deposition in 1850) were on the order of 2 to 3 for Pb and Hg in Oneida Lake, but between 30 and 120 for these metals in Onondaga Lake. These deposition patterns will be compared with those for remote lakes in the Adirondack region of New York State. Diapausing eggs of crustacean and rotifer zooplankton are found in abundance in the sediments of both lakes (see Figure 1). Both show substantial hatching for eggs deposited 40 to 100 years in the past. There is no evidence for a reduction in egg viability in Onondaga Lake, as compared with Oneida Lake, or within Onondaga Lake as a function of sediment metal concentration. Apparently, the "ametabolic" state of zooplankton eggs in diapause protects them from metal toxicity in the sediments. These eggs may thus represent a source for the recovery of lake zooplankton communities from past environmental pollution.

The Role of Colloidal Particles in the Transport of Chemicals Through an Agricultural Watershed

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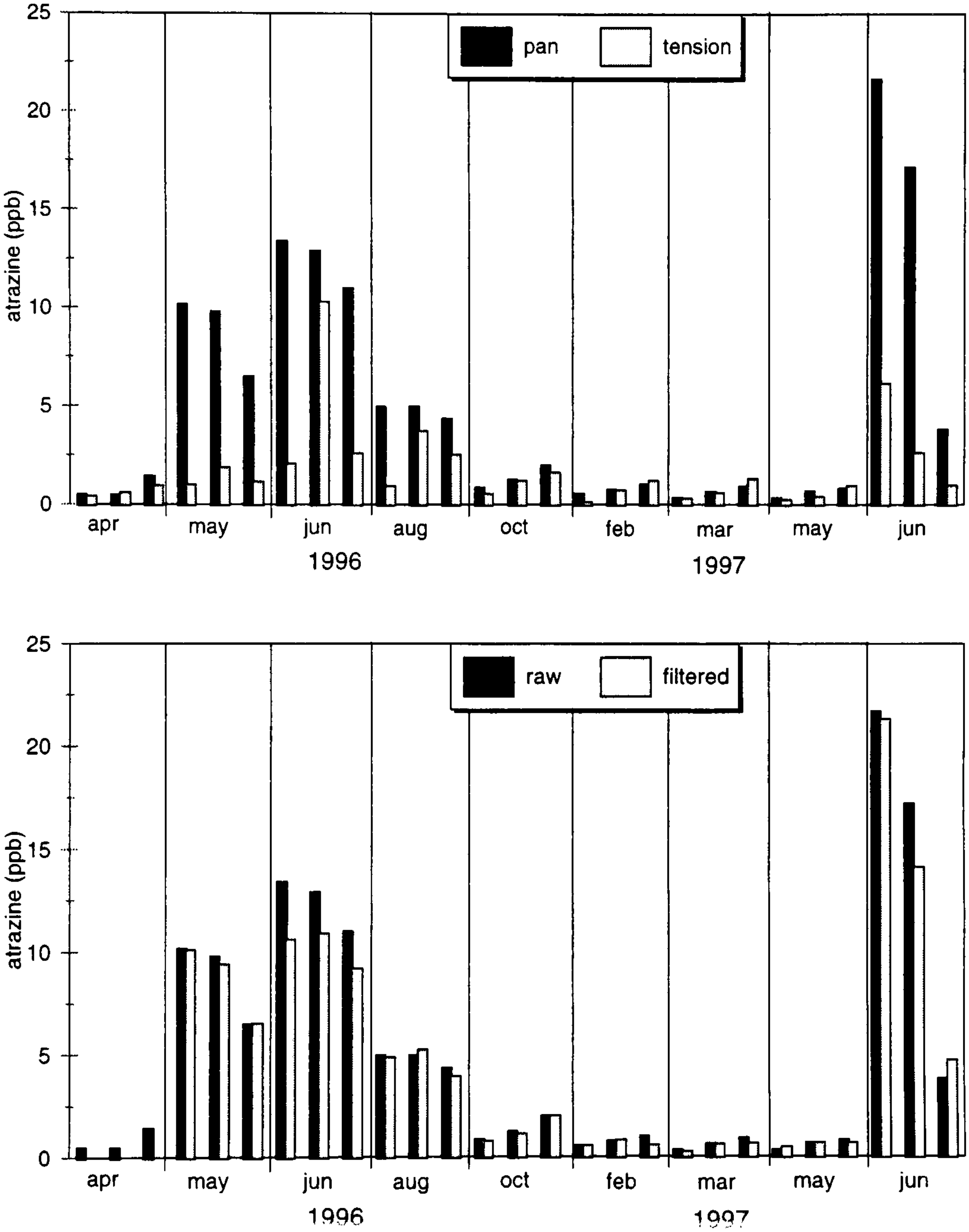
Organic contaminants exhibit complex chemical patterns as they are transported through watersheds to streams. This project has examined the chemistry of the widely used herbicide, atrazine, as it passes through hydrologic systems—from its initial occurrence in the unsaturated soil zone in agricultural areas through the groundwater of a bedrock water-supply aquifer to its appearance in a stream draining the watershed. The goal has been to expand our understanding of herbicide movement through the entire soil-bedrock-stream system in an agricultural watershed. This information will permit informed management decisions about land use and its impact on a sustainable water supply.

Work is being conducted on Muddy Creek, which drains an agricultural catchment in the Shenandoah Valley, Virginia. The research addresses three primary questions: (1) What factors control the variability in the concentrations of colloids and agricultural chemicals in the aquifer-stream system at Muddy Creek? (2) How do aquifer materials and colloidal particles affect the movement of agricultural chemicals such as atrazine and hydroxyatrazine? (3) Do laboratory-based observations of colloid-facilitated transport of agricultural chemicals provide a reliable estimate of transport at the field scale?

In this project, the forms and transport of herbicides in the groundwater flow system will be reported. To evaluate *in situ* soil-water composition, samplers were installed to collect water held under different tensions in the unsaturated zone at three depths at three sites in the catchment. Tension lysimeters were installed in 8 cm diameter holes at depths of 15, 45, and 90 cm. Zero-tension (pan) lysimeters, which sample water flowing through macropores in the soil, were installed by excavating a trench and fitting three pans at the same depths as the tension lysimeters. Soil-water samples were collected, and water volume was recorded from both types of lysimeters approximately every 4-6 weeks from April 1996 through June 1997. Samples were analyzed for atrazine, nitrate, dissolved organic carbon, and colloid concentrations. In the clay-silt loam at our field site, significantly higher concentrations of atrazine were identified in zero-tension lysimeters at three depths (15, 45, and 90 cm) than in corresponding tension lysimeters. Atrazine concentrations in the zero-tension lysimeter were as high as 21 ppb, whereas the corresponding concentrations in tension lysimeters were only ~ 2 ppb (see Figure 1). Colloid concentrations in the zero-tension lysimeters were as high as 650 mg/L. Although the differences between the particle-associated atrazine and the dissolved atrazine in the pan lysimeters are small, they are significant statistically ($p = 0.027$). Concentrations of nitrate are highly variable and not significantly higher in the pan lysimeters than the tension lysimeters, indicating that different processes may control the transport of nitrate relative to atrazine.

Our results indicate that: (1) transport of atrazine is largely via macropores; (2) colloids are mobilized and transported over distances of at least 1 meter in the vadose zone at our site; and (3) nitrate is not a good surrogate for judging atrazine transport. Macropore sampling is required to estimate transport of herbicides in the field, and colloid-facilitated transport of strongly sorbing constituents is of potential importance at agricultural sites such as Muddy Creek.



a. b.

Figure 1. Atrazine concentrations in (a) pan and tension lysimeters and (b) raw and filtered fractions from pan lysimeters.

Geomorphic, Hydrologic, and Ecological Connectivity in Columbia River Watersheds: Implications for Endangered Salmonids

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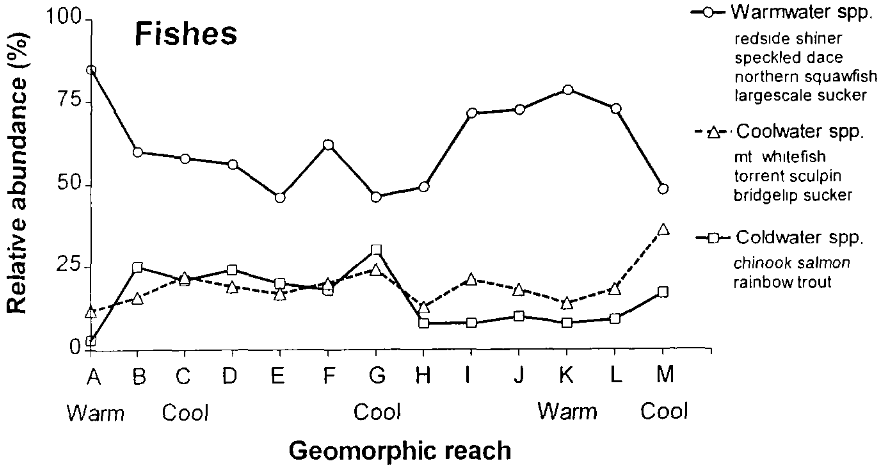

Figure 1. Patterns of fish assemblage structure corresponding to temperature patches among stream reaches.

Coldwater fish communities throughout the Columbia River basin face high risks of extinction due to degraded freshwater habitats. The survival and persistence of these fish communities will depend on our understanding of the processes controlling stream temperatures and fish habitats. This project is investigating the interplay among geomorphic, hydrologic, and riparian-community features and the dynamics of groundwater input and hyporheic flow in pristine and badly disturbed streams in the high desert of the Columbia River. Images captured using Forward Looking Infrared (FLIR) videography revealed that the temperature profile in a watershed disturbed by intensive livestock grazing, the Middle Fork John Day (MFJD), varies by as much as 50° C. However, a stream draining the wilderness basin, the North Fork John Day (NFJD), exhibits the normative temperature patterns. Patterns are similar throughout the year, with consistent magnitudes between stream differences in all seasons.

Presently, there is no clear, single explanation for the temperature patches. Ground truthing has established that it is not an artifact. Intensive stream gaging at selected locations, dye release tests, and measures of vertical hydraulic gradient do not indicate that they are caused by hyporheic groundwater exchange, which is relatively minor in comparison to that documented in streams of the northern Rocky Mountains. Likewise, analyses of bed materials suggest that hydraulic conductivity may be low, although this will be decided with further analysis by ground penetrating radar to map potential pathways of hyporheic flow by measuring depth to bedrock and defining alluvial stratigraphy. These studies were conducted in the MFJD and adjacent drainages with similar geomorphologies. Biogeochemical relationships between subsurface flows, sols, and vegetation in the riparian zone were characterized by measuring annual dynamics of water-table depth, soil redox potential, and chemistry of subsurface and stream waters. In contrast to instream measurements, preliminary results show some degree of lateral hyporheic exchange between the stream and riparian communities as documented by water temperature, redox potential, and dissolved organic carbon concentrations. Livestock grazing appears to affect groundwater exchange. Ungrazed riparian reaches were found to have greater root bio-mass, soil organic matter, water infiltration rates, pore space, and lower soil bulk densities.

Fish surveys in the two watersheds reveal that longitudinal fish community patterns strongly reflect the temperature profiles. There is a gradual shift from cold water to warm water communities in the wilderness stream system (NFJD); whereas, the relative composition of community types in the disturbed stream (MFJD) follows the distribution of temperature patches (see Figure 1). Subsurface flow within reaches was found to be very slow and poorly oxygenated, suggesting that high stream temperatures may force organisms to choose between microhabitats of cooler temperatures, but with low dissolved oxygen versus mainstream habitats that are warmer, but higher in dissolved oxygen. Water chemistry, primary production, macrophytic and algal biomasses, macroinvertebrate abundances, and fish diets at 12 sites along the MFJD were to examine the effects of water temperature and possible hyporheic up-welling/down-welling on the trophic network. This project's analyses do not support the hyporheic corridor concept as an explanation for the distribution of organisms, but an evaluation of the factors dictating temperature conditions will be made.

Resistance of Communities to Chronic Haloaromatic Contamination From Biogenic and Anthropogenic Sources

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Halogenated aromatic compounds are important pollutants characterized by their toxicity, persistence, and accumulation in the environment, and abundant production and frequent use in a variety of industrial processes. This project examines the extent to which the capacity to degrade naturally occurring halogenated aromatic compounds determines the biological impact of anthropogenic halophenol pollutants on marine benthic communities. Dehalogenase enzyme activities and genetic probes are being used to assess the potential for dehalogenation among the polychaete worms, which dominate these sedimentary ecosystems, and the worm-associated bacteria, as well as other principal community members. The enzyme assays and DNA probes plus induction experiments will enable us to determine if dehalogenation potential is an important determinant of organism survival and persistence in biogenically and anthropogenically contaminated locations.

Our findings to date highlight the abundance and broad distribution of benthic macro- and microorganisms capable of production and/or degradation of halometabolites. A large proportion of invertebrate taxa, which are numerically dominant in coastal marine sediments, are halometabolite producers and have enzymatic dehalogenation activity. The native worm species—the most abundant intertidal benthic macrofauna—appear to be segregated among sites with regard to their dehalogenation capacity, and this may be related to the presence of halophenols in their environment. Twelve reductively dechlorinating anaerobic bacterial strains have been isolated from the burrows of a bromphenol-producing and a nonproducing species. These strains reductively dechlorinate 2,4,6-trichlorophenol.

A survey of polychaetes at an undisturbed estuarine site showed that 40 percent of the organisms contained halogenated metabolites. Additional surveys indicated that native species appear to be segregated among sites with regard to their halgenation and dehalogenation capacity, and this may be related to the presence of halophenols in their environment.

Twelve reductively dechlorinating anaerobic bacterial strains have been isolated from polychaete and hemichordate burrow lining materials. Dechlorination of 2,4,6-trichlorophenol, with phenol as the apparent terminal product, was initially rapid but declined after successive subculturing of all strains. A new method for analysis of phospholipid fatty acid data, allowing a more sensitive detection of changes in community composition, also was developed as part of this project.

The investigators have initiated a series of species transplant and halophenol contamination experiments in the field to assess the ability of worms that do not produce halogenated aromatic compounds to survive in their presence and to determine whether dehalogenation activity can be induced. Experiments creating refuge from predators also are in progress to determine the role of predators in controlling the representation of fauna with halometabolites.

Additional near-term activities include the completion of purification and characterization of the bacterial dehalogenase enzymes and the development of probes to characterize the genetic potential for dehalogenation by bacteria associated with the macrofauna. Dehalogenation activities against brominated (common biogenic) and chlorinated (common anthropogenic) haloaromatics will be tested. We have developed a new method, based on neural networks, for analyzing phospholipid fatty acid profiles from sediment bacterial communities. The new method is more sensitive than conventional cluster and principle components analyses and yields greater resolution of community composition than previous approaches.

Influences of Watershed Land Use on Stream Ecosystem Structure and Function

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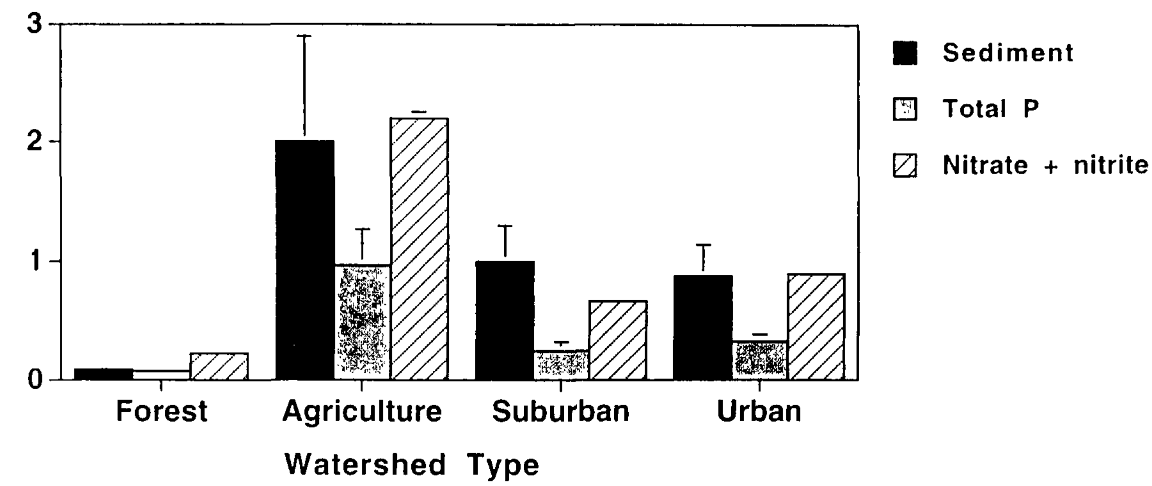
Because natural resource management is more frequently conducted at the landscape and ecosystem levels, it must be determined whether the species and habitat-based approaches currently used by water-quality monitoring programs provide data relevant to assessing interventions at the scale of the landscape or ecosystem. This project has two objectives: (1) to determine how differing patterns of land cover and land use in a watershed alter stream ecosystem structure and function; and (2) to compare measures of stream ecosystem function (rates of community metabolism and transport and cycling of carbon and nutrients) with traditional chemistry-based, water-quality assessment and organism-based bioassessment. The project approach has been to measure ecosystem structure and function in streams draining eight watersheds in the Chattahoochee River basin; two streams drain watersheds in each of four land use categories (i.e., forest, agriculture, urban, and suburban). Urban and suburban watersheds are within metropolitan Atlanta. Poultry is the primary commodity produced in the two agricultural watersheds. The eight watersheds studied range in size from 47 200 km^2; human population density ranges from 190 8,200 persons/km^2. The progress in four areas of research will be reported, including: (1) watershed characterization, (2) patterns of material transport, (3) organic matter dynamics, and (4) nutrient spiraling.

Land cover and land use has been characterized in the watersheds, and impervious surface area has been estimated in different land use classes. Percent impervious surface increases with distance from the stream in urban and suburban watersheds. An Index of Biotic Integrity (IBI) based on fishes was lowest in watersheds with much of the impervious surface area in commercial, industrial, and transportation land uses. There apparently is a threshold at about 30 percent impervious surface area; when percent impervious surface rises above that, IBI scores decrease sharply. Correlations between IBI scores and forest cover in riparian areas (50-meter buffer) were similar to correlations between IBI scores and forest cover in whole watersheds, even though riparian zones had 20 percent greater forest coverage. This analysis suggests that in urban watersheds, the success of riparian restoration projects may be limited by the influence of land use elsewhere in the watershed.

Export of sediments, nitrate, total phosphorus, and particulate organic carbon were highest in agricultural watersheds (see Figure 1). In contrast, dissolved organic carbon export was greatest in urban watersheds, presumably a result of wastewater inputs and runoff from impervious surfaces. These data, when combined with standing crop and respiration data, will provide valuable comparative measures of organic carbon turnover in urban, agricultural, and forested watersheds in the same physiographic area.

Organic matter inputs, retention, storage, and metabolism were measured seasonally in the eight streams. The amount of leaf litter falling directly into streams was greatest in agricultural streams and lowest in urban streams. However, lateral input of litter was greatest in urban streams. Retention of organic matter, measured as uptake lengths of fine particles (fluorescently labeled yeast), and standing crop of benthic organic matter was lowest in urban streams. Leaf decomposition rates were highest in urban and agricultural streams and lowest in forested streams. All streams were heterotrophic, and variance in net ecosystem metabolism was best explained by the standing crop of benthic organic matter.

Uptake lengths of nutrients were shortest (200-400 meters) in forested streams and longest (>800 meters) in the urban streams. Uptake is best explained by hydrologic properties of each channel, especially the size of the transient storage zone and its exchange rate. If human activities decrease transient storage zone size, then nutrient uptake length will increase, thus indicating a reduction in the ability of the stream to remove nutrients from the water column.



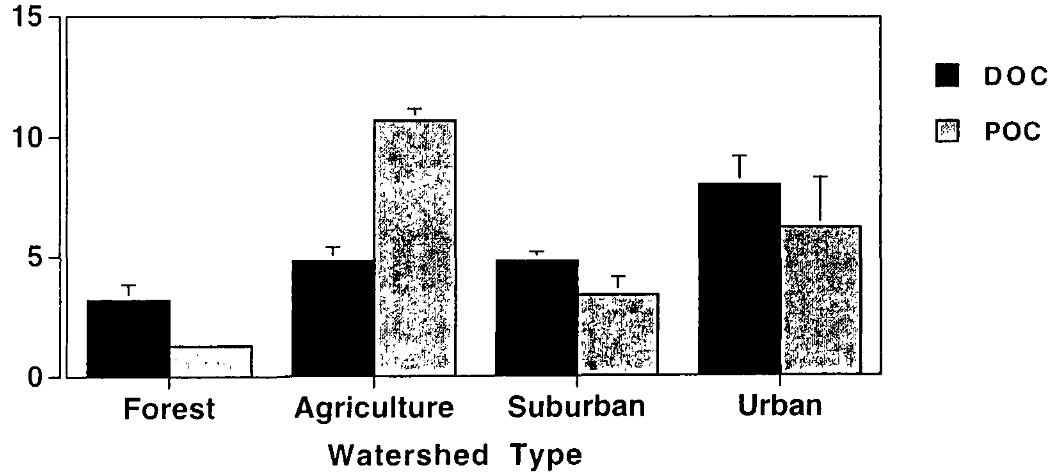


Figure 1. Average daily export of suspended sediment (metric tons km^{-2} d^{-1}), total phosphorus (kg km^{-2} d^{-1}), nitrate and nitrite (kg km^{-2} d^{-1}), dissolved organic carbon (kg km^{-2} d^{-1}), and particulate organic carbon (kg km^{-2} d^{-1}). Values shown are means + standard deviations for the first year of the study.

The Role of Hg (II) Reduction and Chemical Speciation in Controlling the Concentration of Mercury and Its Methylation in Natural Waters

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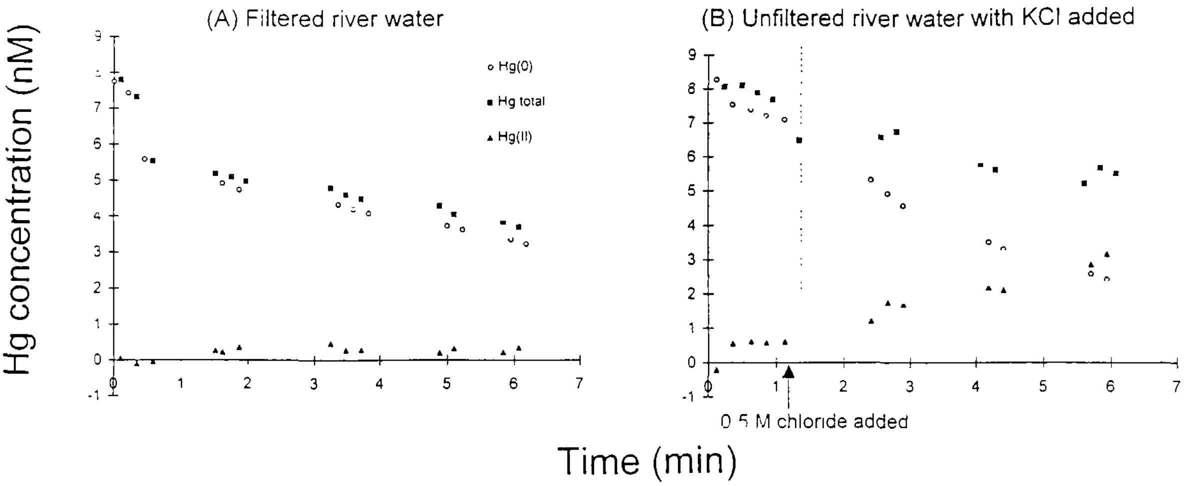

Figure 1. Time series of dissolved gaseous Hg^0, total Hg and Hg(II) concentrations in (A) filtered river water and (B) unfiltered river water with 0.5 M chloride. At the onset, 8.3 nM of Hg^0 was added. Hg(II) was obtained by the difference between Hg^0 and total Hg.

High concentrations of mercury (Hg) that bioaccumulate in fish are a major environmental and human health concern. Research has shown that there is a poor correlation between the extent of Hg contamination and the Hg content of fish in the environment. The objective of this project is to elucidate the conditions and processes that lead to a high rate of formation of methyl mercury, the organic mercuric species that accumulates in the food chain. This project's research, which is based on experimental process studies in the laboratory and in the field, has followed two principal axes: (1) the determination of the chemical conditions that lead to a high rate of bacterial uptake and methylation of Hg; and (2) the quantification of the transformation processes—dissolution, reduction, oxidation—that control the concentration of the various forms of Hg in aquatic systems.

In natural waters, Hg is methylated chiefly by sulfate-reducing bacteria that live in anoxic waters or sediments and respire by reducing sulfate to sulfide. This project has tested the hypothesis that the presence of polysulfides (formed by the reaction of sulfide with elemental sulfur) might enhance the rate of bacterial methylation of Hg via the formation of mercury polysulfide complexes, which would keep the Hg in solution and diffuse rapidly through bacterial membranes. This project found that mercury polysulfide complexes indeed form and enhance the solubility of Hg in sulfidic waters and that the addition of elemental Hg (in the form of polysulfides or particulate sulfur) to cultures of sulfate reducers enhances markedly their rate of Hg methylation. This result is complicated, however, by the changing concentrations of sulfur species in the cultures, and control experiments are under way.

Besides precipitation of mercuric sulfide in sediments, the major pathway of elimination of Hg from aquatic systems is by reduction of ionic Hg to elemental Hg that, as a gas, is then volatilized into the atmosphere. Much attention has been paid to the chemical, photochemical, and microbial processes that reduce ionic Hg, and it has generally been assumed that, once formed, all the elemental Hg eventually escapes to the atmosphere. This study has demonstrated that this is not the case: elemental Hg can be oxidized back to ionic Hg in oxygenated water. This process, which competes with volatilization and decreases the rate of elimination of Hg from aquatic systems, depends both on the chloride concentration in the medium and the presence of appropriate particles. This is illustrated in Figure 1, which depicts oxidation of elemental Hg in unfiltered freshwater after the addition of chloride ions, whereas little oxidation was observed in unsalted filtered freshwater.

These results modify radically our understanding of the processes that control the concentration and the methylation of Hg in aquatic systems. Once confirmed and extended, the results should provide a fundamental understanding of the chemical and biological parameters that determine the extent of bioaccumulation of Hg in various ecosystems.

Formation and Propagation of Large-Scale Sediment Waves in Periodically Disturbed Mountain Watersheds

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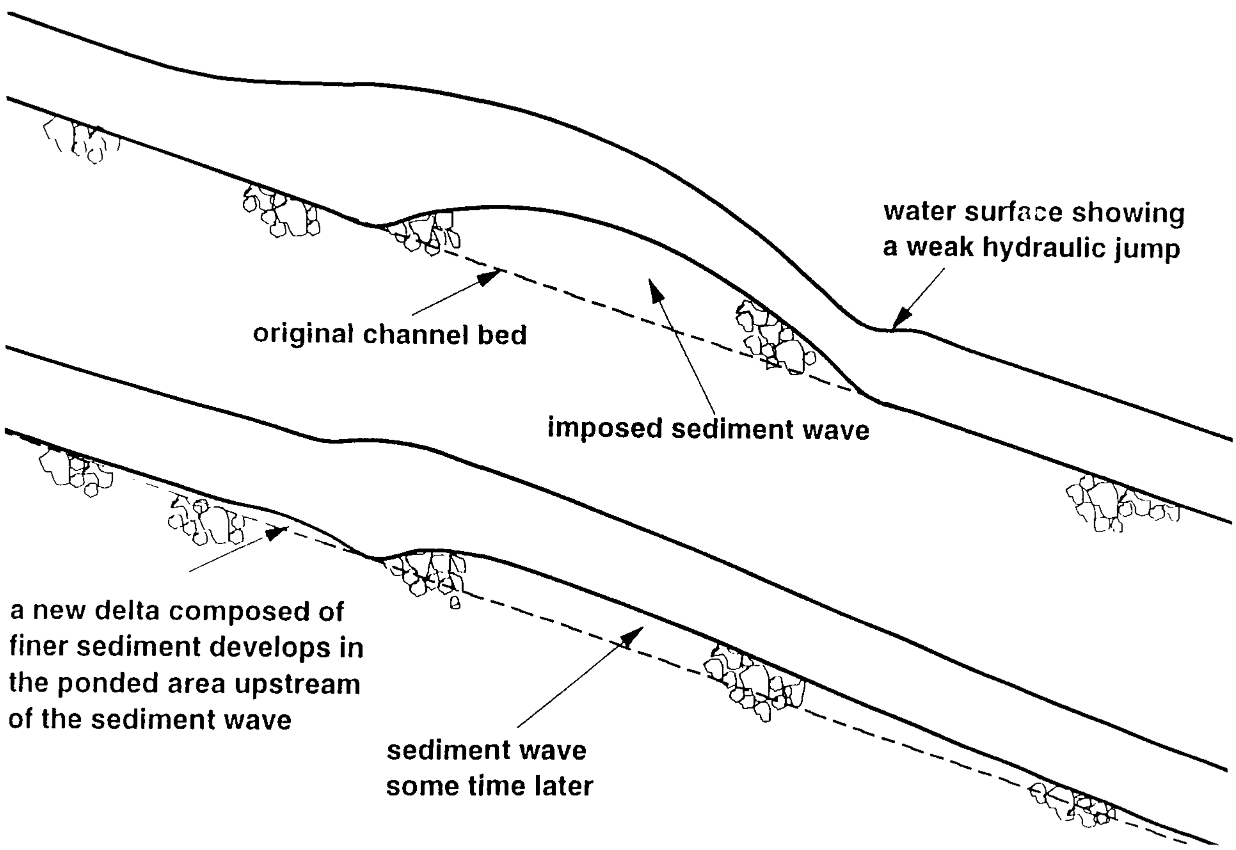

Figure 1. Evolution of a sediment pulse from a sample numerical run.

Human-induced disturbances in watersheds such as mining or timber harvesting, combined with certain hydrologic conditions, often result in the formation of large-scale waves of sediment that are moved (propagated) downstream. These waves have deleterious effects on aquatic and riparian habitat and can result in bridge and pipeline failures at crossings as well as the loss of infrastructure such as roads adjacent to the river.

The goal of this research is to develop a single, global numerical model encompassing backwater effects, abrasion, gravel sorting, transport and deposition of fines, point and distributed sources of water and sediment, and input hydrographs to predict the evolution of sediment waves in rivers. A combination of field work, laboratory experiments, and numerical experiments is employed. The purpose of the field work and laboratory experiments is to provide verification of the numerical model.

A preliminary numerical model has been developed and verified against two small-scale laboratory experiments. The results of a sample run are shown in Figure 1. Also, Figure 1 shows successful modeling of the ponding of water upstream, the formation of a hydraulic jump downstream, the overall upstream propagation of the deposit, and the formation of a new downstream-propagating delta composed of fine sediment at the upstream of the ponded region.

It is easy to suppose that sediment waves in rivers should propagate downstream. However, results from the numerical model reveal that dispersion always dominates the process. That is, the apex of a sediment wave usually does not move too far from its original position. For gravel bed rivers, which usually have steep slopes, the position of the apex is more likely to move upstream than downstream. This finding is important in determining the fate of landslides in rivers.

The next steps of this research include: (1) performing more experiments to verify the findings of the numerical model and (2) fine-tuning the model for an actual river (i.e., Redwood Creek in California). Corresponding field data for this case have been collected. The model will be modified to a user-friendly form so that interested parties can use it as a predictive tool.

Multiscale Statistical Approach to Critical-Area Analysis and Modeling of Watersheds and Landscapes

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Public agencies and corporate landholders are developing and maintaining major environmental databases for computerized mapping and analysis. The cost of such databases increases rapidly with increasing spatial detail. This project undertakes the development of objective and efficient methods for determining patterns of spatial variation from such databases—particularly relating to water resources and landscape ecology—and for making pattern comparisons between databases having different levels of detail. A comparison of patterns emerging from data at different levels of detail will enable managers to select the appropriate spatial resolution necessary for particular purposes. Cost efficiency also will be increased by the ability to indicate likely zones of spatial uncertainty and to detect areas of disagreement between alternate hydrologic models, so that detailed data acquisition can be better targeted and modeling will be more precise. Application of these approaches will provide a better basis for districting watersheds, thereby reducing the cost of monitoring and detecting the need for remediation.

The general nature of the approach to multiscale characterization of landscapes in this project is through analytically induced pattern deterioration. The basic idea is akin to survival of the fittest in natural selection, whereby strong elements persist and weaker ones are progressively vanquished. Although spatial pattern is a complex of properties, one can think in terms of large coherent patches that stand in contrast to their neighbors as being the stronger elements, whereas small internally variable patches having relatively similar neighbors are the weaker ones. As with a large field of contestants in a marathon, the weaker will drop out early while the stronger will withstand considerable stress before being subordinated. Multiscale character is thus reflected in the rate and extent of deterioration for pattern elements under the influence of a progressive degenerative process.

The project considers three kinds of spatial data layers: (1) surface data such as elevations or concentrations; (2) signal data such as remotely sensed reflected energy; and (3) categorical data such as land cover, soil, or geology. Analytical methods appropriate to each kind of data have been conceptualized, and software capability for their application is being developed. Echelon hierarchies of hillforms organized as dendrogram trees apply to surface data, with pruning of the tree being the degenerative process. Patchwork representation by our "PHASE" version of statistical clustering is appropriate for signal data, with information capacity and patch size constraints serving to induce pattern deterioration. Random and modal filters bring about progressive deterioration of spatial pattern in categorical data.

Progressive filtering of categorical data has been studied intensively, and entropy-based measures of patch structure are used to capture the trajectory of pattern deterioration across scales. Transition matrix models have been formulated that exhibit pattern deterioration similar to land cover maps of selected watersheds in Pennsylvania. Model parameters are currently being estimated for 104 major watersheds in Pennsylvania. The fitted transition matrices will be studied for their ability to characterize and differentiate among watersheds.

PHASE formulation not only provides for multiscale exploration of signal data, but also offers an alternative to conventional methods of handling and analyzing digital image data in remote sensing. It compresses multiband image data into a single layer of patch-type identifiers with accompanying table(s) of characteristics for patch types. PHASE compressed image data is a value-added product that is beyond the scope of usual copyrights on image data, thus permitting unlimited distribution (see Figure 1). The compression is sufficient to accommodate 10 scenes of Landsat Thematic Mapper formulations covering Pennsylvania on a single CD-ROM, along with a variety of supplemental vector geographic information systems (GIS) data.

Figure 1. Central Pennsylvania sample PHASE from Landsat Thematic Mapper.

Contemporary Water and Constituent Balances for the Pan-Arctic Drainage System: Continent to Coastal Ocean Fluxes

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Current predictions of global climate change indicate a greater sensitivity in the Arctic than in temperate or tropical regions. During the next century, average temperatures could be warmer by several degrees Celsius, resulting in changes to snow accumulation and melting, depth of soil thaw, and precipitation. Changing plant communities could alter evapotranspiration rates and therefore the water balance across the entire pan-Arctic. These changes, in turn, influence the Arctic Ocean through feedbacks between freshwater discharge, sea ice, and deepwater formation. The primary goal of this research is to provide a quantitative, contemporary estimate of spatially distributed water balance, discharge through rivers, and associated fluxes of constituents from the entire terrestrial drainage system to the Arctic Ocean.

Our approach combines a data-rich geographic information system (GIS) with redundant models applied to establish the pan-Arctic freshwater and material balances. Aerological estimates of water flux conergence and precipitation minus evaporation (P-E) are calculated using rawinsonde (a balloon-borne atmospheric sounding instrument) archives. This has been performed over the Mackenzie, Ob, Yenesei, and Lena drainage basins. In parallel, ongoing development of a permafrost water balance model (P/WBM) has yielded a first set of estimates of water budgets at 0.5 degrees (latitude x longitude) resolution. Freshwater runoff from each of these cells is then cascaded down the river network and discharged into the Arctic Ocean. A database of river discharge gauges (n = 3,500) has been assembled covering land mass contributions from the United States, Canada, and Russia. Additionally, an improved digital stream network has been established to provide the best possible routing of water and constituents downstream to the Arctic Ocean. About 555 gauges from large catchments, greater than 15,000 km^2, were used to validate the network. Figure 1 shows the improvement in the comparison of observed and simulated drainage areas using these gauges. The new discharge data set from the large basins represents an increase of data resolution by an order of magnitude over previous data sets (from 89 to 646 gauges).

Successful simulations using P/WBM were carried out for Imnavait Creek, Alaska. Upscaling of the model is currently taking place with applications to Boreal zone catchments and the entire pan-Arctic region. Preliminary simulations have taken place that span the full 30-year timeframe for this project (1960-1990). High year-to-year variability in many locations potentially masks any progressive climate change.

Preliminary results from rawinsonde data (1974-1992) show high interregional variability in P-E for the Eurasian watersheds. This variability is driven by an occasional large summer negative flux convergence with southerly outflow of water vapor from the basins. In some years, this negative flux is large enough to cause annual P-E to turn negative. Winter balances appear to be realistic. The summer problem appears to stem from the inability of the rawinsonde network to "capture" the high topography at the watershed divides, an effect that is currently being remedied.

Simulations using P/WBM over the entire pan-Arctic region show large errors when compared with observed river discharge records. A significant source of this error is in precipitation, particularly over mountainous regions due to: (1) bias in the locations of the precipitation gauges (typically at low elevations) and (2) the sparse network of meteorological stations in the northern regions giving interpolated fields a high level of uncertainty. Modifications to these interpolated fields are under way and combine existing elevation and rawinsonde data to improve temperature and precipitation estimates.

There continues to be a need to better identify the sources of error in the components of the pan-Arctic water balance. This issue will be pursued in the context of looking at the consistency between rainsonde, water balance model results, and discharge station records.

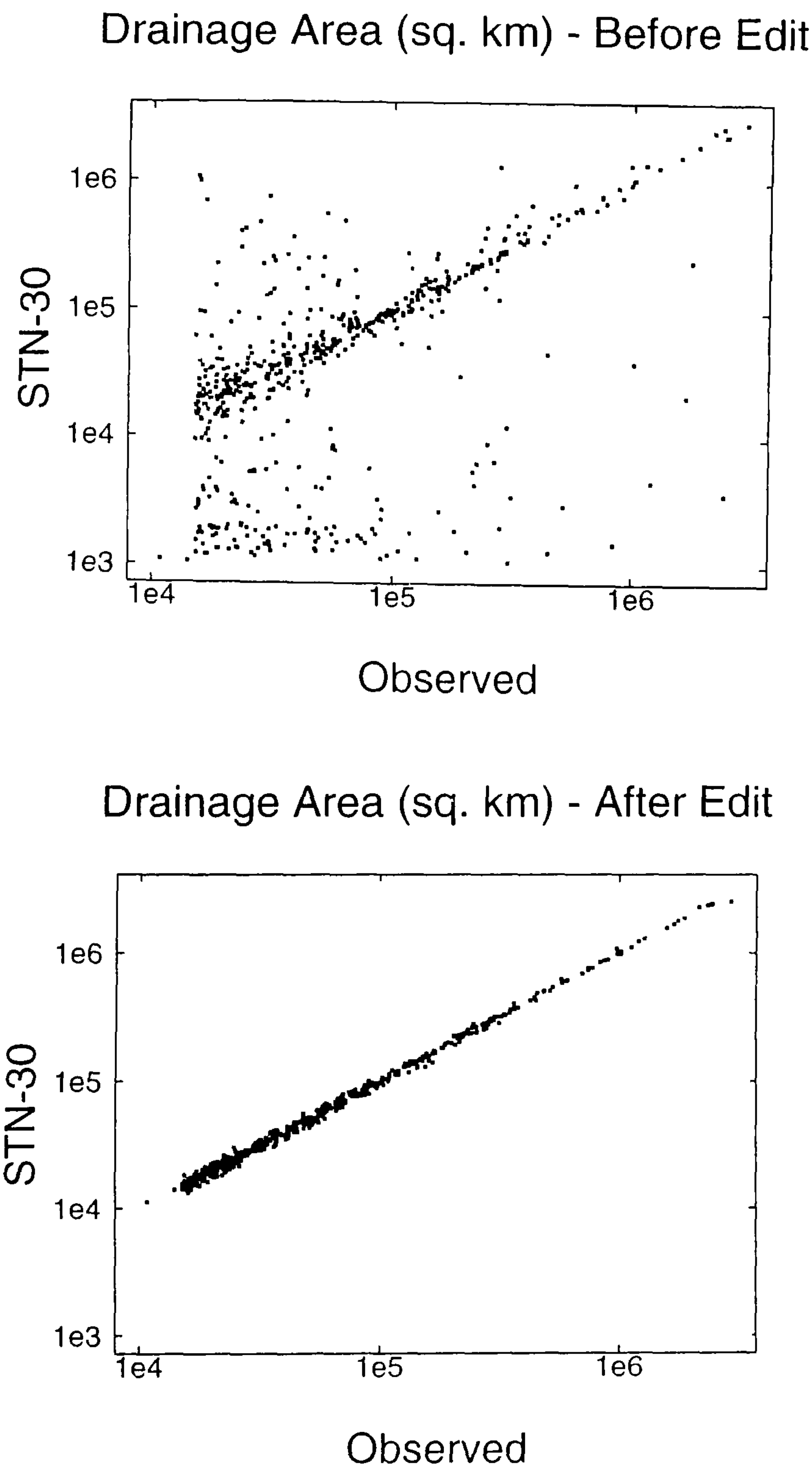

Figure 1. Contemporary water and constituent balances for the pan-Arctic drainage system.

Modeling Temporal Rainfall via a Fractal Geometric Approach

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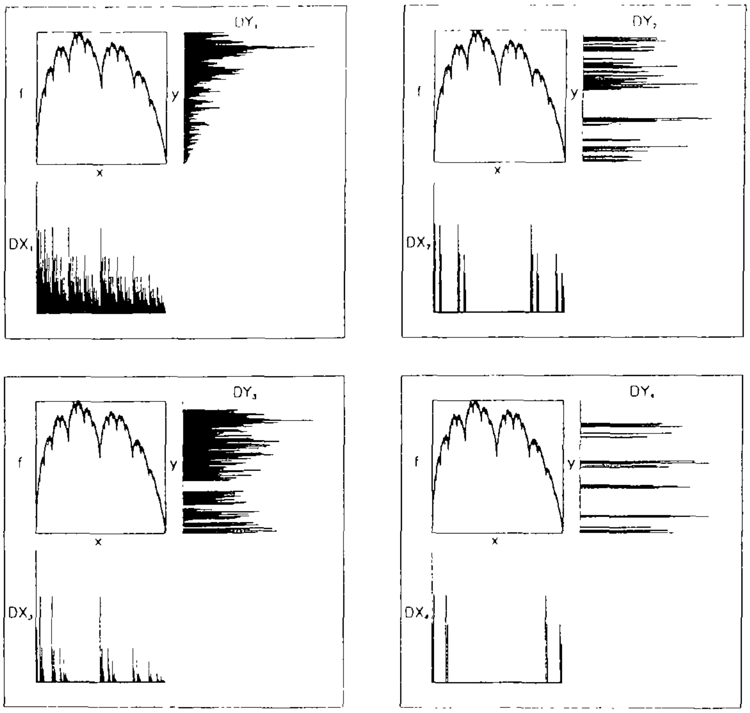

Figure 1. Alternative derived measures *(DY's)* arising from the same fractal interpolating function *f* using alternative parent multifractal measures *(DX's)*.

Accurate rainfall modeling is of vital importance for the proper management of our environment. Rainfall descriptions are required, among others, to model pollution migration, address issues related to climate change (i.e., global circulation), estimate extreme weather events, and manage our watersheds. Although several sophisticated (stochastic) rainfall models exist, they do not capture the variability observed at a fixed location when a storm passes by. They approximate the irregular and intermittent rain patterns by superimposing, for example, randomly arriving rectangular pulses and consequently preserve only some statistical features of the rainfall series (e.g., mean, variance, correlations, etc.). Because these representations are typically limited by their analytical tractability and because there has been a recognition of chaotic and multifractal effects in rainfall, a new class of rainfall models has been developed by our group. The basis for these new models is the belief that predictability could only be improved when the overall trends and observed details present in rainfall events are considered explicitly.

The goal of this project is to develop a better understanding of temporal and spatial rainfall patterns within the State of California under alternative climatic conditions. Parsimonious representations of rainfall records under alternative climatic conditions will be derived so that a classification of observed rainfall patterns may be elucidated. This task will be accomplished by employing the fractal-multifractal representation to encode rainfall records throughout the State of California as suitable fractal transformations of appropriate (turbulence-related) multifractal measures. Once the time series is represented by this approach, a classification of rainfall events will be attempted via surrogate parameters that define the fractal transformation and the multifractal measure. This research should lay a firm foundation for a new approach towards hydrologic dynamics in terms of surrogate geometric information. This methodology should be viable because it concentrates on capturing what is observed (i.e., the geometry of rainfall series).

During this year, studying the nature of the derived measures that are generated via the fractal--multifractal representation has continued under a variety of alternative scenarios. Simple modifications to the original procedure could be made so that data may be generated, similarly to data obtained in rainfall records, transforming a variety of Cantorian measures (measures with holes) via the same fractal interpolating function. The existence of these extensions is most welcome because they are quite parsimonious, requiring only five surrogate parameters. Such extensions are being employed to encode actual data sets in California, solving an inverse optimization problem via genetic algorithms that minimizes squared differences of real and predicted records. A study of the encodings obtained and their relationship to climatic conditions will be performed during the next year.

Effects of Food Web Structure and Nutrient Loading on Lake Productivity and Gas Exchange With the Atmosphere

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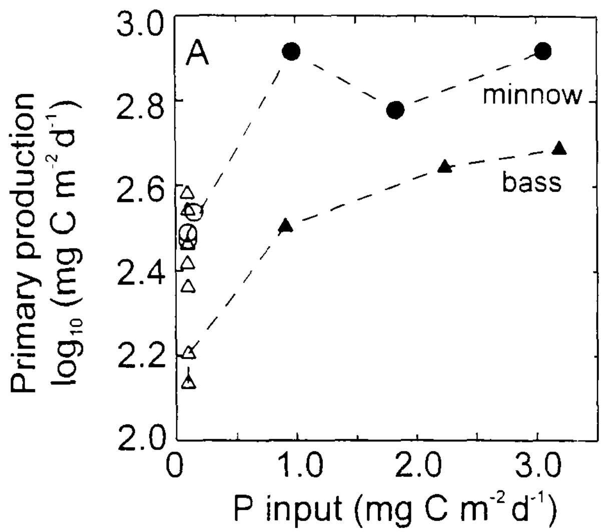

Figure 1a. Effect of P input rate on primary production in four lakes with contrasting food web structures. Each symbol represents a summer mean for 1 lake year combination from 1991 to 1995. Lakes characterized by high planktivory and low-grazing rates are shown by circles. Triangles represent lakes with piscivores and high-grazing rates. Lakes that were experimentally fertilized are denoted by filled symbols: gray symbols are lake years before enrichment; black symbols are during enrichment.

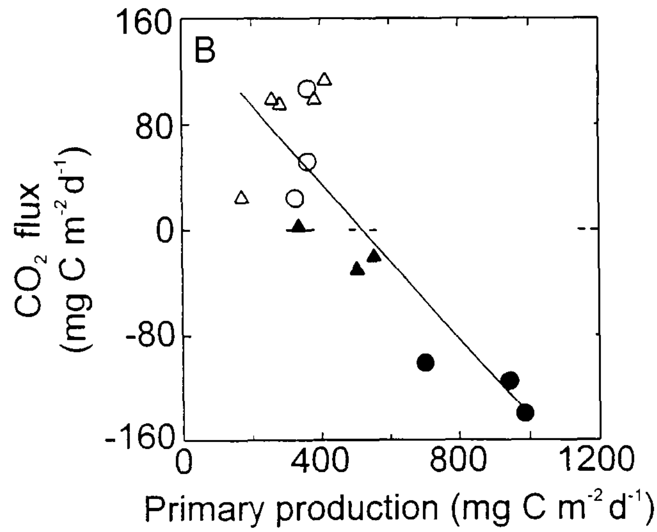

Figure 1b. Relation between calculated carbon dioxide flux between lakes and the atmosphere and the estimated primary production rate in 1992-1995 (correlation -0.84). Positive values of carbon dioxide flux represent net flow out of lakes, and negative values represent flow into lakes. The dashed line represents conditions in equilibrium with the atmosphere. Symbols are as described for (1a).

When lakes are viewed in a landscape perspective, lake ecosystem dynamics are viewed as the outcome of interactions between drivers at the landscape scale (e.g., water, nutrients, and organic carbon) and internal processes (e.g., nutrient cycling and food web interactions). In this project, whole-lake experiments were performed to evaluate the interactions between food web structure and nutrient loading in controlling primary productivity of lakes. Food webs were manipulated by changing the dominant fish species, which resulted in a restructuring of the zooplankton grazer communities. Lakes with piscivorous fishes (bass) have large-bodied zooplankton that are very effective algae grazers. Lakes with planktivorous fishes (minnows) have small-bodied zooplankton that are much less effective at suppressing algae growth. Experimental additions of inorganic nitrogen and phosphorus resulted in substantial increases in algae growth (primary production) in all lakes. However, primary production in lakes with piscivorous fishes was much less responsive to nutrient addition than in lakes with planktivorous fishes. This effect of food web structure on primary production was sustained over phosphorus loading rates that ranged from less than 0.2 mg P/m^2/d to greater than 3 mg P/m^2/d (see Figure 1a).

Food web effects on primary productivity also had implications for carbon dioxide exchange between lakes and the atmosphere. Prior to nutrient enrichment, all study lakes were net sources of carbon dioxide to the atmosphere. Nutrient enrichment increased algae demand for carbon dioxide, causing lakes to become net sinks for atmospheric carbon. At identical nutrient loading, atmospheric carbon invasion was greater in a lake with planktivorous fishes and low grazing than in a lake with piscivorous fishes and high grazing (see Figure 1b). Carbon stable-isotope distributions corroborated the drawdown of lake carbon dioxide and traced atmospheric carbon transfer from algae to top predators. Thus, top predators altered ecosystem carbon fixation and linkages to the atmosphere. Our study reinforces the idea that exploitation of top predators and the introduction of exotic species that cause changes in trophic structure are an aspect of environmental change that have important implications for structure and function of ecosystems.

A Comparative Institutional Analysis of Conjunctive Management Practices Among Three Southwestern States

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Among the more popular contemporary recommendations for improved watershed use and protection is conjunctive use of surface and underground water resources. Conjunctive use involves the coordination of surface water supplies and storage with groundwater supplies and storage for purposes of sustainable watershed use and enhanced watershed protection. Conjunctive use in a watershed requires a great deal of joint effort among human beings, the prospects for which will be affected strongly, though not exclusively, by institutional arrangements that define organizational forms and jurisdictions and provide incentives and disincentives to individuals. Using a comparison of Arizona, Colorado, and California, this project seeks to advance the theoretical and empirical understanding of the relationships between institutional arrangements governing the allocation, use, and protection of water resources and the development, implementation, and performance of conjunctive use programs.

The approach taken in this project is one of institutional analysis. Institutional analysis is based on in-depth comparative analyses of the performance of diverse institutional arrangements. The technique of institutional analysis was developed during the last quarter-century at Indiana University, primarily by Elinor and Vincent Ostrom and colleagues at the Workshop in Political Theory and Policy Analysis (a complete description of the approach is available in E. Ostrom, 1990). In essence, institutional analysis involves: (1) the use of a systematic framework for classifying institutional arrangements (conceived as sets of rules) and levels of action; (2) viewing the development of institutional arrangements as processes of intentional (individual or collective) human choice and action constrained by physical circumstances and community context, recognizing that human beings are capable of multiple levels of action (e.g., as rule makers and rule followers, as organization designers as well as organization members); and (3) assessing the effects of institutional arrangements on human choice and action as well as evaluating the effects and effectiveness of institutional arrangements relative to their intentions.

Given a well-developed and systematic framework, institutional analysis allows for comparisons across situations on a variety of dimensions. For instance, community characteristics and physical settings may be held constant, while rules are varied, permitting an understanding of how different configurations of rules promote various outcomes.

Although Arizona, California, and Colorado face similar physical problems of water distribution in the same geographic region, the three states have devised markedly different approaches to conjunctive water management. Arizona has taken a more state-centered approach. The primary entities engaged in conjunctive water management are the Central Arizona Water Conservation District (CAWCD), the operator of the Central Arizona Project, and the Arizona Water Banking Authority (AWBA). By far, the dominant conjunctive water management approach is the exchange of surface water for groundwater credits, or in lieu recharge. CAWCD makes available to CAP water for agriculture in exchange for agriculture groundwater. CAWCD uses the groundwater for drought protection and to enhance the reliability of the CAP. If a pumping station or a portion of the canal becomes inoperable, CAWCD can deliver groundwater to its customers. Although California uses conjunctive water management primarily as insurance against water shortages, it is primarily local level jurisdictions, and not state entities, that engage in it. The dominant conjunctive water management approach is constructed recharge projects whereby surface water is stored underground through injection wells and spreading basins. Due to recent changes in state law, in lieu recharge is beginning to be used in California. Like California, Colorado's conjunctive management activities occur primarily among local level jurisdictions. Unlike both Arizona and California, however, conjunctive water management is used primarily to protect the rights of senior surface water users under the state's prior appropriation doctrine, and not for drought protection. Colorado jurisdictions use a combination of in lieu recharge and constructed recharge projects.

Institutional arrangements govern the type, development, and uses of conjunctive water management projects. Data collection for this project is in its preliminary stages. As further data are collected, issues of institutional performance, the allocation of costs and benefits, and the environmental impacts of conjunctive water management projects will be explored.

Water and Sustainable Development in the Binational Lower Rio Grande/Rio Bravo Basin

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In its 1994 Regional Assessment of Water Quality in the Rio Grande Basin, the Texas Natural Resource Conservation Commission made two recommendations for further research and policy development: (1) an improved understanding of water issues as they relate to the binational border dynamic and (2) development of lasting links across the U.S.-Mexico border. The goals of this project are to: develop reliable watershed-based data sets from both Mexican and U.S. sources to analyze the whole binational region; analyze water resource issues as critical factors in the region's long-run planning and sustainable development; and engage researchers, policymakers, and the civic community to help answer the question, "What actions can be taken to achieve sustainable development in this rapidly growing, drought-prone, environmentally fragile watershed?"

Mexican and U.S. researchers are paired in teams to perform data compilation and analysis in the following areas: (1) water supply and demand, (2) water quality, (3) population and socioeconomic conditions, (4) ecology, (5) water management and institutions, and (6) geographic information systems (GIS). The teams produce an integrated "baseline report" of current conditions in the region, which then provides the basis for subsequent analysis of alternative future scenarios. Scenarios are developed by combining regional demographic projections to the year 2030 with alternatives for future water availability, irrigation technologies, and management practices.

Involvement of the community is a key element of the project, and mechanisms for stakeholder input and consultation are incorporated into the research process. Researchers and graduate students from Mexico and the United States (as part of a joint University of Texas-ITESM Policy Research Project) have conducted a survey among stakeholders and community leaders. In addition, workshops are scheduled involving researchers and stakeholders from both sides of the border. These outreach components gather insights into the community's concerns, perceived threats, and opportunities related to water and development in the watershed.

The preliminary findings of the study include the following: (1) The population will double by the year 2030, while surface water supply will stay at current levels or decrease. (2) The single source of surface water for 2 million people and intensive irrigated agriculture in the Lower Rio Grande—the combined Amistad-Falcon international reservoir system—is at its lowest level since coming online 25 years ago. (3) The current drought in the upstream parts of the watershed began in 1994 and continues unabated. Mexican farmers lost two harvests, and several irrigation districts in Texas went dry in 1996. (4) The adequacy of the existing water supply system under drought conditions is being tested for the first time. During the drought of record in the 1950's, only 500,000 people lived in the same area where 2 million live today. Amistad reservoir did not yet exist, and Falcon reservoir came on line in the middle of the drought. (5) Significant changes in fauna appear to be correlated with decreasing streamflows, the proliferation of exotic species, and chemical pollution. (6) GIS analysis indicates that irrigated land area in the basin is significantly larger than official records indicate. (7) Rapid growth and development in the San Juan and Conchos River basins in Mexico could significantly reduce the amount of water these tributaries contribute to the main stem of the Lower Rio Grande/Bravo. (8) Initial runs of the agricultural model suggest that significant long-term reductions in water supply would at most have a very small impact on the regional economy because new irrigation technology and cropping patterns would be adopted. (9) Transfers of agricultural water to municipal use occur in Texas through the use of water markets and joint infrastructure improvements on the part of cities and irrigation districts.

The significance of these findings is that the system is flexible—small increases in irrigation efficiency can release significant amounts of water for other uses. In addition, a tremendous opportunity exists for "win-win" arrangements in which municipal water suppliers agree to finance improvement in irrigation efficiency in return for the rights to the water saved. Furthermore, the existing regional water market holds great potential for more efficient use of water.

The research teams plan to meet in January 1998 to discuss the scenario analysis portion of this project. A community workshop involving researchers and stakeholders is scheduled for May 1998, and the integration of scenario analysis is planned for spring 1998.

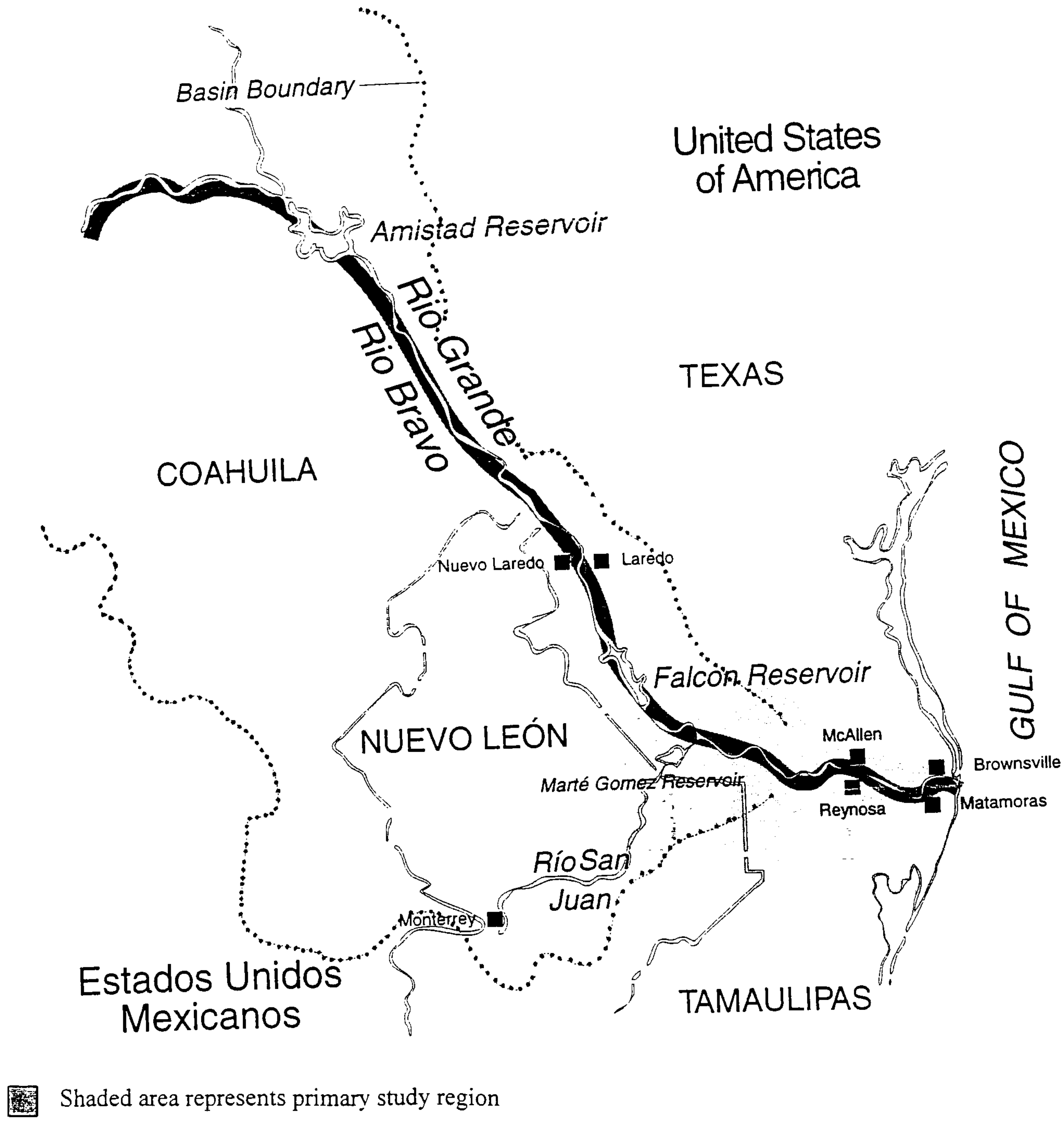

Figure 1. Lower Rio Grande/Rio Bravo Basin.

Environmental Change and Adaptive Resource Markets: Computer-Assisted Markets for Resource Allocation

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Water delivery systems have traditionally been operated by large centralized authorities due to the natural monopoly nature of the industry and the quasi-public good nature of a reliable and clean water supply. In most countries, the era of meeting new demands by increased supply development has been terminated by economic and environmental costs, environmental change, and the shortage of suitable sites. Like the energy and natural gas industries, the water supply industry will have to look to market mechanisms to reallocate existing water supplies and increase efficiency to meet future demands.

This project's goal is to develop a formal mechanism for evaluating alternative market structures for integrated water systems. This goal will be achieved by the following objectives: (1) developing a structural market model for the California water industry, (2) deriving value and cost functions for the different components in the structural model, (3) developing an experimental design that uses the water market model, (4) running experiments on alternative market options using economically motivated subjects in a replicable design, and (5) developing a remote (Internet) experimental ability that allows extension of the market experiments to market participants in the field.

A prototype of a smart water market for the central California water industry has been designed and tested at the Economic Science Laboratory in Tucson, Arizona. The input needed for the player at each node is in the form of a step function representing their willingness to pay for different quantities and qualities of water. Experiments on market price convergence and market efficiency were conducted using students whose earnings were based on their market success. Players represented agricultural, urban and environmental interests, and were given initial endowments of money and water rights reflecting the current allocation in the state. After initial training, the experiments were run for 15 trading periods in four experimental sessions. Student participants were paid between $2 and $70 as a result of their trading actions.

The first set of experiments with the simplified model obtained realistic results. A "smart" computer-assisted market with a double-blind auction structure was used. Under this structure, buyers and sellers do not have to reveal their true valuation for the goods to achieve an outcome that is close to the theoretical optimum under perfect competition. However, the relative share of their defined supply or demand schedule that the players were able to realize differed significantly among players and groups. Alternative allocations of water transport facilities made a significant difference in the outcome between players. The outcomes of the initial experiments shows that it is possible to reproduce price efficiency and convergence results in natural resource markets. The results were obtained using players that included both users and an environmental agent, who was only interested in the level of flows through a certain sensitive node. The initial results show that the novel concept of market interactions between resource users and environmental interests can be modeled in a replicable manner using this approach.

The next steps are: (1) extending the model to a larger number of participants in each sector of the water economy; (2) incorporating a water quality component into the supplies, demands, and the smart market software; (3) developing Windows NT-based Internet software to enable use by outside participants in the experiments; and (4) extending the smart market analysis to water allocation problems in a developing country. Through step (3), the performance of participants who are actually working in the industry can be compared with the student-based results. This latter work will have benefits as a validation of the formal results from student-based experiments and also will make the smart market a practical tool for developing market skills by members of the industry.

Detecting Fecal Contamination and Its Sources in Water and Watersheds

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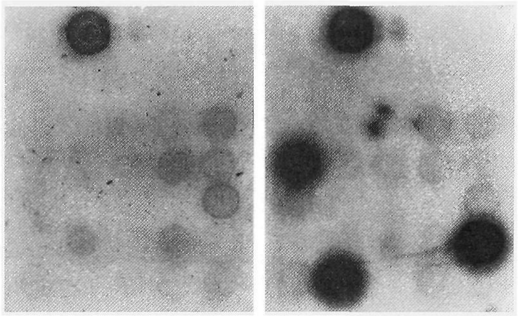

MS2	GA	Qβ	FI	SP
SW1	SW2	SW3	SW4	SW5
SW6	SW7	SW8	SW9	SW10
SW11	SW12	SW13	SW14	SW15
SW16	SW17	SW18	SW19	SW20
SW21	SW22	SW23	SW24	SW25
SW26	SW27	SW28	SW29	SW30

Probe II_A Probe II_B

Figure 1. Lysis zone hybridization for identification of 30 F^+ RNA coliphage isolates from surface water by oligoprobes II_A and II_B. Positive controls consisting of 5 prototype F^+ RNA coliphages (MS2, GA, Qβ, FI and SP) are shown on the top. Thirty field isolates (SW1-SW30) are arranged on the key.

Current methods to detect, quantify, and predict water and watershed quality with respect to fecal contamination are inadequate and unreliable. Because so little is actually known about the levels and sources of fecal contamination in water, there are great uncertainties about the human and environmental health risks from the pathogens associated with contaminated water. The objectives of this research are to further develop, evaluate, and apply new and improved measures of human and animal sources of fecal contamination in water and watersheds. Two main criteria will be used to judge the value and reliability of the candidate indicators: (1) their ability to predict the presence and concentrations of the pathogens relative to the sources of the organisms and (2) their ability to predict the presence, persistence, transport, and fate of the pathogens in response to natural environmental processes.

The investigators have developed reliable methods for the simultaneous concentration of viruses, bacteria, and protozoans from water using disposable, hollow fiber ultrafilters. Recoveries of seeded organisms from surface water are 50-75 percent and the coefficients of variation (CVs) were relatively small.

The new methods previously developed to concentrate human gastroenteritis viruses from water were field tested on a groundwater supply of drinking water that was implicated in an outbreak of viral gastroenteritis. The virus isolated from the water was genetically identical to the virus independently isolated from stool specimens of ill persons by another laboratory. This is the first time such a virus was successfully recovered and detected in an incriminated water supply, and the work was recently published (Bellar et al., *JAMA* 278(7):563-568).

New and improved methods to detect indicator viruses known as coliphages using "gene probes" were improved and field tested (see Figure 1). Also, the researchers found that it was possible to distinguish fecal from nonfecal indicator viruses in water on the basis of bacterial host range and growth temperature. Coliphages of fecal origin grow well at temperatures of 42-45° C, and they have a narrow host range. Coliphages of possible nonfecal, environmental origin will grow well at temperatures of 37° C or lower and not at 42-45° C. Some of these environmental coliphages have a wider host range and will grow on some other bacteria. In field samples of surface waters impacted by known sources of human and animal fecal contamination, levels of various fecal indicator organisms generally increased when fecal waste sources were nearby. Even in areas where animal wastes were managed by land application, adjacent surface waters showed evidence of fecal contamination. Levels of indicators were 10-1,000 times higher than background levels.

Coliphages in the water of stations near animal waste sources were primarily animal groups, and coliphages in the water of stations impacted by municipal wastewater discharges or nonpoint source human wastes were primarily human groups. At stations where both sources were impacting water quality, both groups were detected. These results indicate that sources of fecal contamination can be reliably identified and traced by identifying and grouping the coliphages that are detected using gene probes.

Studies on detecting and quantifying microbial pathogens and indicators of fecal contamination in waters and watersheds impacted by human and animal fecal contamination will be continued in the watersheds now being monitored. An additional watershed will be added during the next 12-month period. Also, the newly developed methods to detect human pathogens of fecal origin will be applied to these waters to determine if the known human and animal waste sources are important contributors of these protozoan and bacterial pathogens. The reliability of the various microbial indicators in predicting the presence and concentrations of these pathogens also will be examined.

Ecoregion-Specific Comparison of Stream Community Responses to Nutrient Gradients Using Both Survey and Experimental Approaches

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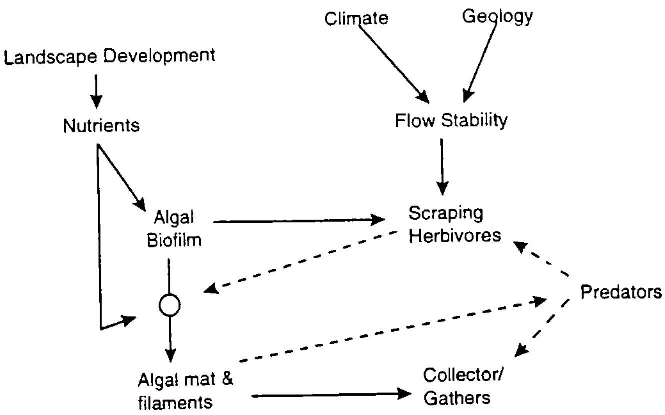

Figure 1. Positive and negative effects on invertebrates in streams. Nutrient effects on algae and invertebrates in streams are highly dependent upon climate, geology, and flow stability of streams. Nutrients stimulate growth rates of algae. If unregulated by grazers, nutrients stimulate the change of algae from thin mats to thick mats and filaments. High flow stability allows invertebrate densities to increase and regulate accumulation of algal mats and some filamentous algae. Low flow stability, either from scouring spates or drought, constrain invertebrate densities so that algae can easily overgrow substrata when nutrients are abundant. When these algae overgrow substrata, changes in invertebrate communities due to the positive effect of the abundant algae on some invertebrates are observed. Little evidence has been found that overgrowths of algae have negative effects on invertebrates in streams (solid lines indicate positive effects; dashed lines indicate negative effects).

Most evidence that exists for regulatory purposes comes from toxicological studies, which are often conducted in laboratory experiments. This project is aimed at providing a credible scientific basis for setting regulatory criteria relating to changes in stream ecosystems along an environmental gradient.

Nutrient loading commonly causes an increase in primary productivity and a replacement of clean-water ecosystem algal-invertebrate communities with a new suite of organisms that results in very different stream structure and function. Quantitatively assessing the relationships between nutrient concentrations and algal-invertebrate communities in streams has been challenging because stream ecosystems are so physically variable and biologically dynamic. This project is designed to develop a better predictive understanding of nutrient effects on stream communities in ecoregions with different hydrological stability. In this project, the investigators are using stream surveys with large within-ecoregion sample sizes, experiments, and analyses of large preexisting databases.

Initial results indicate that chances for high accrual of algae with increasing nutrients is greater in the hydrologically variable streams of Kentucky than in the stable streams of Michigan. Invertebrate abundances, much lower in Kentucky than in Michigan, do not respond to nutrients in Kentucky but do show a positive response to nutrients in Michigan.

Three groups of experiments were conducted during the summer of 1997 to complement previous work. In one experiment, the hypothesis that thresholds in nutrients occur where algae can grow faster than grazers can consume them was tested in experimental streams with 96 experimental reaches. Eight different nutrient concentrations, 2 different grazer treatments, and 6 replicates of each treatment were manipulated in the 96 reaches. In a second experiment, nitrate and phosphate concentrations were varied in 72 different experimental streams to determine the thresholds in nutrient concentrations that saturate algal growth rates when biomass is low and the concentrations that cause peak algal accrual on substrata (nuisance algal growths). Nine different nutrient levels of nitrate and phosphate were used with 4 replicates of each treatment. The third set of experiments assessed the relationship between invertebrates and changing habitat conditions when algae accumulate. Preliminary results indicated overgrowths of streams by long, filamentous green algae (*Cladophora)* can have a positive effect on some stream invertebrates, particularly hydropsychid caddisflies. These experiments showed that these invertebrates prefer rocks with *Cladophora* as compared to bare rocks, and stoneflies preyed more successfully on these caddisflies on bare rocks than on rocks covered with *Cladophora*.

Future work will develop stronger quantitative predictions of the effects of specific concentrations of nutrients on algae and invertebrates in streams in different ecoregions. This will be accomplished by evaluating data from 2 years of algae and invertebrate data from 130 streams in Kentucky and Michigan and from two sets of experiments in which nutrient concentrations were manipulated. In addition, relations between indices of biotic integrity, indices of environmental stressors, and nutrient concentrations will be assessed with data from the 130 streams that were in the study.

Holocene Floodplain Development as a Function of Climate Change and Human Activities: The Arroux and Loire Rivers, Burgundy, France

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Holocene age floodplains of the Arroux and Loire Rivers contain a regionally extensive record of fluvial activity, which can be interpreted within established archaeological, paleoenvironmental, and historically documented climatological frameworks. River morphology and associated deposits record the magnitude and frequency of floods, associated with climate regimes driven by global atmospheric circulation. The reconstruction of past fluvial activity and correlated discharge regimes facilitates the prediction of fluvial adjustments to climatic and anthropogenic changes expected in the near future.

The southern Burgundy region of France is situated at the boundary between maritime, continental, and Mediterranean climates. During the period of historical monitoring, the position and dominance of these climatic regimes has shifted as a function of changes in atmospheric circulation. Discharge regimes have fluctuated as well, but details differ regionally due to geologic and antecedent conditions, and the latitudinal position and style of storm tracks. Historic analog models suggest that the dominance and persistence of a particular climate regime should result in regionally circumscribed, but isochronous alluvial fills containing differing styles of floodplain construction. For example, the Little Ice Age in Europe (ca.1300-1850 A.D.) was marked by episodic cooling, resulting in large floods and flood variability between basins, while Medieval times (ca.700-1300 A.D.) were marked by warmer conditions, and more steady flood regimes, although the magnitude of floods varied between western and eastern drainage basins.

Throughout Europe, enhanced fluvial activity occurred during the period 1250 to 1550 A.D., especially during transitions from dominantly cold subperiods to warmer conditions. The Loire and Arroux valleys follow the same regional trend, with predominantly overbank deposition of sands and silts during the Neoglacial period, which resulted in straightened, chute-cut-off channel patterns and the burial of older alluvial surfaces. This style of fluvial activity began ca. 1050 B.C., contrasting sharply with earlier gravelly, laterally accreting, meandering rivers characteristic of the mid-Holocene. This morphological and sedimentological change predates significant human impacts on the landscape, is regional in extent, and when combined with proxy evidence supports the notion that climate change has been the dominant mechanism in driving fluvial adjustments.

The separation of climatic from human influences on the response of rivers is often difficult to determine, but there is increasing recognition that at regional scales, climate has been the dominant mechanism for changes in fluvial dynamics. Human activities have conditioned these responses locally, and at regional scales have served to amplify existing climatic influences. In southern Burgundy, Roman land use practices were introduced ca. 50 B.C., and noticeable human impacts in upper portions of the Loire basin occurred even later. Roman and Medieval land use practices may have increased the overall thickness of overbank deposits but were most likely not responsible for the overbank discharges permitting such deposition at regional scales.

Land use changes in this rural region have changed little over the last several hundred years, and if we can use the past response of the Loire and Arroux Rivers as analogs to what may happen to this region with future climatic change, we may expect that with decreased temperatures and increasingly meridional circulation, variability in flood frequency will increase, resulting in flood-prone valley bottoms. Moderate increases in temperature and increased zonal circulation may produce less variable discharge regimes, but more regular inundation of lower floodplain positions.

Response and Compensation to a Bivalve Invasion by an Aquatic Ecosystem

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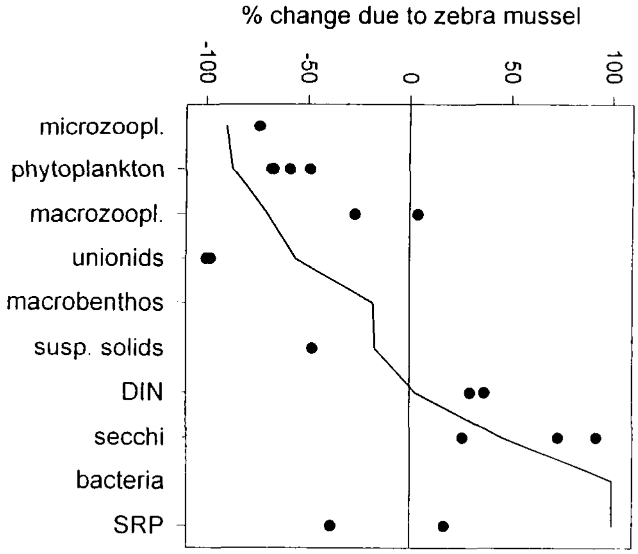

Figure 1. Variation in the response of North American freshwater ecosystems to the zebra mussel invasion. All ecosystems have estimated zebra mussel filtration rates of 70-125 percent of the water column per day. The solid line shows the response of the Hudson River, while the points show responses from Lake Erie, Lake St. Clair, Saginaw Bay, and Oneida Lake (from data of Holland [1993], Fahnenstiel et al. [1995], Fanslow et al. [1995], Holland et al. [1995], Johengen et al. [1995], MacIsaac et al. [1995], Mellina et al. [1995], and Horgan [1996]). DIN=dissolved inorganic nitrogen; SRP=soluble reactive phosphorus.

Bivalves are so abundant in many shallow aquatic ecosystems that their filter-feeding regulates pelagic and benthic variables. Humans cause sudden changes in bivalve populations through the introduction of alien species, water pollution, and overharvesting, which may have large effects throughout the ecosystem. The investigators postulate that the response of an ecosystem to changes in bivalve populations will depend on the characteristics of the ecosystem as well as on the numbers and biological characteristics of the bivalve. Thus, two ecosystems might respond very differently to the same bivalve population. Specifically, the project hypothesis is that the ecosystem response will depend on some characteristics that are fixed (e.g., morphometry, hydrology) as well as flexible compensatory pathways (e.g., functional substitution of species, environmental feedbacks, and induced defenses).

The investigators have been looking at ecosystem responses to bivalve populations by studying the response of the Hudson River to the ongoing zebra mussel invasion and comparing its response to that of other ecosystems, where large bivalve populations appeared or disappeared. This project combines long-term field studies, models, small-scale experiments, and cross-system comparisons. Zebra mussels first appeared in the Hudson in 1991 and became the dominant consumer in the ecosystem by the end of 1992. Estimated clearance times for the entire volume of water in the freshwater tidal Hudson River have been in the range of 1-4 days. Consequently, large changes have emerged through the ecosystem. Densities of phytoplankton and small zooplankton, which are consumed by zebra mussels, fell by 80-90 percent, and the composition of the remaining phytoplankton shifted markedly from preinvasion communities. Populations of native bivalves fell by 50-70 percent in response to the loss of their phytoplankton food. Bacterial densities doubled, perhaps because of losses of small zooplankton that feed on bacteria. Water clarity and dissolved reactive phosphorus both rose as phytoplankton densities fell. The density and extent of rooted plant beds may have increased as the Hudson's water cleared. Densities of other sediment-dwelling animals fell in deep waters but rose in shallow waters, probably in response to changing patterns of primary production.

Generally, other systems exposed to bivalve grazers show qualitatively similar responses to the Hudson, but with very large quantitative differences across systems (see Figure 1). These differences probably reflect the extent to which ecosystem characteristics constrain the strength of the interaction pathways that connect the bivalve with the rest of the ecosystem. Specifically, cross-system comparisons support the idea that ecosystem responses depend on vertical mixing of the water column; the size, structure, and specific composition of the plankton; the nature of factors that otherwise limit growth rates of plankton (i.e., nutrients, light, advection, etc.); the diet breadth of consumers; the magnitude of allochthonous inputs that can substitute as food for phytoplankton; inputs of physical energy to the system; and system morphometry.

Scaling Up Spatially Distributed Hydrologic Models of Semi-Arid Watersheds

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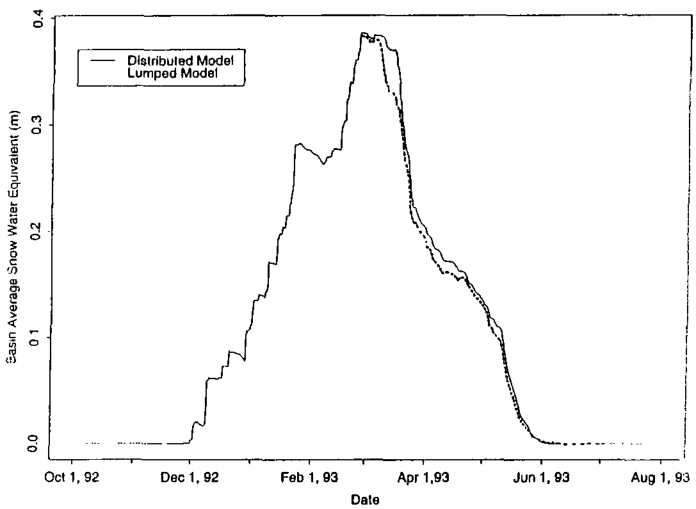

Figure 1. Modeled basin average snow water equivalent in Upper Sheep Creek, 1992/93, using a fully distributed model on a 30-meter grid and lumped model with snow-covered area fraction parameterized using a depletion curve. The good comparison indicates that the depletion curve approach is promising for scaling up the modeling of snow accumulation and melt, allowing small basin size areas (26 Ha) to be modeled as a single node in a distributed model with larger elements.

Semi-arid rangeland and forested watersheds comprise a large portion of the Western United States. The quality, quantity, and timing of runoff from these watersheds is crucial for water supply and affects agriculture, fisheries, recreation, and hydropower. The purpose of this project is to understand interacting watershed processes over a range of scales in the Reynolds Creek Experimental Watershed (RCEW) in southwest Idaho.

The investigators are developing a spatially distributed modeling framework that accounts for spatial variability in topography, vegetation, and soils to quantify the complete water balance at a range of spatial scales. This will provide a framework within which to test hypotheses regarding the hydrology and water balance at Reynolds Creek. As such, it is a working model with alternative modules being switched in and out for comparison against data. The model development is proceeding in parallel with the acquisition and processing of the remotely sensed data. This includes data from six aircraft overflights as well as Landsat data. Field data being used consist of streamflow, meteorological data, soil moisture and groundwater data, and evapotranspiration flux data.

Parameterization of snow subgrid variability has focused on causes for this variability and how to model it. The results to date indicate that the subgrid variability due to drifting was equally or more important than subgrid variability in solar radiation for estimating the quantity and timing of surface water inputs from snowmelt. A parameterization linking snow covered area to basin average snow water equivalent shows promise as a tool in scaling the energy balance up model to larger model elements. Figure 1 shows a comparison of the time evolution of basin snow water equivalent calculated using a 255-point distributed model and the spatially integrated snowmelt model. The close comparison is indicative of the potential of this approach.

Leaf Area Index (LAI) measurements to date indicate that: (1) there is approximately a twofold range in LAI within the major plant communities in the watershed; (2) the maximum LAI occurs early in the growing season, shortly after snowmelt; and (3) the LAI of all the plant communities (i.e., at all sites) decreases steadily during the summer to an apparent minimum in the fall. Different approaches for using remotely sensed imagery to map the spatial distribution of the critical vegetative communities within the watershed are currently being tested. This will allow the incorporation of vegetative dynamics into the surface energy flux modeling.

This project will lead to a better understanding of the spatial variability and scale dependence of hydrologic processes in RCEW. Because this work is aimed at gaining a better understanding of the physical processes and their interactions, results will be generalizable to other watersheds in the semiarid mountainous Western United States.

Traveling Wave Behavior During Subsurface Transport of Biologically Reactive Contaminants: Implications for *In Situ* Bioremediation

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Contamination of soil and groundwater by hazardous chemicals is widely recognized as one of the major environmental problems faced by modern society. Although there is ongoing debate regarding the extent and severity of contamination, there is no disagreement over the staggering economic costs incurred in monitoring and rehabilitating polluted groundwater supplies. In-the-ground (*in situ*) remediation of contamination costs a fraction of other approaches. The objectives of this project are to investigate how transport and mixing processes affect the overall performance of engineered *in situ* bioremediation. Although these processes play a key role in the ultimate success of actual remediation projects, their significance cannot be ascertained through typical laboratory-scale studies.

Mathematical models are being analyzed for a typical bioremediation scenario in which a uniformly distributed organic contaminant is degraded by indigenous soil microbes that are stimulated by an injected material (e.g., an electron acceptor such as oxygen). Our analysis starts with simple, one-dimensional homogeneous systems and progresses to more realistic mutlidimensional heterogeneous aquifers.

The following cases have been studied: (1) one-dimensional uniform flow in a homogeneous aquifer; (2) ideal radial flow from an injection well in a homogeneous aquifer; and (3) two-dimensional flow in a stratified aquifer. For a wide variety of cases, the system evolves to form traveling waves; that is, the spatial profiles of the organic pollutant, electron acceptor, and biomass attain constant shapes that travel in unison. These traveling waves form because of a balanced interaction between solute mixing processes and localized biodegradation processes. This results in a very localized reaction zone where the pollutant and electron acceptor mix together, as can be seen in Figure 1, which is for a two-dimensional stratified aquifer.

For conditions when traveling waves exist, simple formulas have been derived to calculate the long-term rate of pollutant removal due to biodegradation. The removal rate expressions are similar for all the different flow systems that we have examined. The pollutant removal rate depends upon transport properties of the aquifer, but it does not depend upon the initial biomass concentration or upon the rate at which the biomass can degrade the pollutant. Results from the simple formulas were verified by comparison with numerical simulations.

The traveling wave framework is a useful simplifying tool for approximating the complexity of bioremediation modeling. Use of the analytical formulas reduces significantly the computational burden of estimating the efficiency of a remedial design. The results are significant because they indicate conditions for which the long-term pollutant removal rate does not depend upon the laboratory-determined rate of biodegradation. This helps explain the common observation that laboratory-determined degradation rates overestimate the degree of biodegradation attained in many field projects.

In the future, the analysis will be extended to more realistic patterns of aquifer heterogeneity where the soil permeability changes randomly in all directions. Detailed numerical simulations of the cases studied to date indicate that the traveling wave behavior is not established until a certain time elapses. The investigators plan to study this initial time period because the biodegradation rate, which is often much larger than the long-term rate, which is attained after the traveling waves form.

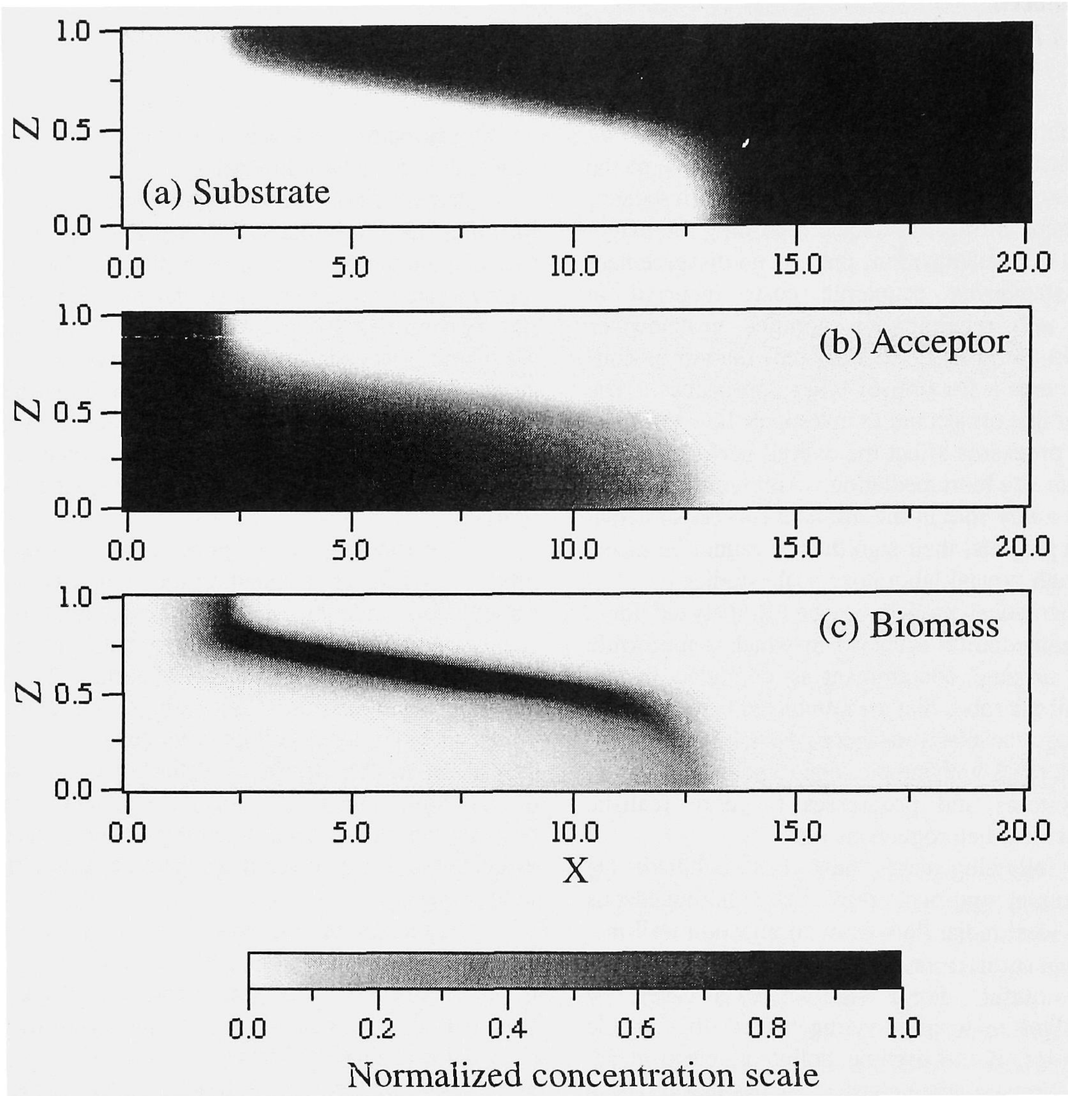

Figure 1. Normalized concentration profiles of the organic substrate (pollutant), electron acceptor, and biomass characterizing enhanced *in situ* bioremediation in a stratified aquifier. The aquifier consists of two layers, with the more permeable layer on the bottom. The electron acceptor is injected from the left-hand boundary. The profiles maintain their shapes as they migrate downstream (to the right) as traveling waves.

Carbon Exchange Dynamics in a Temperate Forested Watershed (Northern Michigan): A Laboratory and Field Multidisciplinary Study

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Beginning in the mid-1800's, humans started an uncontrolled experiment with carbon on earth. It is now apparent that the effects of increasing levels of atmospheric CO_2 resulting from this experiment will alter carbon dynamics and the functioning of terrestrial and aquatic ecosystems in ways that are not entirely understood. The goal of this project is to determine the fate of organic carbon produced in temperate forests. Such forests constitute major potential sinks for anthropogenic CO_2. Importantly, studies of carbon allocation in forests under enhanced and ambient CO_2 growth conditions have shown that above and below ground carbon storage as well as root and microbial respiration processes all increase with elevated CO_2. The question driving this research effort is, "How does the increased rate of carbon fixation and processing in forest stands and soils affect the overall carbon budget at the watershed scale?" Is the additional organic carbon merely recycled via respiration and returned to the atmosphere, or is it transformed and transported from the soil zone to the regional groundwater system for longer term storage?

The project is taking place in a hydrologically and physiographically constrained portion of the Cheboygan watershed. Within the watershed confines are two well-studied forest stands and an established elevated CO_2 experiment in which aspens and sugar maples are grown in mesocosms. Soil compositions and water chemistry are characterized in each experimental mesocosm and in instrumented natural forest stands (aspens vs. sugar maples) to determine how root respiration and microbial processing of organic matter may be linked to carbon transport out of the rooted zone. As a direct measure of mineral weathering effects on dissolved inorganic carbon transport, prepared experimental arrays of feldspar and carbonate minerals have been implanted in natural forests and in experimental mesocosms.

The first year of the project was devoted to hydrologic characterization of the watershed system, establishment of soil water sampling arrays, and general chemical characterization of soil waters, surface waters, and groundwaters in the study area. Soil waters exhibit large vertical chemical variations, generally grading from dilute, dissolved organic carbon-rich solutions in the upper 20 cm into mineralized solutions chemically similar to regional groundwaters by 4 meters in depth. Mass balance among dissolved carbon species suggests that dissolved organic carbon (DOC) originating from reactions in the upper rooted zone is transformed to dissolved inorganic carbon (DIC) via respiration and coupled mineral solubilization reactions. Dissolved silica and aluminum increase rapidly in soil waters suggesting that aluminosilicate minerals, as well as carbonate minerals, are dissolving as DOC (especially organic acid anions) is transformed to DIC (see Figures 1a and 1b). The significant solute acquisition and carbon transformation evident in soil water profiles suggest that organic processes active in the upper soil horizons are closely linked to mineral dissolution mechanisms and the overall rate of solute transport out of the soil zone.

The next 2 years of the project will involve generating an overall carbon budget for the watershed and modeling carbon exchange rates among the main carbon reservoirs. The experimental mesocosms will yield more information on links among growth conditions, soil water chemistry, and DOC/DIC fluxes as the second summer of tree growth begins in 1998. Regional groundwater flow modeling together with more detailed groundwater sampling transects will better define the horizontal transport effects along flow paths relative to the vertical effects in soil water chemical profiles.

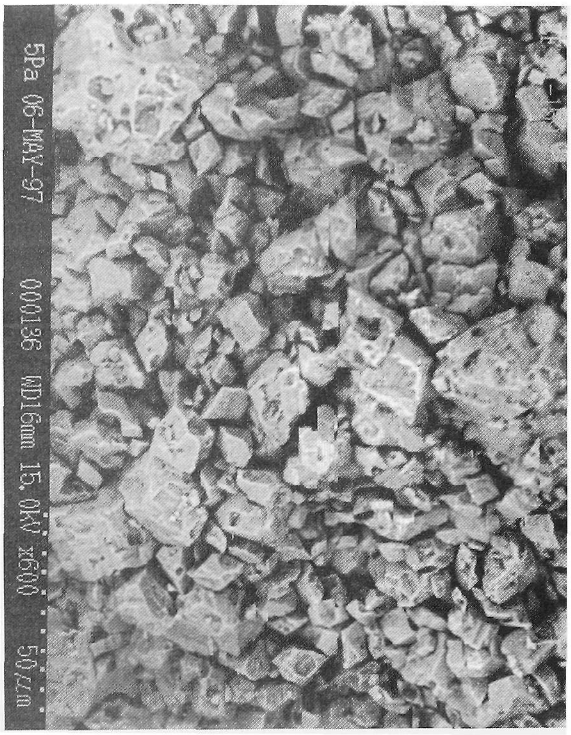

Figure 1a.

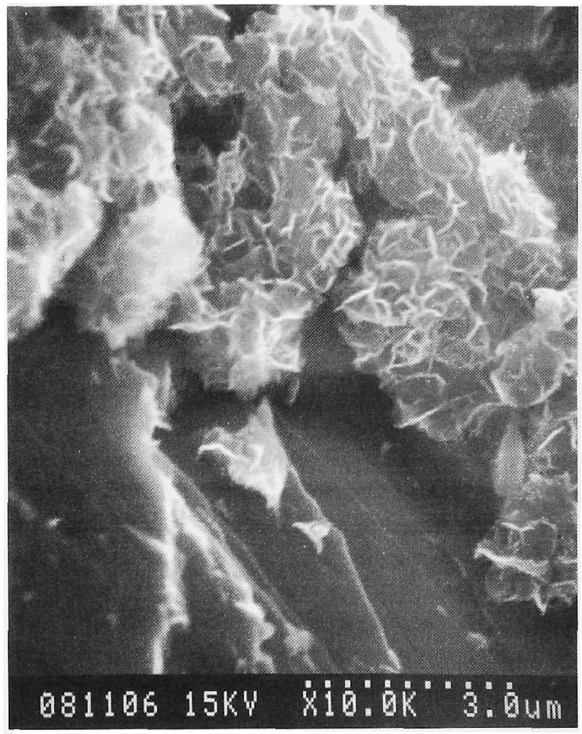

Figure 1b.

Figures 1a and 1b. As shown in scanning electron phomicrographs, "Minerals present in glacial drift soil horizons, such as carbonates (a) or aluminosilicates (b), undergo dissolution and enhanced solubilization in organic acid and CO_2-rich soil waters."

A Comparison of Agricultural vs. Forested Basins: Carbon and Nutrient Cycling Within the Hyporheic Ecotone of Streams

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Figure 1. Installing gravel bar wells at the Ledbetter Creek, Kentucky, hyporheic study site.

Processes and patterns within the hyporheic zone, the interface between groundwater and surface water beneath streams, may help explain differences in stream functions between forested and agricultural basins. Land use effects on subsurface processes mediated by increased nutrient, carbon, and sediment loads are largely unknown. This project's goal is to examine differences in the function of hyporheic ecotones of third order streams in pristine and agricultural watersheds. The hyporheic ecotone functions as a biogeochemically active interface where biogeochemical storage and processing are directly linked to the longterm health and productivity of surface waters. Anthropogenic alterations within watersheds (such as increased sedimentation or runoff) potentially alter hyporheic function and therefore the biotic integrity of stream ecosystems. Ledbetter Creek (LC) is an agricultural watershed located in Calloway County, Kentucky; Panther Creek (PC) is a forested basin located in Stewart County, Tennessee. The two study streams both empty into Kentucky Lake. Hyporheic zones within specific third order sites on both streams have been mapped and monitored with wells, minipiezometers and seepage meters (see Figure 1). Monitoring provides baseline data for specific investigations and manipulations under base flow and high discharge conditions.

At base flow, LC surface discharge contains more nitrogen but less phosphorus than PC. Also, LC carries twice the suspended solids and four times the suspended organic matter load. Fine sediment deposition on the bed surface in LC (at approximately 10 times the rate for PC) appears to decrease surface flow infiltration into the bed and through gravel bars. Decreased surface-subsurface interaction is demonstrated by several measurements. Vertical hydraulic gradients (VHG) are minimal or slightly positive throughout the LC site. Conversely, VHG at PC are more distinct, indicating extensive upwelling and downwelling areas through bed sediments. Conservative tracer studies using bromide and a one-dimensional transport model indicate a much higher degree of surface-subsurface connectivity at PC. Several gravel bar wells at PC have shown rapid hydrologic exchange with surface water (100 percent), while similar wells at LC have shown little hydrologic exchange within a 9-hour period. There is less oxygen in the LC hyporheic ecotone, commensurate with higher concentrations of phosphate, ammonium, iron, and manganese as well as methane, particularly within the gravel bars. In general at base flow, the hyporheic ecotone at LC is much more isolated from surface water than at PC.

A 1-hour, half-inch rainfall in the LC basin produces a steep hydrograph (0.03 to 2.0 m^3 sec^{-1}) within 2 hours but little measurable change in PC discharge because of basin retention differences. With increasing discharge, LC surface water contains exponentially more suspended solids, nitrogen, and phosphorus, presumably derived from runoff but potentially from hyporheic storage as well. At PC, increased discharge causes a slight increase in suspended solids, but surface water nitrogen and phosphorus concentrations decrease, demonstrating surface water dilution. Storm flows in LC tend to remove settled fine sediments, increase subsurface flow, and decrease hyporheic concentrations of ammonium and phosphate. Whether the changes in subsurface chemistry represent flux into surface water or redox changes in the subsurface environment is now being investigated. Concurrent studies in PC and LC hyporheic ecotones are now being conducted on microbial diversity and production, benthic algal production, and sediment fauna (hyporheos) secondary production. Initial results indicate that PC is more biologically diverse with generally higher rates of secondary production.

In Situ Assessment of the Transport and Microbial Consumption of Oxygen in Groundwater

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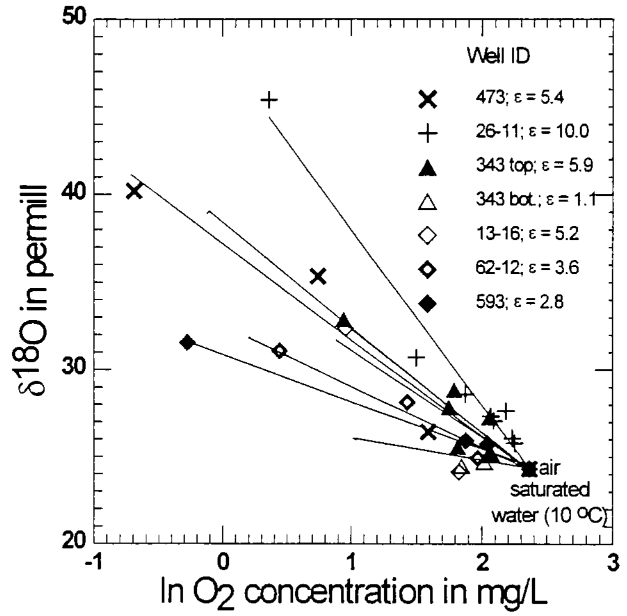

Figure 1. Variations in the concentration and isotopic composition of dissolved oxygen near the upper boundary of a contaminated groundwater plume at Cape Cod. Epsilon (ϵ), the apparent isotope fractionation factor, is defined by a version of the Rayleigh distillation equation: $1{,}000*\ln(R/R_0) = -\epsilon*\ln(C/C_0)$, where $R = {}^{18}O/{}^{16}O$, C = concentration, and R_0 and C_0 denote the initial condition (before reaction). The $\delta^{18}O$ value on the y-axis, a measure of the relative enrichment of $^{18}O/^{16}O$ in a sample, is defined by: $\delta^{18}O = 1{,}000*(R/R_{STANDARD} - 1)$ and is approximately equal to $1{,}000*\ln(R/R°)$. Thus, the ϵ value is a measure of the rate of change of $\delta^{18}O$ during decline in the dissolved O_2 concentration. Here it is assumed that groundwater had initial values around O_2 = 340 μM and $\delta^{18}O$ = +24.3 per mil (in equilibrium with air at 10 · 12°C). The concentrations of O_2 decreased while values of $\delta^{18}O$-O_2 increased from +24 to at least +45 per mil, indicating that the O_2 consumption by microbial processes is taking place in the plume water to varying degrees.

Levels of dissolved oxygen in groundwater influence the rates and extents of biodegradation of organic pollutants within an aquifer. Because microbial respiration is the most important mechanism of oxygen consumption in this environment and thus is a key determinant of aquifer geochemistry, the investigators have been conducting a study to quantify aerobic respiration within a plume of dilute treated sewage in a sand and gravel aquifer in Cape Cod, Massachusetts.

The approaches being used to assess aerobic respiration include: (1) quantifying rates of oxygen consumption using *in situ* tracer tests and laboratory incubations with sediment core and groundwater samples and (2) analyzing the concentrations and isotopic composition of O_2 in various geochemical zones within the aquifer and determining the relative importance of dispersion and respiration in controlling oxygen levels within these zones.

Rates of oxygen consumption were determined by three methods: (1) A natural-gradient tracer test was conducted to directly measure *in situ* rate of oxygen demand. (2) Oxygen consumption was measured in laboratory incubations at *in situ* temperatures and oxygen concentrations with sediment core slurries using a gas chromatographic (GC) technique. (3) An assay of bacterial electron transport system (ETS) activity was conducted in parallel with the GC analysis by amending sediment core slurries with the tetrazolium salt INT, which acts as an artificial electron acceptor.

Rates of oxygen consumption in the sediment core incubations, as measured by GC, were dramatically higher than rates calculated from the *in situ* tracer test. Conversely, rates of oxygen consumption from the INT assay were significantly lower than the *in situ* rates. The data suggest that incubation of aquifer samples within bottles in the laboratory appreciably stimulates microbial respiration, even when *in situ* temperature and oxygen levels are maintained and that INT is toxic.

The main factors that determine the relative enrichment of $^{18}O/^{16}O$ in O_2 in an aquifer are: (1) microbial reduction of O_2 that causes an increase in the ratio of $^{18}O/^{16}O$ in the remaining fraction of O_2 due to kinetic isotope fractionation and (2) dispersion of O_2, which could result in concentration gradients without major isotopic variation. Figure 1 shows an increase of ^{18}O (see the definition in the figure caption) with decreasing O_2 concentration through a vertical O_2 gradient at seven locations in the aquifer, clearly indicating that O_2 consumption has occurred at these sites. The low apparent ϵ values suggest that the vertical O_2 concentration gradient within the aquifer is caused by a combination of O_2 consumption and dispersion in varying degree. Numerical models are currently being applied to better define the relationship between O_2 consumption and dispersion.

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