Compendium of the Results of the 1999 STAR Water and Watershed Grants

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FOREWORD

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1. Introduction

1.1 Background

The Environmental Protection Agency (EPA) STAR (Science to Achieve Results) Grant program funds research in a wide variety of environmental science disciplines. The STAR Water and Watersheds program is unique in that it advocates interdisciplinary research. However, in order for the information gathered from this research to be useful to decision-makers, stakeholders, and the science community, it is beneficial to summarize the results into comprehensive and easily accessible documents. In concordance with their commitment to communication, the National Center for Environmental Research (NCER) is supporting a set of documents that highlights research results and successes. The purposes of this project are to develop a compendium of the results of the 1999 STAR Water and Watershed Grants and to produce a document that outlines the results, products produced, and user communities for each of the 1999 Water and Watershed grants.

Because this product will be used directly by EPA, and to avoid any bias associated with the research projects, an extramural contract was chosen as the appropriate vehicle to complete this task.

1.2 Summary

Eight 1999 Water and Watershed EPA STAR Grants were reviewed in detail to determine how the results can be used by other researchers and decision-makers. Products that are useful to both groups include:

- More than 15 models
- New research techniques and tools, including a sets of biomarkers and a Coral Mud Resuspender
- Procedures that improve the use of current models
- Social science research and implementation methods, including numerous public surveys and an interactive computerized simulation program

All eight grants were multi-criteria studies, and all included a social science or public policy component that involved determining public opinions and practices or working with decision-makers. Each grant also incorporated one or more of the following thematic areas:

- Agriculture
- Economics
- Fishing
- Scientific techniques
- Social Science
- Urban

Two conclusions can be ascertained from these multi-criteria endeavors:

- Regional and policy changes that protect water resources and watershed ecosystems can be implemented at local and regional scales when two-way communication exists between stakeholders and the science community.
- Social science methods are useful in implementing behavioral or policy changes.

To make the findings and products from these research projects more assessable to readers, the information is presented in several formats. The first section summarizes each grant and lists results,

products, users, and themes. Appendix A provides a table that lists each grant's number, title, principal investigator, common themes, relevance, products, and successes and lessons learned. The table in Appendix B shows grants by common themes. Lastly, Appendix C briefly describes grant efforts as they relate to a thematic area.

2. SUCCESSES, RESULTS, AND FINDINGS

2.1 STAR Grant R828007

The Impact of Lawn Care Practices of Aquatic Ecosystems in Suburban Watersheds
Principal Investigator: Kevin Ambrust, University of Georgia

Successes and Lessons Learned:

- Pesticide concentrations in aquatic ecosystems are related to both watershed size and the quantity of pesticides being used in stream drainage areas.
- Types and concentrations of pesticides detected in streams were not related to the socioeconomic status of the neighborhood. However, the majority of the biological effects were seen at some of the sites with higher property values.
- Homeowners identified pride of ownership, respect for neighbors, and pride of place as the primary motivations for maintaining their residential landscapes
- Professional applicators and maintenance companies are prevalent, but residents do a significant amount of the application of lawn-care products. Resource managers and decision-makers wishing to develop ecologically sensitive lawn-care practices must consider the impact of private homeowners, as well as professionals (Ambrust, Final Report, 2004).

Products:

- Numerous publications and presentations on the topics, methodologies, and results of the grant

User Community:

- Home and business owners
- Resource managers and decision-makers
- Lawn-care companies
- Watershed associations

Themes:

Economics, social science, multi-criteria studies, urban

In many suburban watersheds, pesticides and nutrients used for lawn and turf care have been linked to the degradation of aquatic ecosystems. Combining both social science and biological studies, this project assessed homeowner socio-economic factors concerning residential lawn care and determined if these factors were related to aquatic ecosystem health in the associated watersheds. The investigators focused on multiple residential areas of differing property values in suburban Atlanta and Peachtree City, Georgia, as well as on a golf course. To determine the effects of homeowner factors, researchers surveyed selected homeowners concerning their values and beliefs on lawn care and observed residential and professional lawn-care practices. To determine ecological impacts, they monitored streams in the study areas for pesticides, nutrients, metals, and biological impacts, using monthly water and sediment samples from the streams and water samples from the fairway tile drains.

The most commonly detected pesticides in the water and sediment from the Peachtree City residential sites were chloropyifos and dithiopyr. The loadings of these chemicals from neighborhoods was more strongly associated with the amount of impervious surface and the size of the drainage area within the neighborhood than with the socioeconomic status of the neighborhood (Overmyer, Final Report, 2004). These chemicals also were commonly found in samples from the golf course. Concentrations and frequencies of detection tended to be higher at sites downstream from the golf course (Armbrust, 2001 Progress Report), and concentrations were highest immediately after application.

Nutrient levels tended to fluctuate with the seasons at all study locations**.** While few differences existed among the study locations, ammonium nitrate and soluble phosphorus concentrations were greater at the higher income residential areas. Researchers attributed this correlation to the fact that diamonimum phosphate is one of the most commonly used fertilizers for lawn care.

As insecticides are often used in urban areas as a lawn care tool, researchers felt it was important to better understand how these chemicals affect species of aquatic invertebrates. They conducted toxicity tests with mixtures of three of the most common lawn-care insecticides used in urban watersheds, carbayl, chloropyrifos and malathion. The effects associated with these chemicals were determined by studying their impacts on the growth, development and survival of the black fly larvae, *S. vittatum*. All three chemicals were highly toxic to the black fly larvae. Researchers concluded that invertebrate populations in urban and suburban streams may experience a higher-than-expected increase in toxicity-related effects when all three chemicals are present in a waterway.

Effects on macroinvertebrates (e.g., insects, crustaceans, worms) were evaluated in six Peachtree City streams. Each stream was assessed using EPA's Rapid Bioassessment Protocol for Wadeable Streams and Rivers. Results were used to determine the impacts of lawn-care chemical runoff. Streams were ranked using a pesticide toxicity index to determine if impairment detected with the macroinvertebrate data was related to pesticide exposure. The investigators also used the North Carolina Biotic Index (NCBI) to help determine which metrics best predicted the effects of pesticides on macroinvertebrate communities. The combined results of these analyses indicated that lawn-care pesticides used in residential locations have a more profound effect on macroinvertebrates inhabiting the study streams than physical factors, habitat constraints, or metals in the study. However, similar studies at two streams sites adjacent to the golf course indicated that poor habitat (resulting from a beaver dam) deterred the presence of varied macroinvetebrates more than pesticide runoff.

Investigators also determined if lawn-care practices adversely affect aquatic fungi and, consequently, leaf decay in streams. Researchers compared tulip-poplar leaf decomposition rates among streams. These correlations were related to variations in human lawn-care practices in the watershed. Results showed that the physical factors associated with higher water velocities controlled the leaf breakdown rates in the study streams, rather than chemical or biological factors.

The investigators also monitored freshwater clams and mussels. Results showed that clams may be able to compensate for adverse cellular effects associated with exposure to lawn-care chemicals, but that the energy required to do so eventually would negatively affect the organism's health.

The social science portion of this study provided a better understanding of homeowners' perceptions regarding residential land aesthetics. The investigators interviewed property owners of varying ages and property values from four neighborhoods. Overall, participants identified pride of ownership, respect for neighbors, and pride of place as the primary motivations for maintaining their residential landscapes. In addition, residents indicated that caring for their lawns and gardens was more a pleasant hobby than an unpleasant chore. A positive relationship existed between income and the amount of money spent on pesticides, herbicides, and fertilizers. In Peachtree City, the study revealed that for each additional $100 dollars of income, one more dollar was spent on lawns and gardens. The total average expenditure by residents on lawn care was estimated to be about $920 a year, indicating that residential lawn care in higher income neighborhoods potentially could impact the environmental health of the streams.

This research provided a better understanding of the impacts of turf-care products on streams in urbanized watersheds. The data and information can be used by communities to help develop lawn-care practices that are sensitive to neighborhood beliefs and values, as well as to a watershed's ecological integrity.

2.2 STAR Grant R828008

Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices

Principal Investigators: Robert H. Richmond, University of Guam

Successes and Lessons Learned:

- At least six chemically mediated steps are critical to the successful replenishment of reefs affected by watershed discharges.
- Watershed discharges had a substantial effect on the composition, structure, and function of coral communities.
- Using molecular biomarkers, sublethal stress was observed in corals affected by watershed discharges.
- Molecular biomarkers are useful in identifying specific causes of coral reef decline.
- Over fishing of herbivorous fishes contributes to sediment accumulation and chronic impacts of sediment from land-based sources.
- Mitigation methods for these coral reef communities should include improved erosion control on land and a reduction in benthic fleshy and filamentous algal cover.
- The three bays studied demonstrated differences in the magnitude of response, based on the characteristics of the adjacent watershed and the receiving water.
- Successful management of fringing coral reefs adjacent to high islands may not be possible without proper land-use management in the surrounding watershed.
- Mangroves buffer fringing coral reefs from excessive sedimentation.
- It is not possible to manage coral reefs; the key is managing human activities that affect reefs.
- Community involvement in the study, including hiring a community member as a facilitator and the use of peer pressure, helped change land-use practices and policies.
- A moratorium on cutting and filling mangroves was achieved after a researcher's presentation to chiefs, fishermen, and community members in the Palauan language in the village meeting house.
- Science must go beyond documentation of environmental degradation and be used as a tool for managing human activities that impact ecosystems. The social sciences are key to the application of data to sound policy development and implementation.

Products:

- Development and verification of the HOME (hydrology, oceanography, meteorology, ecology) ecohydrology model that predicts the impact of natural and human disturbances from land runoff on coral reefs
- Development of a coral mud resuspender to quantify the amount of mud trapped on coral reefs (marine snow) and available for resuspension by waves
- Development of a suite of biomarkers for identifying stress in corals

User Community:

- Republic of Palau
- Palau International Coral Reef Center
- Palau Conservation Society
- Airai Village, Palau
- U.S. Territory of Guam
- Pew Oceans Commission
- U.S. Commission on Ocean Policy
- U.S. Coral Reef Task Force
- NOAA

Themes: Economics, fishing, multi-criteria studies, politics and policies, scientific techniques, social science

Human-induced factors have placed an increasing amount of pressure on coral reef ecosystems. In the islands of Micronesia human activities in the watershed have caused significant coral reef degradation. To better understand the dynamics between human activities and coral reef ecosystem health, researchers under this grant sought to:

- characterize watershed discharges effecting coastal reefs chemically, temporally, and spatially
- determine the types and amounts of coastal pollutants that most significantly impact coral reef health
- develop standards that can identify stresses in coral reef heath before mortality occurs
- determine if coral reef recovery is possible and practical after reefs have incurred human-induced and natural stresses
- quantify the cultural and economic impacts of land-based developments that affect coastal resources and incorporate this information into decision-making processes
- educate stakeholders
- develop a set of recommendations for maintaining the integrity of coral reef habitats and provide potential remediation techniques.

The project resulted in findings in each of the program areas of biological, physical, and social sciences.

Biological Sciences:

The research on coral reproduction and recruitment demonstrated that at least six chemically-mediated steps are needed to successfully replenish reefs affected by watershed discharges:

1) synchronization among conspecific corals (of the same species) during spawning
2) egg-sperm interactions
3) fertilization
4) embryological development
5) settlement and metamorphosis (recruitment), and
6) acquisition of symbiotic dinoflagellates (zooxanthellae).

Water-soluble pollutants were a concern for stages 1, 2, 3, 4, and 6. Lipophilic substances (organophosphate pesticides) were a problem for recruitment, as the tested pollutants appeared to block both metamorphic inducers and larval receptors. Watershed discharges had a substantial effect on coral community composition, structure, and function.

Stress at sublethal levels could be observed in corals affected by watershed discharges, using molecular biomarkers of exposure. Researchers assayed six classes of responses: geonomic integrity, protein metabolic condition, xenobiotic detoxification, metabolic integrity, oxidative damage and response, and membrane integrity (Richmond, Final Report, 2004). Molecular biomarkers in corals identified exposure and subsequent effects of an oil spill associated with a ship's grounding. Biomarkers of exposure appear to be able to serve the needs of resource managers for identifying specific causes of stress to corals at sublethal levels and for measuring the effectiveness of mitigation measures in reducing stress levels.

Sediment particles from land sources were found to serve as nuclei for bacterial and microfaunal aggregations that resulted in the formation of “marine snow.” This material settles on the reef substrata, smothering coral recruits and contributing to the nocturnal biological oxygen demand along reef surfaces. Field data demonstrated that over fishing of herbivorous fishes contributes to sediment accumulation and chronic impacts of sediment from land-based sources. After periods of increased wave action, more than 50% of suspended sediment particles came from material trapped in benthic algae. Therefore, mitigation

measures need to include both improved erosion control on land and reduction of benthic fleshy and filamentous algal cover.

Physical Sciences:

This research focused on three bays, two in Palau and one in Guam. Each bay had different magnitudes of response, based on the specific characteristics of the adjacent watershed and characteristics of the receiving watershed.

The bay in Guam drains a small catchment area of steeply sloped, highly erodible, lateritic soils. Floods are short-lived and the sediment load is large. Data from this bay supports the premise that successful management of fringing coral reefs adjacent to high islands may not be possible without proper land-use management in the surrounding watersheds.

The catchment area of one of the bays in Palau had been extensively cleared and farmed, and the sediment yield was 10 to 19 times higher than that of the other bay in Palau, which had a catchment area that was still pristine at the time of the study. The bay in the cleared area was protected from ocean swells; therefore, trapped mud smothered coral reefs, creating a shift from coral to fleshy algae dominance and changing habitats within the bay. Mangroves were an important buffer for both systems. They comprised 3.8% of each estuarine area and trapped about 30% of the riverine sediment in both systems, thus protecting fringing coral reefs from excessive sedimentation.

A model was developed to explain coral and algal abundance on coral reefs as a function of natural disturbances. The model includes competition for space between corals and algae, coral recruitment and reef connectivity. For the two sites and two scales on which the model was tested, it successfully reproduced the observed distribution of algae and coral. For both sites, it suggested that the reefs have been degraded by human activities on land and that they will recover, provided remedial measures are implemented on land to restore the water and substrate conditions.

Social Science:

The social science component of this research program provided insight into the application of scientific data and the implementation of policies designed to meet management and, hence, stakeholder needs. The watersheds selected for study were chosen for their physical characteristics, as well as the willingness and interest of the adjacent communities to participate and take ownership of the results. The two primary study sites were Guam, which has a Western political system with an elected governor, legislature, and independent judiciary, and Palau, which has elected leaders, traditional Chiefs, and well-organized women's groups within a matrilineal society. A key understanding reached early in the project was that "coral reef management" is a misnomer. It is not possible to manage coral reefs; rather, the focus must be on management of human activities as they affect coral reefs.

In Guam, regular meetings were held in the local village with the mayor, the municipal planning council, and interested community members. A member of the community was hired as a facilitator and served as a conduit between the scientists and the village. Input on the project was solicited continually from the community, and feedback was provided on the progress. The mayor provided space for some of the research, and local school students participated in outreach activities. Community leaders took on a major problem of the burning of vegetation to enable better hunting of feral pigs and deer. In addition, the municipal planning council requested the Legislature to establish a Marine Protected Area to ban fishing herbivorous fish. NOAA provided additional funding to allow this effort to continue.

In Palau, the Palau International Coral Reef Center conducted a door-to-door community outreach effort, and a well-respected congressional delegate facilitated numerous meetings with local chiefs and fishermen. Following a presentation by two Palauan researchers (in the Palauan language) to chiefs, fishermen, and interested community members, a moratorium on cutting and filling of mangroves was implemented around the study area. Two years later, the ban remained in place, and no additional damage had occurred to the mangrove ecosystem. Educational materials, funded by the EPA STAR grant, were developed through the Palau Conservation Society and reached all villages in Palau. Continuing efforts in the translation of science into policy continue with the support of a NOAA grant.

Both Guam and Palau allowed the PIs to work with local communities and to cooperate with regulatory agencies and legislative bodies. In Palau, data collected in the morning were presented to members of the community the same evening. While the biological and physical data were being presented, the participants were able to observe and evaluate the "social" reaction. Local fishers, already aware of the problem of poor land-use practices, became empowered with scientific data to begin actions to stop the environmental degradation. This was an exercise in developing political will through the application of scientific data, and a key legislator used the information to write a law on mangrove protection.

Having adequate and accurate data does not solve problems, but rather provides information upon which to make sound decisions. It was found that all three components of this study (ecology, physical science, and social science) were of equal value. Without the social science, implementation would not have occurred. The researchers' perspective includes the philosophy that science must go beyond documentation of environmental degradation and destruction and be used as a tool for managing human activities as they impact ecosystems. The social sciences are proving to be the key to the application of data to sound policy development and implementation. While the data from each discipline was in different forms and units, the researchers found the synthesis provided much more than the sum of the individual parts.

2.3 STAR Grant R828009

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

Principal Investigators: John Day, Louisiana State University – Baton Rough

Successes and Lessons Learned:

- River diversions in the watershed have resulted in increased nutrient uptake (reduction in nutrient concentration), marsh accretion, lower salinity levels, and the incorporation of riverine materials into local food webs.
- The diversion of freshwater in the watershed has a beneficial effect on the marsh communities. The increased freshwater discharge rendered less loss of land and preserved habitat diversity.
- An increased nutrient level caused by the presence of a diversion has the potential to cause eutrophication.
- Long-duration pulse events (the high-intensity release of river water) of one month or more can lead to depressed yields of both shrimp and oysters fisheries within the study location.
- The socio-economic model developed under this grant can be used to illustrate to decision-makers and ecosystem managers that efforts used to improve natural systems will lead to improved local economic wellbeing.
- River diversion is more cost-effective than dredging in restoring and protecting coastal wetlands; however, temporally and spatially, dredging is more controllable.

Products:

- Eutrophication model that includes nitrogen, silicon, and phosphorus uptakes and multiple algal assemblages. The model runs as a stand-alone module or can be linked to a larger two-dimensional hydrodynamic model.
- Environmental dataset for the Caernarvon Watershed that includes precipitation, air, temperature, solar irradiance, water temperature, river state, diversion discharge, and nutrient loading from 1956 to 1998 (Day, Progress Report, 2001)
- A spatially distributed dataset that includes topological and vegetation maps for the areas
- An integrated physical-biological water quality model of the Caernarvon River watershed.
- Framework for the implementation of a two-dimensional hydrodynamic model for the Caernarvon diversion
- Conceptual model of the interaction of natural and economic systems in the Caernarvon watershed.
- Annual one-day workshops to show preliminary results of the Pulses Project to a diverse set of stakeholders at the Louisiana State University, Baton Rouge, Louisiana
- Numerous presentations to scientific and natural resource management communities.

User Community:

- State and Federal government agencies
- Environmental groups
- Local citizens
- Educational groups and universities

Themes: Economics, fishing, multi-criteria studies, social sciences

River inputs to floodplains, marshes, and coastal wetlands are important to long-term ecological productivity and watershed resources. In much of the Mississippi River drainage basin and delta, levees and dams constructed during the past 100 years have isolated rivers from their natural connections to floodplains and deltaic wetlands. In 1991, the U.S. Army Corps of Engineers (USACE) installed a gated

river diversion system to deliver freshwater and its accompanying nutrients and sediments from the Mississippi River to the coastal bays and marshes in Breton Sound (USACE, 1998), located within the Caernarvon coastal watershed of Louisiana. The goal of the diversion project was to reduce deterioration of estuarine marshes and enhance fish and wildlife resources in the area. Researchers under this grant conducted a series of physical and ecological studies to assess habitat response to riverine inputs. They evaluated marsh plant growth responses to river inputs, water quality changes, the function of wetland soils and benthic sediments in response to flooding events, effects on fish, shrimp, and oysters, and changes in phytoplankton production and possible eutrophication. Social science studies were conducted with the goal of developing methods and models that would clarify the linkages between human and natural systems to decision-makers (2001 Progress Report).

One of the main purposes of the USACE river diversion was to help promote vertical accretion of the freshwater marshes in Breton Sound, an area that was once losing about 1,000 acres annually to erosion (USACE, 1998). In order to study marsh accretion, investigators under this grant conducted a series of sediment deposition studies during pulses, or high-intensity river discharges events. Results indicated that the volume of sediments delivered by the freshwater diversion sustain current elevations in the Breton Sound estuary, but that the fine-grained sediment composition and transport mechanism to the marsh surface is not adequate (Day, Final Report, 2004). Researchers also concluded that diverting freshwater into Breton Sound estuary primarily benefits interior marsh sites located within 6 km of the diversion outfall, particularly during pulsing events.

Researchers also investigated nutrient distributions resulting from the diversion at 20 water sampling sites throughout the watershed. They assessed nutrient processing abilities of the wetland soils and benthic sediments (Day, Final Report, 2004). Analysis led researchers to conclude the following.

- Nitrate and nitrite concentrations appear to be controlled by the volume of Mississippi River water put into the estuarine system.
- Concentrations of ammonium within the estuarine system do not reflect the discharge from the diversion structure.
- Phosphate concentrations varied with the seasons; however, distinct bands of high phosphate concentrations were evident during periods of high discharge during the winter months.
- Silicate levels appeared highest during high discharge events in the winter, suggesting that the Mississippi River is a large source of silicate. Variability within silicate concentrations occurred mainly in the middle and lower estuary.
- Concentrations of total nitrogen (TN) were high in the upper basin and decreased with increasing distance from the diversion structure. TN concentrations increased from late winter to early spring in relation to increased input from the Mississippi River.
- An increase in total phosphorus concentrations was observed throughout the estuary during periods of high discharge from the diversion.

Other water quality tests showed that the diversion impacted salinity, temperature, and chlorophyll *a* concentrations throughout the estuary, depending on the season and duration and intensity of the pulse event.

Analyses of the nutrient processing abilities of watershed soils indicated that the estuarine sediments have the capacity to function as nutrient sinks. This characteristic is important, as the existence of functioning nutrient sinks can help prevent eutrophication and the occurrence of potentially harmful algal blooms. Studies also suggested that nutrients from the Mississippi River are incorporated into the watershed's food web.

As a result of this project, several models were produced. One consists of a calibrated 2-dimensional system that describes and predicts potential changes in the nutrient concentrations and phytoplankton biomass in Breton Sound under various diversion pulse scenarios. Using this model, it is possible to make overall nutrient export estimates to the coastal ocean. This can help managers and decision-makers in their efforts to reduce hypoxia in the Gulf of Mexico. The second model is a watershed process model of the Caernarvon marshes in Breton Sound. This model can be used to predict regional habitat change. This Caernarvon Watershed Model was first calibrated using historical environmental conditions within the watershed. The model was then used to assess potential future habitat conditions under three scenarios: no discharge, scheduled discharge, and pulsed discharge. Results revealed that freshwater has a beneficial effect on the marsh community. Increased freshwater discharge translated into a reduction in land loss and preservation of original habitat diversity (Day, Final Report, 2004).

As a final component to this project, researchers conducted a socio-economic and stakeholder analysis. The socio-economic analysis resulted in a conceptual model that linked natural and human systems. This model can be used to illustrate to decision-makers and ecosystem managers that efforts used to improve natural systems will lead to improved local economic wellbeing. The stakeholder analysis consisted of a series of questionnaires passed out at meetings, mailed, or delivered door-to-door throughout the study area. On-the-spot interviews also were conducted. The analysis revealed that although there is a high level of agreement that coastal land loss is a significant problem, diversions are not always viewed as the most appropriate solution (Day, Final Report, 2004).

This study provided insight into the benefits and the potential consequences of constructing a diversion system to introduce freshwater into a watershed system. Diversions can result in nutrient uptake, marsh accretion, lower salinities, and the incorporation of riverine materials into local food webs; however, they also have the potential to cause eutrophication and can depress the yields of certain fish species. As a result, resource mangers and decision-makers must consider these costs and benefits when determining if a diversion project is right for their watershed.

2.4 STAR Grant R828010

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

Principal Investigators: Richard C. Lathrop, University of Wisconsin – Madison

Successes and Lessons Learned:

- Steady spring flow can be supported by preferential flow through thin zones of shallow bedrock (Swanson, 2004). The potential for sandstone aquifers to contain continuous preferential flow zones has important implications for managing groundwater resources and protecting water supplies from sources of contaminants.
- In this geologic setting, pumping caused frequent cycling of water levels in the lower aquifer, while the upper aquifer had relatively steady water levels that primarily respond to precipitation.
- Simulations of increased groundwater withdrawal indicated the need for maintaining or enhancing local recharge to limit negative impacts on groundwater-fed wetlands in the watershed.
- Fen and sedge meadow vegetation are more sensitive to hydro periods and variations in water chemistry than marsh vegetation. Therefore, careful management of remaining fens and sedge meadows is critical to preserving the functions they perform.
- Simple reductions in fertilizer use, flooding, or sedimentation alone will not suffice to protect wetlands from being overtaken by invasive reed canary grass.
- Innovative practices, such as grass swales and rain gardens that infiltrate water, can reduce thermal pollution from urban watersheds when compared to traditional storm-water practices, such as detention ponds.
- Model results indicated that urban cluster developments produce the smallest volume of runoff and that significant reductions in runoff can be achieved in 4 different types of development approaches if infiltration practices are used to treat many impervious surfaces (Brander, et al., 2004).

Products:

- A model that simulates potential effects of urban expansion and increased groundwater pumping. The model simulates the effects of preferential bedrock flow zones and improves the calibration of spatial variations in groundwater discharge to streams and at springs.
- A conceptual model of a wetland transect that illustrates the interaction between stratigraphy, groundwater discharge, and vegetation gradients
- A conceptual model that explains how nutrient-rich runoff from urban or rural landscapes accelerates takeover of invasive species at the landscape scale.
- Multiple numeric models that can be used to design or evaluate the effects of small-scale infiltration practices
- Numerous articles in scientific journals and numerous presentations at scientific meetings

User Community:

- State of Wisconsin
- Local governments
- Citizen groups

Themes: Agriculture, multi-criteria studies, politics and policies, scientific techniques, social science, and urban

The urbanization of agricultural landscapes throughout the United States is associated with the degradation of aquatic systems. Fundamental changes in watershed hydrology result from the construction of impervious surfaces, wells, and sewage systems. The researchers in this grant developed and evaluated alternative management and urban development practices that could assist local

governments and citizens groups in mitigating negative hydrologic environmental affects from the urbanization of agricultural regions (Lathrop, Abstract). Their objectives were to:

- improve knowledge about alternative managements practices and patterns of urbanization
- extend or develop analytical and modeling tools to minimize hydrologic affects of urbanization
- compare the costs, social acceptability, and affects of different land- and water-use scenarios
- examine urban impacts on wetlands, especially their biodiversity
- evaluate farming behaviors needed to reduce high phosphate concentrations in the soil
- evaluate barriers to low-impact development and provide guidance for improving the management and protection of critical aquatic resources in rapidly urbanizing landscapes (Lathrop, 2001 Progress Report).

The research was conducted in the Pheasant Branch sub watershed of the Lake Mendota watershed near Madison, Wisconsin. Land use there is largely agricultural, with urban expansion imminent. The watershed influences several aquatic systems, including a large spring complex, wetlands, and the most significant lake in the county. The investigation involved the development of models and research concerning hydrogeology, wetland biodiversity, thermal impacts, agricultural manure management, and social impediments to low-impact development.

Hydrogeology
A major goal of this component was developing a numerical model of groundwater flow to be used to evaluate the effects of municipal pumping and enhanced infiltration practices. The investigators developed a model and studies that illustrated the effectiveness of the regional shale aquitard in isolating the lower bedrock aquifer, confirming the hypothesis that steady spring flow rates are maintained by water discharging from the shallow bedrock (Lathrop, Final Report).

Researchers developed another model that simulated potential effects of urban expansion and increased groundwater pumping. Simulations of increased groundwater withdrawal, based upon projections for the year 2020, resulted in relatively modest decreases in base flow in Pheasant Branch. However, decreases of about 7% in groundwater discharge to wetlands were found when simulations included either deep or shallow wells near the Pheasant Branch marsh wetland system. The impacts were greater still when simulations incorporated the decreases in recharge that would accompany increased impervious area from urban development. These results indicated the need to maintain or enhance local recharge to limit negative repercussions on groundwater-fed aquatic ecosystems.

Wetland biodiversity
To assess the impact of urban disturbances on wetland biodiversity and to design effective restoration strategies requires knowledge of hydrogeologic and geochemical conditions. The researchers conducted a detailed study of a relatively undisturbed wetland in which sharp transition of plant communities occurred — from fen to sedge meadow and shallow marsh. The resulting conceptual model showed that cattails, the dominant marsh species, were tolerant to a range of chemical conditions, but that fen and sedge meadow vegetation were more sensitive to hydroperiods (periodic flooding or saturated soil conditions) and variations in water chemistry. The results have noteworthy implications for wetland trading and creation. Because subsurface stratigraphy can control hydroperiods and water chemistry, the absence of subsurface conditions that allow steady groundwater discharge may preclude the establishment of sensitive vegetation communities.

In the Midwestern United States, reed canary grass (*Phalaris arundinacea L.*) has invaded wetlands that receive chronic runoff from agriculture activities and urban development. Once invaded by Phalaris, wet meadows retain few species. In sedge meadows with apparent hydrological disturbance from culverts and drainage ditches, the researchers found up to 15 fewer species than in nearby undisturbed areas. The lost

species tended to be rarer, more specialized species (Kercher, 2003). Microcosm studies linked loss of native plants to prolonged flooding and sedimentation; these factors and extra nutrients greatly increased the biomass of *Phalaris*.

The researchers also developed a conceptual model that indicates how nutrient-rich runoff from urban or rural landscapes accelerates the incursion of invasive species. Their findings suggested that a holistic approach is needed to control invasive species including: 1) minimizing runoff through infiltration-enhancing measures, such as swales; 2) removing invasive species through herbicides or sod removal; 3) replanting natives; 4) providing long-term surveillance and spot treatment of re-invading clones; and 5) reintroducing native species that do not self recover.

Thermal Impacts of Best Management Practices

Researchers examined thermal data for the water retained by a detention pond, a bio-engineered wetland, and a grass swale. Grass swales that infiltrate water reduced thermal pollution, whereas detention ponds increased the heat output of runoff by an average of 10%.

Hydrologic Modeling: Individual Infiltration Practices

Small-scale infiltration practices, such as bioretention facilities and infiltration trenches, can prevent increases in the volume of storm runoff and decreases in the volume of groundwater recharge. The researchers developed numerical models that could be used to design and evaluate the benefits of such infiltration practices. Two models were developed for simulating the performance of a multi-layered infiltration practice in continuous time.

The first model uses Richard's Equation to simulate flow. It demonstrated the following three points. There is an optimal facility size, if the purpose of the facilty is to increase groundwater recharge. An optimally designed bioretention facility can yield groundwater recharge rates well above rates that occur in undeveloped conditions. An infiltration facility designed to maximize groundwater recharge can significantly reduce runoff volumes (Dussaillant et al., 2004).

This model has long run times, making it unsuitable for design use, so the researchers developed a much faster model, based on the Green-Ampt equation. This model incorporated a user-friendly interface that allows a user to evaluate the performance of a multi-layered infiltration practice with an under drain. It also can determine the size of the facility required to insure a specific volume of storm water retention.

A spreadsheet model, augmented to account for infiltration practices, was developed based on the commonly used Natural Resources Conservation Services "curve number" method. This model assessed potential benefits of infiltration practices in the context of four alternative development types: conventional curvilinear, urban cluster, coving, and new urbanism. Urban cluster developments produce the smallest volume of runoff due to the large portion of land left in natural condition. Significant reductions can be achieved in the four development types if infiltration practices are used to treat many impervious surfaces.

Researchers also modified the U.S. Geological Survey Precipitation Modeling System to model infiltration practices at the watershed scale. Tesults indicated that intensive use of infiltration practices can preserve groundwater recharge rates in both moderate and high development scenarios, but cannot preserve runoff volumes in the high development scenario.

Agricultural Practices

This research was conducted in the "urban fringe," where farming competed with land development. Urbanization pressures resulted in a fragmented pattern of land ownership and rental, which caused greater separation of farm fields, resulting in the need to haul manure greater distances (Cabot et al., 2004). These conditions tended to produce two equally unattractive propositions: paying to have excess manure hauled elsewhere or over-applying manure on a field. Rather than hauling partial loads of manure to a field or return from the field with the spreader still half-full, producers preferred over-applying manure to portions of their fields. Due to these complications, some producers were reluctant to implement nutrient management plans.

One strategy for managing manure to better balance and reduce the surplus of phosphorus on the fields is to encourage cooperative agreements between dairy and livestock producers and cash-grain farmers. However, the ongoing urbanization complicates this arrangement, because tracts of grain land tend to be sparse and beyond the maximum distance that producers can profitably haul the manure. Another strategy is to encourage manure brokering programs that direct manure to land that can accept and use it without further polluting the runoff and groundwater. Finally, precision conservation may make it possible for producers to manage manure and nutrients at levels at or below those at which nonpoint source pollution originates. However, precision conservation uses geographic positioning systems (GPS), making it costly and unfamiliar to most producers.

Social Impediments to Low-Impact Development

The social research portion of this grant revealed two barriers that must be overcome if low-impact development is to be adopted in urban design: institutional barriers, such as zoning and subdivision regulations, and human biases or inadequate knowledge of key players. Subdivision ordinances are critical tools for guiding lot size, building setbacks, determining street configuration and width, and establishing procedures and standards that must be followed when subdividing a large parcel of land. The vast majority of subdivisions in this study included large impervious surfaces that reduce storm-water infiltration and increase runoff. There was little evidence of "best management practices." Many of these environmentally unfriendly ordinances stemmed from the interests of various institutional players, such as the fire department and snow removal personnel. Another barrier to low-impact development was the lack of knowledge by many engineers and planners of alternative infiltration practices and their effectiveness under varying conditions.

Different problems existed with retrofitting established urban areas with infiltration systems. Individual homeowners and commercial property owners are the key players for implementing infiltration systems at the individual property scale. Voluntary installation of rain gardens by local residents can help to alleviate chronic flooding problems in their community. It was determined that voluntary participation in these programs brought about a greater sense of buy-in by the participants and eliminated those unwilling or unable to maintain their rain gardens. Because many homeowners had no prior knowledge of rain gardens they associated the term "garden" with work, and, therefore, did not want to participate initially. The other common reason for not participating was, "I don't have a water problem, so I don't need a garden."

To reduce land development impacts, local subdivision ordinances should be examined, and, if necessary, revised to be consistent with smart-growth principles. They should promote, if not require, low-impact development practices. This research identified ordinances that are barriers to low-impact development and recommendations will be made by the researchers to eliminate these barriers.

2.5 STAR Grant R828011

Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed

Principal Investigator: Brett Sanders, University of California – Irvine

Successes and Lessons Learned:

- Enterococci bacteria are present at high concentrations in urban runoff, bird feces, and marsh sediments and on marine vegetation (Grant, 2001).
- During dry weather, concentrations of fecal indicator bacteria (FIB) are highest in inland urban runoff; they are intermediate in tidal channels with variable mixtures of urban runoff and ocean water; and they are lowest in ocean water at the base of the watershed (Sanders, Final Report, 2004).
- The vast majority of FEB loading occurs during storm events. FIB loads during dry periods account for only 1% of the annual runoff load and dissipate in tidal channels.
- FIP loads exported from the watershed to the surf zone during dry weather are deflected along the shoreline by wave-driven currents and can cause the standards for water-contact recreation to be exceeded. The origin of these loads is scouring by tidal currents of channel and marsh sediments.
- Sediment contamination from bird droppings, decaying vegetation, and bacterial regrowth is linked to urban runoff during wet and dry periods. Since intertidal wetlands are natural generators of FIB, these results call into question the exclusive use of FIB as the basis of health standards for water-contact recreation at beaches near the outlet of intertidal wetlands.
- Stakeholders, including beach-goers, business owners, and environmentalists, have diverse opinions about the causes of beach pollution, the health risks, and the financial responsibility for correcting the problem.

Products:

- A hydrodynamic flow and transport model that elucidates the volumetric exchanges that occur between the upper and lower portions of the watershed and the coastal zone illuminate the hydraulic connectivity of the system.
- An approach to using first-principle models to predict fecal indicator bacteria in an estuarine setting with significant non-point sources of pollution.
- A survey on public's concerns, opinions, and attitudes about efforts to investigate and improve coastal water quality.

User Community:

- Huntington state and city beaches in Southern California
- Orange County Health Care Agency, California
- Beach goers
- Environmentalists
- Local businesses
- Public health officials
- Wastewater utility managers.

Themes:

Multi-criteria studies, politics and policies, and urban

In an effort to better protect public health, California has mandated a new state law to monitor recreational water quality at California beaches that receive 50,000 or more visitors a season. Within a year of the bill's passage, two beaches in Southern California, Huntington State Beach and City Beach, posted 99 water quality hazards. Investigations indicated that the source of the beach pollution problems

was urban runoff from the nearby Talbert Watershed (Sanders, 2000 Progress Report). Researchers under this grant were tasked with investigating the problem. Specifically, researchers sought to:

- characterize the spatio-temporal variability of microbial pollution in urban runoff and to identify the association between pathogens and indicator organisms,
- develop a strategy to control the impact of urban runoff on the microbial water quality of coastal wetlands and beaches during non-storm periods, and
- develop a multi-objective decision model to aid stakeholders in selecting strategies to mitigate microbial pollution problems in coastal waters.

The study watershed is urbanized and consists of residential developments, commercial districts, plant nurseries, and light industry. The storm water system is separate from the area's sanitary sewer system; therefore, dry and wet weather runoff flows to the ocean without treatment. The Talbert Marsh is a 10-hectare remnant of an original 1200-hectare saltwater wetland and dune system drained and filled during the last century for agricultural and urban development. Construction of the Pacific Coastal Highway and flood control measures isolated most of the remaining historical wetland from tidal flooding. As part of a habitat restoration effort, tidal flushing was restored in 1990, with the construction of a new tidal inlet. Since its restoration, the marsh has become a typical tidal saltwater marsh with open water, wetland, and upland habitats (Grant, 2001).

Researchers conducted extensive monitoring of surface waters to measure the spatio-temporal variability of fecal indicator bacteria (FIB) loads; examined factors that control fate and transport; and monitored and examined the association between FIB and other fecal indicators. The investigators also developed one- and two-dimensional hydrodynamic models to analyze the fecal indicator bacteria loads in tidal channels and into the surf-zone and to develop a predictive tool for examining how bacteria loads would be altered by operational changes to the infrastructure. They performed surveys to measure stakeholder preference in the context of multi-stakeholder, multi-objective beach pollution problems and to support decision-making analysis.

Using numerical modeling, the researchers predicted FIB loads in tidal wetlands. Total coliform were predicted more accurately than *E. coli* or *enterococci*, both in terms of magnitude and tidal variability. This work represented the first case where first-principle models were successfully applied to predict FIB in an estuarine setting with significant non-point sources of pollution. The approach is highly transferable and could benefit both wetland restoration and water quality compliance efforts on a widespread basis (Sanders et al. 2004).

This analysis showed that FIB loads in runoff during dry weather periods accounted for only about 1% of the watershed's annual runoff load. The vast majority of FIB loads are shed during storms and are associated with particles scoured from the water collection system, including street gutters, storm pipes, and storm channels. The loads exported from the watershed to the surf zone during dry weather are deflected along the shoreline by wave-driven currents, which can cause water-contact recreation standards to be exceeded. Models showed that such loads originate when tidal currents scour channel and marsh sediments that have been contaminated by urban runoff from bird droppings, decaying vegetation, and bacterial regrowth.

On the basis of FIB control, the efficacy of dry-weather diversion for FIB control in the Talbert Watershed is unclear, although the diversions also deter other types of pollution, such as oil and heavy metals).

2.6 STAR Grant R828012

The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems

Principal Investigator: Margaret A. Palmer, University of Maryland – College Park

Successes and Lessons Learned:

- Urbanized streams tended to have incised channels, lower base-flow, more extreme peak flows and lower levels of invertebrate diversity than agricultural streams.
- Agricultural streams had very high nutrient levels and very low ammonia uptake compared with urbanized streams.
- Invertebrate diversity was strongly related to land use, showing a linear decline as the percentage of development increased.
- The high invertebrate diversity in agricultural streams could be attributed to pro-active conservation management and best management practices (BMPs) conducted in the study locations.
- There was a strong relationship between invertebrate species richness and percent riparian forest buffer in the most urbanized study sites. In areas with a high percentage of impervious surface (60%), stream invertebrate diversity appeared relatively protected if the surrounding riparian forest was intact
- Riparian buffers and the levels of nitrogen in the stream influenced the nutrient uptake of ammonium.

Products:

- A spatially explicit model that incorporates feedback over time among land parcels, based on their location relative to one another
- GIS- techniques for modeling land-use change and its consequences on flows in small urbanizing or urbanized watersheds
- A new method that uses historical and aerial photography, current land-use maps, and tax map information to create an annual time series of spatially distributed land use
- Three types of models for geomorphology and sediment transport in urbanizing watersheds
- A model that provides comprehensive predictions of the morphology, texture, and elevation of a stream reach
- Multiple regression models to predict ecosystem structure and function

User Community:

- Resource Managers and Decision Makers – Montgomery County, MD, Department of Environmental Protection; Howard County, MD; Maryland Department of Natural Resources, Maryland Biological Stream Survey; Maryland Department of the Environment; Maryland-National Capital Park and Planning Commission.
- University of Maryland
- Urban Planners
- U.S. Environmental Protection Agency – Office of Water, Office of Environmental Information

Themes:

Economics, multi-criteria studies, politics and policies, scientific techniques, and urban

Researchers under this grant developed a four-phase, multidisciplinary project to gain insight into the impact of human land conversion on stream habitat and ecosystem health. In addition researchers sought to examine how government policy and economic analyses could guide the patterns of future land development and growth to minimize ecological impacts (Palmer, Abstract).

Research focused on contrasting two sets of watersheds in Maryland, the Paint Branch and Northwest Branch watersheds characterized by older neighborhoods close to Washington, DC, and the Hawlings and Cattail

watersheds in the rapidly developing rural-urban areas of Montgomery and Howard Counties, Maryland. Within these watersheds, 69 study sites were selected to conduct research that would allow investigators to gain insight into the connection between the hydrology, geomorphology, ecology, and the economics of land-use change.

Researchers in each of the four major topic areas worked closely as a team to complete detailed analyses of the following:

- the factors controlling land-use change within the study watersheds
- how land use affects peak and base stream flows
- channel geometry
- the abundance and diversity of fish and invertebrates
- the effects of land-use change on stream metabolism, nutrient uptake, and decomposition (Palmer, Final Report, 2004).

Researchers also worked to enhance a current economic model of land-use change using new advances in economic theories. This model incorporates aspects of the regulatory environment governing land-use changes and, as a result, can capture the effects of various regulatory land-use scenarios. To test the effectiveness of this model, researchers compared it to the currently used SLUETH model. Based upon the comparison, it is evident that unlike this new model, the SLUETH model cannot adequately capture the effects of land-use policies and, because it is not "process-based," the SLUETH model tends to confuse correlation with causation ((Palmer, Final Report, 2004).

As a result of the researchers' assessment of the impacts of land-use change on hydrology, several new GIS-based techniques were developed for modeling. These techniques helped researchers better understand the consequences of land-use change on the flows of small urbanized and/or urbanizing watersheds. These new techniques were based on two unique approaches: 1) the incorporation of historical land and aerial photography, current land-use maps, and tax map information to create an annual time series of spatially distributed land use; and 2) the use of this new time series to model the evolution of peak and low flows as a function of land-use change (Palmer, Final Report, 2004). In addition to these new techniques, researchers developed a new index, the Hydrologic Disturbance Index, which can be used to describe changes in flow behavior within a watershed as a result of land-use change.

Geomorphic studies resulted in the development of 4 additional models. These new numerical models can be used to predict:

- changes in stream channel width
- sediment yield and the evolution of stream bed material grain size and distribution
- the morphology of the and stream bed sediment characteristics of a reach subjected to changes in discharge and sediment supply caused by varying land use and climate
- the morphology, texture and elevation of a reach (Palmer, Final Report, 2004).

Geomorphic field studies also assisted researchers in establishing empirical relationships that help estimate the changes in pool depth and ripple frequency as a function of land use. Both pool depth and ripple frequency are important elements in the evaluation of fish habitat.

The results of the ecological studies conducted at 68 stream reaches across the four study watersheds revealed the following.

- Urbanized streams tended to have incised channels, lower base-flow, more extreme peak flows and low levels of invertebrate diversity when compared to agricultural streams.
- Agricultural streams had very high nutrient levels and very low ammonia uptake compared to urbanized streams.

- Invertebrate diversity was strongly related to land use, showing a linear decline as the percentage of development increased.
- The high invertebrate diversity in agricultural streams could be attributed to pro-active conservation management and best management practices (BMPs) being conducted in the study locations.
- A strong relationship existed between invertebrate species richness and percent riparian forest buffer in the most significantly urbanized study sites. In areas with a high percentage of impervious surface (60%), stream invertebrate diversity appeared to be relatively protected if the surrounding riparian forest was intact
- The nutrient uptake of ammonium was influenced by both the presence of riparian buffers and the levels of nitrogen in the stream.

Because of this research, resource managers and decision-makers now have better insight into the effects of human land-use conversion on both stream habitat and ecosystem health. The new tools and methodologies will help these regulators better assess the impacts of land-use change and help guide them through future land development and growth.

2.7 STAR Grant R828021

Linking Environmental and Social Performance Measurements at National Watershed Levels: Modeling and Statistical Approaches

Principal Investigator: Scott Farrow, Carnegie Mellon University

Successes and Lessons Learned:

- A key outcome of this research grant has been the formulation of a modeling approach to determine the unit damages and appropriate trading ratios for different water pollution sources.
- Results of the predictability analysis for the existing National Water and Pollutions Control Assessment Model (NWPCAM) showed a positive and statistically significant correlation between NWPCAM results and field data; however, predictions did not highly correlate with the collected water quality data.
- Analyses of use-support predictions (i.e., Is the water body fishable or swimmable?) showed a positive and statistically significant correspondence between STORET and NWPCAM use-support classification approaches; however, the level of agreement between the predictions was not high.

Products:

- The Reduced Form Model (RFM) for evaluating surface water quality
- A new calibration measure for the NWPCAM
- New semi-automated calibration procedures for NWPCAM to determine model coefficients that best match the observed data from the EPA's water quality database, STORET.

User Community:

- Water quality, watershed, and environmental managers
- Water resource regulatory agencies
- U.S. Environmental Protection Agency

Themes:

Multi-criteria studies, politics and policies, scientific techniques

Using statistics and modeling, the researchers under this grant developed a tool for evaluating surface water quality that integrates physical, ecological, and social sciences data. To achieve this, the researchers assessed and modified an existing nationally-scoped watershed model, the National Water and Pollutions Control Assessment Model (NWPCAM), and developed a new Reduced Form Model (RFM). In addition, researchers investigated the benefits associated with establishing a water quality emissions trading program.

Initial investigations involved testing the NWPCAM to assess its performance, interpret its outputs, and enhance its utility for watershed and environmental managers (Cooter et al., Final Report). Model assessments addressed the integration of physical, ecological, and social performance measures at the watershed level by helping to establish the credibility of the ecological modeling tool. Testing was conducted at the watershed level. Strategies included validation of both the operational aspects of the computer program, as well as the predictive ability of the water-quality model. Predictability testing was based on a comparison of model results to a series of field observations conducted in six watersheds within the Monongahela River Basin and to data from the U.S. Environmental Protection Agency's (EPA's) water quality database STORET. Results of the predictability analysis showed a positive and statistically significant correlation between NWPCAM results and field data. Despite these correlations, predictions made by the model were not highly correlated with STORET water quality data collected in the watershed. Use-support predictions (In other words, is the water body healthy for boating, fishing, or swimming?) also were assessed by comparing STORET data and NWPCAM model results. Analyses showed a positive and statistically significant correspondence between STORET and NWPCAM use-

support classification approaches. However, the level of agreement between the predictions was not high. In order to reduce prediction errors, researchers applied a new calibration measure to the NWPCAM and developed new semi-automated calibration procedures to determine model coefficients that best match the observed data from STORET.

The NWPCAM often is used by managers and regulatory agencies to evaluate policy choices. However, due to the design of the model, there has been no easy or cost effective way to incorporate factors of uncertainty into the decision-making process to allow managers to fully test policy assumptions and outcomes. Researchers developed the Reduced Form Model (RFM). The RMF has the ability to efficiently and effectively simulate potential water quality policy outcomes from both a physical and economic perspective. To date, RMFs have been developed and applied in the states of Arizona, Iowa, Maryland, and Pennsylvania.

In addition to model testing, researchers under this grant investigated the benefits associated with establishing water quality emissions trading programs. Researchers investigated optimal point and non-point source pollution trading ratios to meet various pollution standards. Researchers used these ratios to develop a modeling approach to determine potential damages and appropriate trading ratios for different water pollution sources. Outcomes from this emissions trading study are now being considered as input by the U.S. EPA in the development of an exploratory pollutant emissions trading program focused on nutrient control for the Ohio River Basin.

2.8 STAR Grant R828070

An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin

Principal Investigator: Olen Paul Matthews, University of New Mexico

Successes and Lessons Learned:

- Twenty-six percent of stakeholders surveyed throughout the Middle Rio Grand River Basin considered themselves well informed about water-use issues; 65% indicated that they participate in water-planning activities.
- Fifty percent of stakeholders strongly supported mandatory water-use controls over price increases as the preferred form of water resource management.

Products:

- Modification of the Geographic Information System (GIS) Powerism Model
- The Organizational Stakeholder Survey

User Community:

- Stakeholders
- Water resource managers
- Regulatory agencies
- Watershed conservation groups

Themes:

Economics, politics and policies, scientific techniques, and social science

Water allocation and reallocation is a significant issue in the western portion of the United States. Researchers under this grant selected the Rio Grande watershed in New Mexico to test a model that integrates components of physical, environmental, and human systems to help simulate potential watershed changes related to water-policy options. In addition, researchers conducted an in-depth stakeholder evaluation to assess the social and economic impacts of various water-policy options within the study location.

The model selected for use was the Powerism Model. This model was developed by the researchers at the Sandia National Laboratory and was modified under this grant to better represent the spatial distribution of water use throughout the Middle Rio Grand region. As a result of this modification, researchers could better examine the hydrology, ecology and demography of the Middle Rio Grande basin to assess various water-use management decisions.

Three stakeholder surveys were conducted throughout the study watershed. The first, the Organizational Stakeholder Survey, was administered to 13 organizations throughout the Middle Rio Grande, including government representatives, environmentalists and pro-industry advocates. The survey focus was to learn the perceptions of various groups regarding the current use and supply of water in the region, as well as their view on how it might change over the next decade. Researchers also hoped to gain insight into measures or practices various stakeholders would like implemented throughout the region to ensure adequate water supply.

The other two stakeholder surveys targeted individuals. These surveys asked stakeholders about their individual water-use practices and their involvement in their region's water planning activities. Participants also were asked to make hypothetical water-use allocation decisions among agricultural, municipal/industrial, and ecosystems areas either for three distinct reaches of the Middle Rio Grande or for the region as a whole. Seventy percent of those surveyed were on a municipal water system; 26% considered themselves well informed about water-use issues; and 65% participated in water-planning

activities (Mathews et al., 2004). In addition, 65% monitored and compared their water use over time. In terms of water-use management, 50% strongly supported mandatory water-use controls over price increases.

During the final phase of this research effort, stakeholders were invited to participate in a computerized simulation study using the updated Powerism model. The simulation allowed them to assess the physical and economic outcomes of various water-use management practices. Participants were divided into three user groups: urban, agricultural and riparian habitat and were asked to enter water-use allocations into the model via a web-interface developed by the Earth Data Analysis Center (EDAC) at the University of New Mexico. Each participant received the physical and economic results of their entries in the form of maps showing changes in use intensity, graphs depicting changes in water available to each user group, and numbers showing the economic gain or loss experienced by each group (Mathews et al., 2004).

Through the enhancement of the Powerism Model and stakeholder evaluations, researchers provided stakeholders with the tools and knowledge to more accurately evaluate water reallocation policy options within their watershed.

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APPENDICES

APPENDIX A. 1999 WATER AND WATERSHED GRANTS SUMMARY TABLE

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8007**	The Impact of Lawn Care on Aquatic Ecosystems in Suburban Watersheds	Armbrust, K. – University of Georgia	Economics, Multi-criteria studies, Social science, Urban	Assessed affects of homeowner lawn-care values and practices on suburban watersheds	• Publications & presentations on research findings and methodologies	• Pesticide concentrations in aquatic ecosystems are related to watershed size and the quantity of pesticides used in stream drainage areas. • Types and concentrations of pesticides in streams were not related to the socioeconomic status of the neighborhood. However, the majority of the biological effects were seen at some of the higher valued property sites (Overmyer and Raymond, 2004) • Homeowners identified pride of ownership, respect for neighbors, and pride of place as primary motivations for maintaining their residential landscapes (Overmyer and Raymond, 2004). • Professional applicators and maintenance companies are prevalent, but household labor is significant in the application of lawn-care chemicals. (Overmyer and Raymond, 2004). As a result, resource manager and decision-makers wishing to develop ecologically sensitive lawn-care practices must consider the impact of private homeowners, as well as professionals.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8008**	Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices	Richmond, R.H. – University of Guam	Economics, Fishing, Multi-criteria studies, Politics and policies, Restoration, Scientific techniques, Social science	Developed tools for predicting impact of human activities on coral reefs and described mitigation methods and land-management activities that can aid coral reef health.	• HOME (hydrology, oceanography, meteorology, ecology) ecohydrology model that predicts the impact of natural and human disturbances from land runoff on coral reefs • Development of a coral mud resuspender to quantify the amount of mud trapped on coral reefs (marine snow) and available for resuspension by waves. • Development of a suite of biomarkers for identifying stress in corals.	• At least 6 chemically mediated steps are critical to the successful replenishment of reefs affected by watershed discharges. • Watershed discharges substantially affect the composition, structure and function of coral reefs. • Using molecular biomarkers, sublethal stress was observed in corals affected by watershed discharges. • Molecular biomarkers are useful in identifying specific causes of coral reef decline. • Over fishing of herbivorous fishes contributes to sediment accumulation and chronic impacts of sediment from land-based sources. • Mitigation methods should include improved erosion control and a reduction in benthic fleshy and filamentous algal cover. • The three bays studied demonstrated differences in the magnitude of response, based on the characteristics of the adjacent watershed and the receiving water. • Successful management of fringing coral reefs adjacent to high islands may not be possible without proper land-use management in the watershed. • Mangroves buffer fringing coral reefs from excessive sedimentation. • It is not possible to manage coral reefs; the key is managing human activities as they affect coral reefs. • Community involvement was instrumental in changing land-use practices. • A moratorium on cutting and filling mangroves was achieved after a researcher's presentation to chiefs, fishermen, and community members in the Palauan language in the village meeting house. • Science must go beyond documentation of environmental degradation and be used as a tool for managing human activities as they impact ecosystems. Social sciences are a key to the application of data to sound policy development and implementation.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8009**	PULSES – The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Lousiana	Day, J. – Louisiana State University – Baton Rouge	Economics, Multi-criteria studies, Social sciences	Researchers sought to investigate the ecological responses of the marshes and bays of Breton Sound to an Army Corps of Engineers' river diversion project.	• Eutrophication model that includes nutrient uptakes and multiple algal assemblages. The model runs as a stand-alone module or can be linked to a larger 2-dimensional hydrodynamic model. • Environmental dataset for the Caernarvon Watershed, including precipitation, air, temperature, solar irradiance, water temperature, river state, diversion discharge, and nutrient loading from 1956 to 1998. • A spatially distributed dataset that includes topological and vegetation maps for the areas. • An integrated physical-biological water quality model of the Caernarvon River watershed. • Framework for implementing a 2-dimensional hydrodynamic model for the Caernarvon diversion. • Conceptual model of the interaction of natural and economic systems in the Caernarvon watershed. • Annual workshops at Louisiana State University, Baton Rouge, on preliminary results of the Pulses Project. • Numerous presentations to scientific and natural resource management communities.	• River diversions in the watershed have resulted in increased nutrient uptake (reduction in nutrient concentration), marsh accretion, lower salinity levels, and the incorporation of riverine materials into local food webs. • The diversion of freshwater in the watershed has a beneficial effect on the marsh communities. The increased freshwater discharge translated in less land loss and a preservation of habitat diversity in 1988. • An increased nutrient level caused by the presence of a diversion has the potential to cause eutrophication. • Long-duration pulse events (high-intensity release of river water) of one month or more can lead to depressed yields of both shrimp and oysters fisheries within the study location. • The socio-economic model developed under this grant can be used to illustrate to decision-makers and ecosystem managers that efforts used to improve natural systems will lead to improved local economic wellbeing. • River diversion is more cost-effective than dredging in restoring and protecting coastal wetlands; however, temporally and spatially, dredging is more controllable.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8010**	Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems	Lathrop, R.C. – University of Wisconsin - Madison	Agriculture, Economics, Multi-criteria studies, Politics and policies, Restoration, Scientific techniques, Social science, Urban	The researchers developed and evaluated alternative management practices that could assist local governments and citizens groups with improving the protection and management of critical aquatic resources in an agricultural area undergoing urbanization.	• A model that simulates potential effects of urban expansion and increased groundwater pumping. The model simulates the effects of preferential bedrock flow zones and improves calibration of spatial variations in groundwater discharge to streams and at springs. • A conceptual model of a wetland transect that illustrates the interaction between stratigraphy, groundwater discharge, and vegetation gradients • A conceptual model that explains how opportunistic invasive species become established in wetlands. The model indicates how nutrient-rich runoff from urban or rural landscapes accelerates takeover of invasive species at the landscape scale. • Multiple numeric models that can be used to design or evaluate the effects of small-scale infiltration practices • Numerous articles in scientific journals and numerous presentations at scientific meetings	• Steady spring flow can be supported by preferential flow through thin zones of shallow bedrock (Swanson and Bahr, 2004). Recognition of the potential for sandstone aquifers to contain continuous preferential flow zones has important implications for managing groundwater resources and protecting water supplies from sources of contaminants. • In this geologic setting, pumping caused frequent cycling of water levels in the lower aquifer, while the upper aquifer had relatively steady water levels that respond primarily to precipitation. • Simulations of increased groundwater withdrawal indicated the need for maintaining or enhancing local recharge to limit negative impacts on groundwater-fed wetlands in the watershed. • Fen and sedge meadow vegetation are more sensitive to hydro periods and variations in water chemistry than marsh vegetation. Therefore, careful management of remaining fens and sedge meadows is critical to preserving the functions they perform. • Simple reductions in fertilizer use, flooding, or sedimentation alone will not suffice to protect wetlands from being overtaken by invasive reed canary grass. • Innovative practices, such as grass swales and rain gardens that infiltrate water, can reduce thermal pollution from urban watersheds when compared to traditional stormwater practices, such as detention ponds. • Model results indicated that urban cluster developments produce the smallest volume of runoff and that significant reductions in runoff can be achieved in 4 different types of development approaches if infiltration practices are used to treat many impervious surfaces (Brander, et al., 2004).

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8011**	Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed	Sanders, B. – University of California	Multi-criteria studies, Politics and policies, Urban	This research examined factors controlling the fate and transport of Total coliform, *E. coli* and *Enterococus* in tidal channels and into the surf-zone and assessed how infrastructure changes would affect bactera loads.	• A hydrodynamic flow and transport model that elucidates the volumetric exchanges that occur between the upper and lower portions of the watershed, and between the coastal zone illuminate the hydraulic connectivity of the system • A survey on public's concerns, opinions, and attitudes about efforts to investigate and improve coastal water quality. • Articles in scientific journals	• Enterococci bacteria are present at high concentrations in urban runoff, bird feces, and marsh sediments and on marine vegetation (Grant, 2001). • During dry weather, concentrations of fecal indicator bacteria (FIB) are highest in inland urban runoff; they are intermediate in tidal channels with variable mixtures of urban runoff and ocean water; and they are lowest in ocean water at the base of the watershed (Sanders, Final). • The vast majority of FEB loading occurs during storm events. FIB loads during dry periods account for only 1% of the annual runoff load and dissipate in tidal channels. • FIP loads exported from the watershed to the surf zone during dry weather are deflected along the shoreline by wave-driven currents and can cause the standards for water-contact recreation to be exceeded. The origin of these loads is scouring by tidal currents of channel and marsh sediments. • Sediment contamination from bird droppings, decaying vegetation, and bacterial regrowth is linked to urban runoff during wet and dry periods. Since intertidal wetlands are natural generators of FIB, these results call into question the exclusive use of FIB as the basis of health standards for water-contact recreation at beaches near the outlet of intertidal wetlands. • Stakeholders, including beach-goers, business owners, and environmentalists, have diverse opinions about the causes of beach pollution, the health risks, and the financial responsibility for correcting the problem.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8012**	The Spatial Patterning of Land-use Conversion: Linking Economics, Hydrology, and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems	Palmer, M.A. – University of Maryland – Collage Park	Economics, Multi-criteria studies, Politics and policies, Scientific techniques, Urban	This research provides resource managers and decision-makers improved information about the effects of human land-use conversion on stream habitat and ecosystem health. It provides new tools and methodologies to help regulators better assess land-use changes and to guide them through future land development and growth.	• A spatially explicit model that incorporates feedback over time among land parcels, based on their location relative to one another • GIS- techniques for modeling land-use change and its consequences on flows in small urbanizing or urbanized watersheds • A new method that uses historical and aerial photography, current land-use maps, and tax map information to create an annual time series of spatially distributed land use. • Three types of models for geomorphology and sediment transport in urbanizing watersheds • A model that provides comprehensive predictions of the morphology, texture, and elevation of a stream reach • Multiple regression models to predict ecosystem structure and function	• Urbanized streams tended to have incised channels, lower base-flow, more extreme peak flows, and lower levels of invertebrate diversity than agricultural streams. • Agricultural streams had very high nutrient levels and very low ammonia uptake compared to urbanized streams. • Invertebrate diversity was strongly related to land use, showing a linear decline as the percentage of development increased. • The high invertebrate diversity in agricultural streams could be attributed to pro-active conservation management and best management practices (BMPs) conducted in the study locations. • There was a strong relationship between invertebrate species richness and percent riparian forest buffer in the most significantly urbanized study sites. In areas with a high percentage of impervious surface (60%), stream invertebrate diversity appeared to be relatively protected if the surrounding riparian forest was intact • Riparian buffers and the levels of nitrogen in the stream influenced the nutrient uptake of ammonium.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8021**	Linking Environmental and Social Performance Measurement for Management at National and Watershed Levels: Modeling and Statistical Approaches	Farrow, S. – Carnegie Mellon University	Multi-criteria studies, politics and policies, Scientific techniques	Researchers developed the Reduced Form Model (RFM) to provide managers and decision-makers with a better water quality assessment tool. The RMF has the ability to efficiently and effectively simulate potential water quality policy outcomes from both a physical and economic perspective.	• Reduced Form Model (RFM) for evaluating surface water quality • Researchers applied a new calibration measure to the NWPCAM and developed new semi-automated calibration procedures to determine model coefficients that best match the observed data from the EPA's water quality database, STORET.	• A key outcome was the formulation of a modeling approach to determine the unit damages and appropriate trading ratios for different water pollution sources. • Results of the predictability analysis for the existing National Water and Pollutions Control Assessment Model (NWPCAM) showed a positive and statistically significant correlation between NWPCAM results and field data. However, predictions were not highly correlated with the collected water quality data. • Analyses of use-support predictions (i.e., Is the water body fishable or swimmable?) showed a positive and statistically significant correspondence between STORET and NWPCAM use-support classification approaches; however, the level of agreement between the predictions was not high.

Grant Numbers	Grant Title	Principal Investigator	Common Themes	Relevance	Products	Successes/ Lessons Learned
-R82**8070**	An Integrated GIS Framework for Water Reallocation and Decision-making in the Upper Rio Grande	Matthews, O.P. – University of New Mexico	Economics, Multi-criteria studies, Politics and policies, Social sciences	Through the enhancement of the Powerism Model and stakeholder evaluations, researchers provided stakeholders with the tools and knowledge to more accurately evaluate water reallocation policy options within their watershed.	• A modified Geographic Information System (GIS) Powerism Model • Stakeholder survey	• Twenty-six percent of stakeholders surveyed throughout the Middle Rio Grand River Basin considered themselves well informed about water-use issues; 65% indicated that they participate in water-planning activities. • Fifty percent of stakeholders strongly supported mandatory water-use controls over price increases as the preferred form of water resource management.

APPENDIX B. 1999 WATER AND WATERSHED GRANTS COMMON THEMES CHART

	Agriculture	Economics	Fishing	Multi-criteria Studies	Politics and Policies	Scientific Techniques	Social Science	Urban
R82**8007**		X		X			X	X
R82**8008**		X	X	X	X	X	X	
R82**8009**		X	X	X			X	
R82**8010**	X			X	X	X	X	X
R82**8011**				X	X	X	X	
R82**8012**		X		X	X	X		X
R82**8021**				X	X	X		
R82**8070**		X		X	X	X	X	

APPENDIX C. 1999 WATER AND WATERSHED GRANTS COMMON THEMES

Agriculture

R828010 – **Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems** – Lathrop, R.

Researchers examined the effects on groundwater and surface water systems in a largely rural area where agriculture now competes with ongoing urbanization. They assessed changes in farmers' fertilization practices that have resulted from new developments and weighed solutions that would be less detrimental to the watershed.

Economics

R828007 - **The Impact of Lawn Care Practices of Aquatic Ecosystems in Suburban Watersheds –** Ambrust, K.

This project investigated the relationship between homeowner income and expenditures on pesticides, herbicides, fertilizers, and irrigation choices and found a significant relationship between income and total lawn and garden maintenance expenditures.

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

Investigators quantified the cultural and economic impacts of poor land-use practices on the resources of 3 bays in Palau and Guam. This information was incorporated into community decision-making process concerning land practices.

R828009 – **PULSES – The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Louisiana**, Day, J.

Based on a socio-economic and stakeholder analysis, researchers developed a conceptual model that links natural and human systems. This model can be used by resource managers to illustrate the link between efforts to improve natural systems with enhanced local economic wellbeing.

R828012 – **The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems** – Palmer, M.

Using new economic theories, researchers enhanced a current economic model of land-use change. The model also can capture the effects of various regulatory land-use scenarios.

R828070 – **An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin –** Matthews, O.

The grant recipients updated the Powerism model, which enables users to assess the physical outcomes and economic gains or losses caused by various water-use management practices.

Fishing

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

Fishermen were involved in community meetings where researchers presented findings that showed the effects of poor land-use practices on fish and other natural resources in their local coral reef system. The findings prompted fishermen to find solutions to the environmental degradation affecting their livelihood. Researchers also learned that over fishing of herbivorous fishes contributes to sediment accumulation in the ecosystem.

R828009 – **PULSES – The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Louisiana**, Day, J.

In assessing the diversion of river water to the Breton Sound coastal area in Louisiana, researchers determined if commercial and recreational fisheries and wildlife productivity had increased because of the diversion. Changes in fishery production were analyzed. Preliminary results showed an increase in gulf menhaden and other finfish; however, the potential also existed for an increase in eutrophication, which could depress yields of certain species.

Multi-criteria Studies

R828007 - **The Impact of Lawn Care Practices of Aquatic Ecosystems in Suburban Watersheds –** Ambrust, K.

The project evaluated whether the values, socioeconomic status, and lawn-care practices of homeowners contributes to nutrient and pesticide loads in the watersheds in their study. Researchers investigated concentrations of turf-care products and biological indicators of ecosystem health in selected residential watersheds and determined cultural beliefs and practices of lawn-care maintenance by home-owners.

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

Researchers called upon the biological, physical, and social sciences to determine which coastal pollutants were of greatest concern to coral reef sustainability in Palau and Guam, to characterize watershed discharges affecting coastal reefs, and to develop an ongoing flow of information between themselves and community members during the policy-making process.

R828009 – **PULSES – The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Louisiana**, Day, J.

To gain insight into the effects of a river diversion project, researchers conducted a series of physical and ecological studies. Using social and socio-economic analyses, they developed a model for decision makers that clarified the linkages between human and natural systems.

R828010 – **Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems** – Lathrop, R.

To assess the affects of altered hydrologic regimes caused by urbanization in a rural area, researchers assessed plant biodiversity, including an invasive species, developed a conceptual model for hydrology related to groundwater discharge, assessed phosphorus levels attributable to manure application, and developed models simulating the hydrologic functioning of rain gardens.

R828011 – **Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed – Sanders, B.**

Researchers characterized the spatio-temporal vaiability of microbial pollution in urban runoff, developed a strategy to control the impact of urban runoff on the microbial water quality of coastal wetlands and beaches, and developed a decision-making model to aid community members in mitigating the microbial pollution causing beach closures.

R828012 – **The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems** – Palmer, M.

This four-phase project provides insight into the impact of human land conversion on stream habitat and ecosystem health. Research covered land use, geomorphic and ecologic structure and function, government policy and regulations, and ecological factors such as species richness, nutrient levels, and riparian buffers.

R828021 – **Linking Environmental and Social Performance Measurements at National Watershed Levels: Modeling and Statistical Approaches** – Farrow, S.

This project team addressed the integration of physical, ecological, and social science factors in their assessment of the performance of a watershed-based water-quality model, the National Water Pollution Control Assessment Model.

R828070 – **An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin –** Matthews, O.

This project had two primary aspects. One involved developing an integrated Geographic Information System framework to simulate interactions and changes within the Rio Grande watershed in New Mexico. For this economic, legal, and biophysical information was collected and incorporated in the model. The other aspect involved stakeholder evaluation of future water-use policy options.

Politics and Policies

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

Scientists regularly presented their questions and findings to community representatives, including Chiefs, fishermen, and community groups. The communities used this information to make policies, which included a fishing ban, a moratorium on cutting and filling of mangroves, and other actions.

R828010 – **Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems** – Lathrop, R.

Researchers identified institutional and social barriers to low-impact storm-water management practices. These included municipal ordinances, such as standards for curbs and street widths, and a lack of knowledge about alternative storm water management practices among builders, planners, and related professionals.

R828011 – **Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed** – Sanders, B.

Researchers used a multi-objective decision model to aid stakeholders in selecting strategies to mitigate microbial pollution problems on their local beach. They found that different interest groups had divergent views concerning the risks of beach pollution, as well as of the costs of correcting the problem.

R828012 – **The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems** – Palmer, M.

This research team included local government scientists and policy makers as well as academicians from the fields of ecology, economics, hydrology, and geomorphology.

R828021 – **Linking Environmental and Social Performance Measurements at National Watershed Levels: Modeling and Statistical Approaches** – Farrow, S.

Researchers formulated a modeling approach to determine unit damages and appropriate trading ratios for different sources of water pollution (Farrow, et al., 2004).

R828070 – **An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin –** Matthews, O.

Researchers conducted three stakeholder surveys that included civic representatives and environmental and business advocates. From the surveys they learned what participants thought about the supply and use of water in their region, how they anticipated water supply and demand would change in the next decade, and what changes they would want implemented.

Scientific Techniques

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

The HOME (hydrology, oceanography, meteorology, ecology) model, developed and verified by the investigators, has predictive capability that can be useful to watershed and reef managers in quantifying the link between land-use activities and coral reef health.

R828011 – **Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed** – Sanders, B.

To analyze the fecal indicator bacteria loads in tidal channels and in the surf zone, investigators developed 1- and 2-dimensional hydrodynamic models. They also successfully used first-principle models to predict FEB in an estuarine setting with

significant non-point sources. Their approach is highly transferable and could be used for wetland restoration and water quality compliance efforts (Sander, et al. 2004).

R828021 - **Linking Environmental and Social Performance Measurements at National Watershed Levels: Modeling and Statistical Approaches** – Farrow, S.

In assessing the existing National Water and Pollutions Control Assessment Model, the researchers determined that there was no easy or cost effective way to incorporate uncertainty factors into the decision-making process with the model. They remedied that problem with the development of the Reduced Form Model. They also developed a modeling approach to determine the unit damages and appropriate trading ratios for different water pollution sources.

R828012 – **The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems** – Palmer, M.

The research team developed 7 models and multiple regression models that provide various types on feedback on land use changes in different scenarios. The new tools and methodologies can help regulators and resource managers better assess the impacts of land-use changes and help guide them through future growth and development.

R828021 – **Linking Environmental and Social Performance Measurements at National Watershed Levels: Modeling and Statistical Approaches** – Farrow, S.

These researchers assessed and modified the National Water Pollution Control Assessment Model (NWPCAM). Their evaluation revealed numerous issues and potential flaws in the water quality model, user interface, and the input databases. The researchers also developed a new Reduced-Form Model that reduces simulation costs and provides managers with capability not available with the NWPCAM.

R828070 – **An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin –** Matthews, O.

The researchers tested and refined a model that simulates potential watershed changes related to water policy options. The model integrates components of physical, environmental, and human systems.

Social Science

R828007 - **The Impact of Lawn Care Practices of Aquatic Ecosystems in Suburban Watersheds –** Ambrust, K.

Researchers conducted homeowner interviews in four neighborhoods to learn beliefs and values about lawn care and lawn-care practices.

R828008 **– Integrating Coral Reef Ecosystem Integrity and Restoration Options with Watershed-based Activities in the Tropical Pacific Islands and the Societal Costs of Poor Land-use Practices** – Richmond, R.

The investigators successfully relied upon social science practices to learn community members' concerns, to communicate their findings with the community, and to support policy changes.

R828009 – **PULSES – The Importance of Pulsed Physical Events for Watershed Sustainability in Coastal Louisiana** – Day, J.

The stakeholder analysis conducted by the researchers revealed that community members generally agreed that loss of coastal land is a significant problem; however, there was less agreement among stakeholders that diversions are the appropriate solution.

R828010 – **Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems** – Lathrop, R.

Researchers examined the social and institutional impediments associated with establishing low-impact development practices in new housing areas and in retrofitting such practices in existing neighborhoods. They obtained social information through interviews with municipal officials, planners, builders, developers, farmers, and new residents.

R828011 – **Identification and Control of Non-point Sources of Microbial Pollution in a Coastal Watershed** – Sanders, B.

Surveys showed that local businesses consider economics associated with beach pollution and cleanup most importantly, whereas beach goers weigh health risks more heavily. Stakeholders also disagreed on the severity of the problem. For example, those associated with environmental groups viewed health risks associated with beach closures as greater than beach-goers viewed them.

R828070 – **An Integrated GIS Framework for Water Reallocation and Decision-making in the Middle Rio Grande Basin –** Matthews, O.

Stakeholders from government and environmental and business groups were involved throughout the project. They identified specific problems and policies related to water allocation in the Middle Rio Grande, identified future-use scenarios, and participated in computerized simulations of water allocation decision-making using the model modified in this project.

Urban

R828007 - **The Impact of Lawn Care Practices of Aquatic Ecosystems in Suburban Watersheds –** Ambrust, K.

Investigators assessed the use of lawn-care products by four metropolitan neighborhoods and a suburban golf course. They also assessed levels of pesticides, nutrients, metals, and insecticides in the streams in these suburban watersheds.

R828010 – **Alternative Urbanization Scenarios for an Agricultural Watershed: Design Criteria, Social Constraints, and Effects on Groundwater and Surface Water Systems** – Lathrop, R.

Researchers examined hydrologic and environmental issues related to urbanization of a rural area. They developed models that account for runoff and determine the effectiveness of infiltration practices at the watershed scale.

R828012 – **The Spatial Patterning of Land-use Conversion: Linking Economies, Hydrology and Ecology to Evaluate the Effects of Alternative Future Growth Scenarios on Stream Ecosystems** – Palmer, M.

This team evaluated multiple effects of land-use change in two sets of watersheds. One set involved older communities outside of Washington, D.C., and the other included two more recently urbanized areas where growth remains rapid.