South Carolina Water Resources Research Institute Annual Technical Report FY 2001

Introduction

As the South Carolina Water Resources Center moves into the new millennium it seeks to find answers to complex water-related issues. These issues many (if not most) times involve linkages between human social systems, biological systems and physical systems. They often involve links between terrestrial and aquatic systems. SCWRC seeks out multidisciplinary research teams in order to research and inform the public on these many complex issues. Below is a representation of some of the institutions SCWRC has partnered with to move research forward.

Recent Collaborators with SCWRC

Oklahoma State University University of South Carolina - Beaufort SUNY Albany USDA EPA Region IV EPA Region I US Forest Service University of Washington University of South Carolina College of Charleston Florida State University NOAA National Ocean Service NOAA Coastal Services Center US Fish and Wildlife Service Cooperative Research Unit Georgia Tech University University of Georgia

Research Program

South Carolina Water Resources Center - 2001

Goals: Land consumption by human activities and resulting affects on land and water resources is going to be a dominating theme of research for the SCWRC in the foreseeable future. Clemson University recently joined the Ecological Resiliency Network, a worldwide consortium of universities interested in the concept of sustainability of ecosystems in the face of increasing human encroachment. We are discussing the possibilities of initiating a land resources research center at STI. It is my hope to combine the SCWRC with this land resources center in order to maximize and efficiently manage the studies of these interrelated resources in the sustainable ecosystems concept. Projects currently underway: Initiating Effective Algae Reduction on Lake Greenwood, South Carolina Funding Agency: USGS/SC Water Resources Center PI: Dr. Grant Cunningham and Sean Blacklocke Clemson University

Reestablishment of an Estuarine Marsh and Waterway after Causeway Removal Funding Agency: USGS/SC Water Resources Center PI: Dr. Carla Curran and Dr. Randall Cross University of South Carolina at Beaufort

Monitoring Coastal Wetland Change and Modeling Ecosystem in SC Funding Agency: NASA/EPSCOR Program Partners: University of South Carolina, College of Charleston

GIS Analysis of Polluted Streams and Animal Agriculture in SC Watersheds Funding Agency: CU Cooperative Extension Service Partners: CU Dept. of Ag and Applied Economics, CU Dept of Sociology

GIS Analysis for the Savannah River Basin Watershed Project Funding Agency: US Environmental Protection Agency Cooperating with many watershed stakeholders

"The Saluda and Reedy River Watersheds Land Use and Water Quality Assessment" Funding Agency: Multiple contributors Partners: Multidisciplinary effort at Clemson University, Lander University and Furman University

GIS-based Database Management and Spatial Modeling for Coastal Ecosystems Funding Agency: S.C. Sea Grant LU-CES Program Partners: University of South Carolina, NOAA NOS Southeast Fisheries Center

Biocomplexity: Consequences of Urban Encroachment on Natural Ecosystems Funding Agency: National Science Foundation Partners: University of South Carolina, SUNY-Albany

Building a Stream Network on National Forest Lands through Spatial Analysis Funding Agency: U.S. Forest Service

Non-point Source Runoff and Water Quality in a Rapidly Growing Urban Watershed

Basic Information

Title:	Non-point Source Runoff and Water Quality in a Rapidly Growing Urban Watershed
Project Number:	2001SC3741B
Start Date:	7/1/2001
End Date:	6/30/2002
Funding Source:	104B
Congressional District:	Second
Research Category:	Not Applicable
Focus Category:	Non Point Pollution, Surface Water, Water Quality
Descriptors:	Watershed, organic carboon, dissolved oxygen, pH, nutrients
Principal Investigators:	Stefka G. Nikolova Eddins, Douglas F. Williams

Publication

Statement of Critical Regional Water Problem

Between 1970 and 1990, population in Richland county has increased by over 20% (South Carolina Statistical Abstract, 1999), and has been continuing to grow (Dobson et al., 2000). As a result, the potential for introduction of non-point source runoff in various county watersheds has been intensifying. Non-point source pollution encompasses runoff from land surfaces after rain events or snow melts. Various environmentally harmful entities, such as sediments, oil, grease, litter, pesticides, fertilizers, bacteria and nutrients, may be detected in non-point source runoff. These materials find their way to lakes, streams, wetlands, and even groundwater, and gradually deteriorate water quality, leading not only to destruction of wetlands and wildlife habitat, contamination of drinking water, but also to economic losses from diminishing property value and low recreation potential.

This study will focus on the Gills Creek watershed, South Carolina, which is a highly urbanized water system (1,620 people per square mile, DeVier, 1999) located in central Richland County. For a year, the study will monitor and document the impact of non-point source runoff on water quality in the Creek, following rain storm events. We chose the Gills Creek watershed because it has been characterized by poor water quality for over 30 years. This watershed is an important water resource in the South Carolina Midlands, because it is currently classified as FW by the South Carolina Department of Health and Environmental Control (SC DHEC). This classification allows for all major water uses, including supply of drinking water after conventional treatment (DeVier, 1999). Gills Creek flows in the Congaree River. Part of the river's flood plain is occupied by the Congaree Swamp National Monument, which preserves in its wilderness state "the largest intact tract of old-growth bottomland hardwood forest in the United States" (National Park Service, 2000). The monument not only supports a variety of recreational activities (National Park Service, 2000b) but also serves as an International Biosphere Reserve, National Natural Landmark, Wilderness Area, and a Continentally Important Bird Area (National Park Service, 2000a). Moreover, Gills Creek runs through the site of a controversial, 4,600 acre development project that has been proposed by the Burroughs and Chapin Company and will include homes, golf courses and businesses (Davis, 2000; Hill, 2000). It is logical to expect that if the Burroughs and Chapin development proceeds as planned, then Gills Creek water quality will potentially deteriorate further. Thus a detailed baseline investigation of the impact of non-point source runoff on Gills Creek watershed is necessary for the adoption of best management practices for this valuable water resource in Richland County.

Statement of Results or Benefits

Locally, this study will serve a twofold need. First, it will provide a detailed look at the impact of non-point source runoff on water quality in the Gills Creek watershed before the development proposed by the Burroughs and Chapin Company. Second, should the development proceed, our results will not only serve as a baseline in an environmental monitoring program, but also as relevant material to educate the developers as well as the public- potential property owners.

Regionally, and even nationally, the study will draw attention to the impacts of urban sprawl and development on the nation's water resources, regardless of resource magnitude. development and associated urban sprawl and non-point source pollution are serious problems which have been subjected to continuing policy debate (Dobson et al., 2000). It is conceivable that one possible solution to these problems will be the introduction of federal legislation, in which case, studies like this proposed one will be needed to demonstrate the need for such a measure.

Nature, Scope and Objectives of the Research

The proposed project is field-based, with daily water sampling and physical parameter measurements for a week following rain events in the watershed over the course of twelve months. The project's scope is local-to-regional, as the research focuses on a watershed located in one of the fastest growing areas of Richland county, however, the research addresses a wide spread regional problem, namely rapid and uncontrolled urbanization and resultant deterioration of water quality. The project will aim to:

1) Establish a comprehensive, year-long record of non-point source runoff generated after rain events in the Gills Creek watershed.

The Gills Creek watershed is characterized by an average of 15 storms / year, with precipitation exceeding an inch, and 33 storms / year, with precipitation between 0.5 and 1 inch (South Carolina Department of Health and Environmental Control, 1997). Combined, these yearly frequencies add up to a rate of one storm with precipitation exceeding 0.5 inches occurring approximately once every week. Such high frequency suggests that pollutant may be supplied faster than the watershed can manage to "buffer" them. Specifically, following a rainstorm, one would expect that the concentration of dissolved oxygen in the water column would decrease, while nutrient concentration and biochemical oxygen demand will increase. The concentration of total suspended solids would increase, thus limiting light penetration for photosynthesis and the resultant replenishment of oxygen in the water column. Such conditions place aquatic organisms and plants under certain levels of stress. If conditions in the water column do not return to normal before the next storm, then water quality will deteriorate rapidly.

2) Compare the magnitudes of non-point source runoff generated after rain events to baseline, background levels of non-point source pollution in the watershed in order to quantify the rate of non-point source pollutant input.

This objective has direct implications for the recommendation of best management practices to reduce non-point source pollution in the Gills Creek watershed. Because of the expected high pollutant input rates resulting from frequent rain storms in the area, measures for reduction of non-point source pollution in the watershed will have to include both a decrease in pollutant inputs and an increase of riparian buffers in the watershed. Because urban development in the watershed would increase the area of impervious surfaces, making it easier for direct introduction of pollutant runoff in surface waters, construction of adequate riparian buffers becomes especially important.

Proposed Timeline of Activities

Even though funding is requested for 12 months only, i.e. for the duration of the field and analytical components of the proposed project, we anticipate that this project will actually be completed in 18 months, with additional six months (no-cost) needed for data interpretation, presentation and publication. The project's field and analytical components will begin in July of 2001, and will end in June of 2002. Samples will be collected daily for a week following rain events in the Gills Creek watershed, and will be analyzed immediately following each sample collection.

Methods, Procedures, and Facilities

Water samples will be collected daily, over the course of 12 months, for a week following rain storm events in the Gills Creek watershed. In addition, physical parameters, such as water turbidity, water and air temperature, as well as meteorological conditions will be recorded. Water samples will be collected using a 1 L stainless steel Kemmerer bottle. Subsamples will be set aside for total suspended sediment, nutrient (ammonia, nitrate-nitrite, and ortho-phosphate), and biochemical oxygen demand measurements. Dissolved oxygen, water temperature, pH and turbidity will be measured directly in the field using a HYDROLAB H2O® multiprobe system. In addition, meteorological conditions will be recorded and rain storm information (type, duration, magnitude) will be gathered from the State Climatology Office.

Our sampling scheme will replicate the three sampling stations in the Gills Creek watershed that are currently monitored by South Carolina Department of Health and Environmental Control (figure 1). Proceeding downstream, station C-068 is located at the dam on Forest Lake. Station C-001 is located in Gills Creek, at the US Highway 76 bridge, and station C-017 is furthest downstream, on Gills Creek, at SC Highway 48 (figure 1). SC DHEC yearly average data indicate that biochemical oxygen demand is highest at station C-001, and lowest at station C-068. Ortho-phosphate concentration is lowest at station C-068, but similar for the remaining two stations (South Carolina Department of Health and Environmental Control, 1997). In addition to these three stations, we will add a fourth one, GC-CR, right at the confluence of Gills Creek and Congaree River (figure 1).

In the lab, total suspended solids will be measured gravimetrically, using a 0.45 µ membrane filter (Metricel). Ammonia, nitrate-nitrite, and ortho-phosphate concentrations will be measured spectrophotometrically. Specifically, ammonia will be measured using the indophenol method outlined by Grashoff (1976); nitrate-nitrite will be measured using the cadmium reduction method, and ortho-phosphate - using the

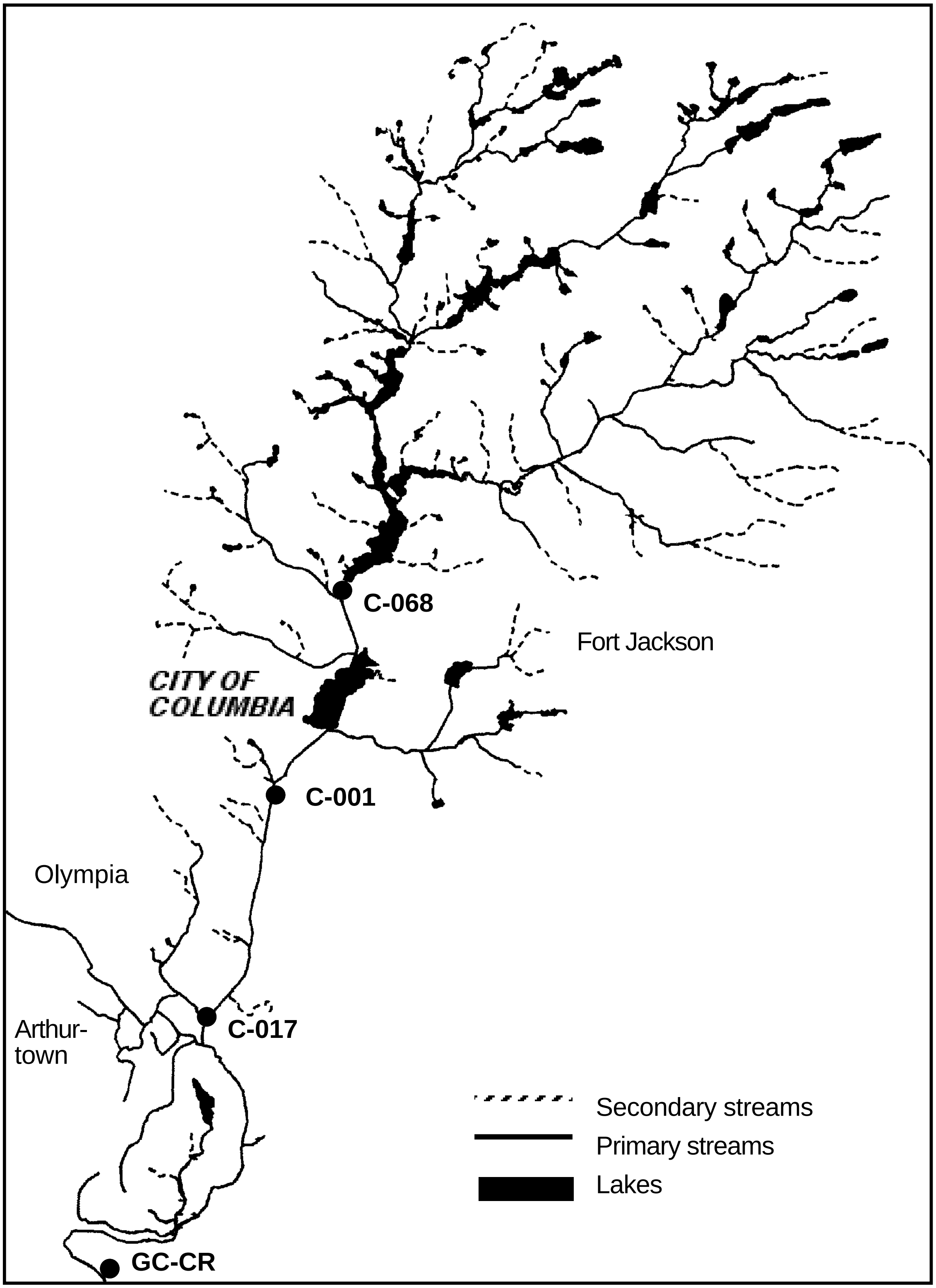

Figure 1. Map of Gills Creek watershed with sampling stations.

Morphy-Riley method (Grashoff, 1976). All data handling and statistical calculations will be performed using Microsoft Excel software.

All sample analyses will be conducted at the Stable Isotope Lab at the University of South Carolina. A HACH DR 2000 direct reading spectrophotometer is available at the lab. A HYDROLAB H2O® multiprobe system will be borrowed from the Bureau of Water, SC DHEC (contact person: Mr. David Chestnut).

Related Research

The South Carolina Department of Health and Environmental Control began monitoring the Gills Creek watershed in 1994, part of an initiative called "The Gills Creek Nonpoint Source Pollution Project", which continued through 1996 (South Carolina Department of Health and Environmental Control, 1997). The goal of the project was to observe non-point source pollution in the watershed in order to recommend appropriate control measures in surrounding communities. Following the completion of the project, which was initiated under the mandate of the 1987 Clean Water Act amendments (DeVier, 1999), SC DHEC has continued monitoring the watershed on a regular monthly basis, including observations of nutrients, dissolved oxygen, fecal coliform bacteria, five -day biochemical oxygen demand, pH, total suspended solid data are available from SC DHEC. We will use these long term data as baseline information in order to compare with the observed values following rain events.

Training Potential

The proposed study has an excellent student training potential, as it will be linked with an established undergraduate research program at the University of South Carolina - Columbia, the Marine and Aquatic Research Experience program (MARE, *mare*, Latin for sea).

MARE is a field-intensive, student-directed program in which teams of undergraduates design and execute their own research agenda, and enlist faculty and technical staff as partners and mentors in their research. Since its inception three years ago, MARE has conducted eight research expeditions on the second largest watershed on the East Coast, Winyah Bay, South Carolina. Over 60 marine science, biology and engineering majors from the University of South Carolina have been involved in these expeditions. Currently the MARE students have organized themselves into geological, chemical, biological and physical thematic research groups. The students have started to accumulate a database of protocols, associated materials and results which have been presented nationally (Benson et al., 2000a,b; Ranhofer et al., 2000; Robinson et al., 2000).

Because the Gills Creek watershed is close to campus, this proposed project will be able to involve students in all research steps: field sampling activities, sample analyses, data interpretation and presentation. Students will also be involved in preparation of results for publication in refereed journals. Currently, MARE includes approximately 20+ marine science, geography, engineering, biology and geology majors.

For a detailed report of number of students to be trained, please see Appendix C.

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Using Spatial Techniques to Assess the Contribution of Animal Agriculture on Watershed Impairment for the Saluda River Watershed in South Carolina

Basic Information

Title:	Using Spatial Techniques to Assess the Contribution of Animal Agriculture on Watershed Impairment for the Saluda River Watershed in South Carolina
Project Number:	2001SC3761B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	Third
Research Category:	Not Applicable
Focus Category:	Agriculture, Hydrology, Models
Descriptors:	Watershed water quality agriculture impairment
Principal Investigators:	Donald van Blaricom

Publication

STATEMENT OF CRITICAL REGIONAL OR STATE WATER PROBLEM

As basic natural resources become more scare with increased population and development, various government entities come into conflict with each other over these resources. Clean water and clean air are basic resources any community needs to support life and maintain living standards. Already in the Southeast US, conflicts have arisen between communities over the right to clean water versus the need to develop economically. A prominent national example has been the dispute between Canton, NC on the Pigeon River and towns and citizens downstream from Canton. The question persists, does one community, in its efforts to develop a strong economic base have the privilege of spoiling water or air resources that must also be used by communities downstream or downwind? Answering these questions is more in the realm of law and land use policy. However, as these issues become more heated, there arises a need for clear fundamental research into cause and effect as it relates to clean water and air. In cases such as Canton, NC, a single paper mill can clearly be seen to impair out-flowing water quality. Much different is the circumstance such as the dispute between Greenwood and Greenville, SC. Greenwood takes its drinking water from Lake Greenwood on the Saluda River (Fig. 1). Upstream lies Greenville. The Reedy River, a tributary of the Saluda, flows through downtown Greenville. The upper reaches of the Saluda flow through the greater Greenville metropolitan area. Greenville has a famously protected municipal reservoir and prides itself on the quality of its drinking water. The Greenwood reservoir, on the other hand, shows many of the symptoms one might expect from a "downstream" water resource: sedimentation, nutrification, and algae blooms. Therein lies the debate. Water flowing into Greenville reservoir is clean. Water flowing into Lake Greenwood is much less so.

Professionals working in resource management, water quality, land use and such may feel there is abundant research tying land use/land cover to water quality downstream. Certainly much research has been aimed at this issue. What becomes apparent in listening to disputes between communities is the extent in which fundamental research does not translate to sound policy or even to informed debate. One community can assert, using "conventional wisdom", often supported somewhat by research, that agricultural land use is a severe stress on water quality. As such, it is the quantity of agricultural land on within the Saluda Watershed that may cause the impairment. This point of view gains support following well-publicized stream contaminations at swine farm sites in NC in the mid 1990s. The other community, citing other "common knowledge" claims that urban/suburban/industrial land use is the most damaging. Again, research may even be cited in support of this. What is missing is information tying the specifics of reservoir impairment to specific land use in the watershed above the impairment. In other words, in this particular case, what appears to account for the bulk of the impairment to the inflow of Lake Greenwood. Without this level of information, debates between communities regarding water quality cannot rise above accusation and finger pointing.

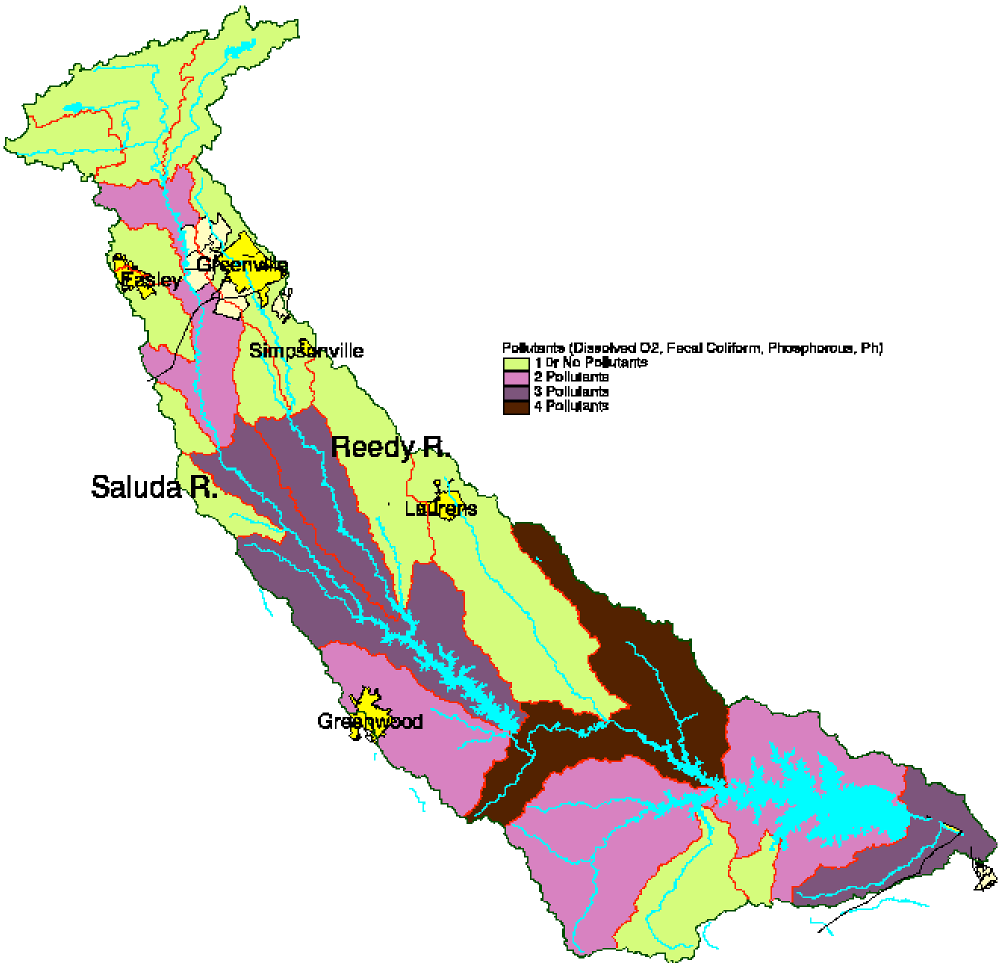

Figure 1.

STATEMENT OF RESULTS OR BENEFITS

For policy makers to make sound decisions on water quality they need sound information. Their information must be correct but also appropriate to the scale that they operate. Highly detailed studies showing the transport of sediment and nutrients across different land covers do not help a planner assess which of two possible sources of water impairment is most critical. Region wide studies showing trends in water quality also do not indicate whether those trends hold for a single watershed of interest.

We are seeking to provide a level of information targeted to the subject at hand. Do animal agricultural populations account for the level of impairment of tributary streams to Lake Greenwood? Do human populations better account for the impairments? In this way, we hope to provide a better level of information to the public debate on water quality. The issues are real and important to the communities involved, and only when research data be provided to policy makers in an understandable form can it be used in the public forum to guide land use policy.

NATURE, SCOPE AND OBJECTIVES OF THE RESEARCH

The proposed research effort seeks to clarify this specific water quality issue by using real, publicly available data, to relate land use in the various watersheds above Lake Greenwood tributaries to water quality from those tributaries. Specifically, we will try to determine if impaired tributaries are related more to agricultural animal populations or to human population.

This effort will be confined to the Saluda River Watershed above and including Lake Greenwood. This watershed includes the Reedy River tributary. The cities within the watershed are Greenville, Greenwood, Laurens, Simpsonville, and Easley, SC. There are 19 USGS, 11-digit hydrologic units within the Saluda River watershed.

An attempt to quantify the mechanism of impairment by collecting field data throughout the watershed would be well beyond the scope of this research funding. What we intend to do instead is use available, public data on human population, agricultural animal intensity, land use/land cover data, and water quality measurements on Lake Greenwood, to see which of these "domestic" animals populations might statistically account for more of the water quality impairment.

In parallel with statistical correlation, we will run EPA's BASINS model as a recognized benchmark with which to compare our statistical model.

METHODS, PROCEDURES AND FACILITIES

This effort intends to be less a data collection process and more of a data gathering, processing, and interpreting task. The input data sets will be publicly available animal and human population information supplemented with ongoing water quality data collected in Lake Greenwood , collected by Lynn Deanhardt Professor of Chemistry at Lander University. Other data such as land use and elevation models will be used to round out the processing.

First water quality information will be acquired on the tributaries of Lake Greenwood. These data are being collected continually for a research effort conducted by Dr. Deanhardt, funded by a private foundation. Several techniques were used to record levels of nitrate and phosphorous in lake water (2). These parameters are common indices of nutrient load.

The locations of these sample sites are fixed and known. We will build watersheds above these sites using USGS 30-meter Digital Elevation Models and GIS software. In this way the watershed boundaries will not necessarily correspond to USGS watershed boundaries, but will be specific to each sample point. The watershed boundaries will be used to accumulate the animal, human, and land use data much as they accumulate the water flow through the sample point.

The agricultural animal population will be derived from two sources. USDA agricultural census data from 1997 will provide animal counts. These data are currently on-line at the Strom Thurmond Institute and are coded by zip code. These data will be converted to per/acre values so that they may be later overlaid with watershed boundaries and summed to provide population by watershed. We will focus on cattle, swine and poultry populations from these data, though the data will be most useful in assessing cattle and swine population densities.

SC Department of Health and Environmental Concern or DHEC maintains data on agricultural facilities. These data are site specific, including spatial coordinates. These data indicate the type of facility, its location, and an indication of its size. This type of data is well suited for spatially specific modeling rather than assuming that all animal populations are distributed evenly throughout a zip code area. As such it is better suited for accumulating information by watershed boundary. For some animal populations such as poultry, the number of facilities is a better indicator of animal density that simple population of animals. We will use the data that best represents population density for each animal class.

US Census data from 1990 or 2000, summarized at the block or block group level will be used as the source of human population. These data show population in terms of individual people, households, families, and housing type. It is assumed that population alone will be sufficient for our analysis but the greater depth of data will be available if it is needed. US Census data is currently stored on-line at the Strom Thurmond Institute and used in support of several ongoing programs and research efforts. These data are linked to block, block group, and tract boundaries to provide adequate spatial resolution. Still, since the data is not aggregated by watershed boundary, it will need to be expressed in per acre units to allow for overlaying with watersheds.

We will need an overall assessment of land cover and land use for our parallel BASINS modeling. This data will come from SC Department of Natural Resources' (DNR) GAP analysis. This classification provides over 70 levels of land use information. This classification is made using 30 meter LANDSAT TM data and is of sufficient resolution to give an overall land use profile within each watershed boundary.

Task 1:

Using the derived watershed boundaries, animal and human population data will be aggregated by watershed, for each of the watersheds. Statistical regressions and correlations will be performed on this aggregated data. The goal of these analyses is to determine which populations can account for more of the variation in water quality for each sub-watershed. Further, this statistical analysis will seek to determine the proportion of water quality impairments accounted for by human and animal populations together.

Task 2:

Many water and land resource professionals are familiar with EPA's BASINS water quality and quantity model (3, 4, 5). This software is available within ESRI's Arcview GIS package. BASINS uses land use GIS data with many other parameters, including rainfall and topography to predict the quantity and quality of water flowing through a watershed pour point. BASINS can be calibrated using available water quality information. We will use the data from Lake Greenwood for this purpose.

The primary purpose of using the BASINS model in parallel with Task 1 is to provide a comparison of our model with a familiar index of water quality and not as a goal of its own. The purpose of this project is to provide specific water quality information for public policy professionals in a form readily understood by the public. Still we recognize the need to relate this analysis to accepted and familiar models in order to gain the trust of land and water resource professionals and provide a context for our model.

RELATED RESEARCH

In the wake of well-publicized water contamination problems in NC involving large-scale swine farms, there was great concern in South Carolina over the prospect of a similar problem in SC. The public was justifiable concerned with water quality and the prevailing public opinion was tilted toward the assumption that animal agriculture was a primary contributor to water pollution. The SC legislature, in the mid to late 1990s, enacted a very restrictive farm bill, essentially curtailing large scale hog farms, partially based on this public opinion, and perhaps without a sound scientific basis. The SC Agricultural Extension sought to determine public sentiment on agriculture and water quality. SC extension conducted surveys and compiled data that was later published in a book "Animal Agriculture in South Carolina: A Fact Book." The Strom Thurmond Institute contributed to this effort by creating maps of agricultural animal populations and watershed impairment. These maps and associated analyses were found in the article "Spatial Relationships of Polluted Streams, Animal Agriculture, and Human Population in South Carolina Watersheds" (1) in 1998. USDA Agricultural Census data from 1992 were displayed on top of USGS 8-digit watersheds, coded by SC DHEC 303d assessment of impairment. The 303d impairment information indicates whether or not a watershed is impaired on a certain parameter, including dissolved oxygen, fecal coliform, phosphorous, and pH. This information is then classed 0 (unranked), 1, 2, or 3 based on the number of impairments. No statistical analysis was attempted on this data. This was simply a mapping of available data. The maps seemed to suggest, though, that animal agriculture was not the only contributor to water quality impairment, at least in SC.

When the maps were published, the level of public, government and farm industry interest in the maps was striking. Many pointed out some flaws in this simplified mapping approach to the issue. Among the weaknesses were:

- The maps were made using 8-digit hydrologic units for watershed impairment, which is too coarse in spatial resolution to truly assess site specific impacts on water quality,
- The "assessments" were purely visual interpretations of the maps and not supported by statistical analysis,
- DHEC's 303d assessment is somewhat coarse and difficult to translate into quantifiable water quality indexes, and
- Many people disputed the conclusions inferred from the maps.

There was sufficient interest in this analysis to fund a second phase of the project to address some weaknesses of the first project. In the second phase, updated data were used and the spatial resolution improved:

- USGS 11-digit hydrologic units were used, greatly increasing the spatial resolution of the water quality data.
- Updated Agricultural census data from 1997 were used.
- Agricultural Census data was supplemented with SC DHEC animal facility data to give better spatial resolution to the animal population data, showing the spatial pattern and areas of concentration of agricultural populations.

- Statistical, canonical regressions were performed to quantify the relationships between animal agriculture populations and water quality impairments.

This project still used a statewide, macro approach to the issue and while showing overall patterns, did not show how animal populations might affect water quality in specific areas. This project is ongoing, but preliminary statistics indicate that there is a weak but significant correlation between animal agriculture populations and watershed impairment ($F=2.4140$ $R^2 = .259$). This analysis seems to support the visual information in the previous maps that animal agriculture alone does not account most of the variation in water quality in watersheds.

Reservoir Shoreline Erosion and Sediment Deposition with Cohesive Sediments

Basic Information

Title:	Reservoir Shoreline Erosion and Sediment Deposition with Cohesive Sediments
Project Number:	2001SC3781B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	Third
Research Category:	Not Applicable
Focus Category:	Sediments, Acid Deposition, Surface Water
Descriptors:	cohesive sediments, reservoir circulation,reservoir bank erosion, sediment transport, reservoir sedimentation
Principal Investigators:	Paul A. Work

Publication

1. Elci, Sebnem and Paul A. Work, 2002, Prediction of Shoreline Erosion and Sedimentation in Hartwell Lake, SC/GA, Georgia Tech Regional Engineering Program Civil and Environmental Engineering, Report No. GTREP-CEE/2002-1, South Carolina Water Resources Center, Clemson University, Clemson, South Carolina, 97 pages.

Reservoir Shoreline Erosion and Sediment Deposition with Cohesive Sediments

Statement of critical regional or State water problem

Man-made reservoirs fulfill a variety of needs; those found in the southeastern United States were typically built with flood control, power production, recreation, and water supply needs in mind. Water quality and quantity issues have both become more prominent in recent years as awareness of biological and hydrological issues and limitations have become more recognized.

Reservoir operators or regulatory bodies often impose building limitations to enforce no-development zones, sometimes in the form of buffer strips along the reservoir shoreline. Such setback regulations should consider multiple factors, including regional biology, hydrology, and long-term reservoir evolution, including shoreline erosion. Allowing development in regions with high erosion rates leads to expensive and often unattractive shoreline armoring that may also be detrimental to flora and fauna, terrestrial and aquatic. In coastal settings, setback regulations are common, and are usually based on site-specific, long-term erosion rates, but reservoir regulations rarely consider site-specific erosional conditions.

The proposed project involves development and refinement of techniques for prediction of reservoir shoreline erosion rates and depositional zones. The project is thus relevant to many different problems, related to land use planning, habitat evaluation, contaminant transport, and even real estate development. Although one reservoir will be the focus of the study, the methods applied will be suitable for other sites.

Some previous work on this problem has been done by the principle investigator. A pilot study led to predictions of relative erosion rates for one reservoir (Hartwell Lake, on the Savannah River in the Piedmont region of SC/GA), and an ongoing companion study with colleagues in the biological sciences is investigating grasses, shrubs, trees, and geotextiles suitable for natural-looking erosion control on artificial reservoirs with cohesive sediments and fluctuating water levels. A number of end-users of study findings have been included in discussions of project methods, sites, and results: Soil Conservation Service personnel, landowners (individual homeowners, as well as multi-user properties, such as a local sailing club), State of South Carolina Dept. of Natural Resource employees, U.S. Army Corps of Engineers personnel, representatives from Duke Power, and a local company specializing in shoreline armoring on reservoirs.

The proposed project is also relevant to contaminant transport problems. In addition to investigating long-term shoreline erosion, the fate of the eroded sediments will also be addressed. Predictions of reservoir hydrodynamics will indicate likely zones for deposition of the eroded sediment. This information is relevant for prediction of the fate of any contaminants sorbed onto the sediments, a problem particularly relevant at the chosen study site, where a tributary contributed large amounts of PCB contaminants. The U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and private contractors have all been involved in predicting the fate of the contaminated sediment, but their predictions have focused primarily on the upper reaches of the lake, and the transport of non-cohesive sediments. The new project will concentrate on the downstream portion of the lake, and the cohesive sediment fraction, which has the potential to travel greater distances.

Statement of results or benefits

The project will yield a method for making objective, quantitative predictions of shoreline evolution on a reservoir featuring cohesive sediments, and describing the fate of the eroded sediment. Site-specific results will be provided for Hartwell Lake, SC/GA, and presented in tabular and graphical form to illustrate long-term erosional risk as a function of location on the lake. Predictions will be calibrated by comparison to available data indicating shoreline change from two sites on the lake.

Nature, scope, and objectives of the research (include a timeline of activities)

Most previous studies for modeling changes in shoreline morphology have addressed erosion and accretion on exposed ocean coasts, typically with non-cohesive sediments in a relatively energetic environment. Reservoir bank erosion is a different process, particularly when the reservoir shoreline is composed of a significant amount of fine, cohesive sediments. Waves strike the shoreline and put the fine sediment into suspension. The fall time for this sediment is much greater than that for sand, so even the slightest current can advect the sediment away from its source. The freshwater environment makes flocculation less significant than in saline water, so the erosion problem may be even more pronounced than in a tidal estuary or coastal setting with a similar energy level.

Bathymetry, and water level time histories will differ significantly between the reservoir and coastal settings as well. Reservoirs are optimally quite deep to achieve suitable flood protection and power generation benefits, with bathymetry that is much steeper than the typical nearshore coastal region. Water level fluctuations on reservoirs may be greater than the tide range in most coastal regions, and the time scale of the fluctuation is typically much longer. Severe storm surge at a coastal site might elevate the mean water level by several meters for several hours (e.g. Garcia 1995), whereas a severe flood in a watershed might increase the water level in a reservoir by meters for days to weeks. Lastly, there are obviously significant differences between waves on a reservoir and those at a coastal site, primarily because of the vast difference in fetch. Because of the reduced fetch in the reservoir setting, wave heights and periods will be substantially less. Short period waves in deep water are unaffected by bathymetrically induced wave transformation (shoaling, diffraction and refraction). Wave transformation should therefore be largely negligible on most reservoirs, compared to the coastal setting.

The proposed project has three primary objectives:

1) Refine and calibrate an objective technique for prediction of long-term shoreline evolution on man-made reservoirs featuring cohesive sediments.
2) Make predictions of erosion hazard zones for the test case of Hartwell Lake, SC/GA and present in an easy-to-interpret format.

3) Use an existing three-dimensional, numerical, hydrodynamic model to make predictions of depositional zones for fine sediments within Hartwell Lake, SC/GA.

The project timetable is as follows:
Month 1: Acquire all necessary data to drive the hydrodynamic model and to make predictions of shoreline change.
Months 2-3: Make predictions of long-term shoreline change for the two chosen verification sites, including the influences of water level fluctuations and spatial variations in scarp height and beach slope. Develop computational mesh for hydrodynamic model.
Months 4-6: Refine and calibrate shoreline change prediction methodology. Perform initial hydrodynamic model runs.
Months 6-10: Make predictions of shoreline change for selected sites around the downstream (largest) portion of Hartwell Lake. Perform hydrodynamic model runs for selected forcing conditions and determine depositional zones.
Months 10-12: Perform final model runs and develop project report and journal and conference publications.

Methods, procedures, and facilities

Two modeling procedures will be employed to generate project results. One will provide predictions of erosion rates at chosen locations around a reservoir, based on reservoir and shoreline geometry, sediment type, and wind and water level conditions. The second model will yield predictions of zones where fine sediments either eroded from the shoreline or carried into the reservoir by tributaries will be deposited.

The approach to shoreline change prediction is adopted from similar studies of coastal shoreline change. Bank erosion is assumed to be driven primarily by breaking waves, as mean flows are typically too slow to put consolidated, cohesive sediments into suspension, although these mean currents (caused by horizontal pressure gradients arising from inflows and wind) are important in controlling where the eroded sediment is later deposited.

Sediment transport rate is assumed proportional to the power of the flow or waves (e.g. Bagnold 1966). This approach has been used for both longshore sediment transport (Watts 1953, Caldwell 1956, Komar and Inman 1970) and for cross-shore sediment transport (Kriebel and Dean 1985, Larson and Kraus, 1987). Longshore sediment transport predictive equations typically involve the longshore component of wave power, which is zero for shore-normal waves. For waves incident on a cohesive shoreline, however, even shore-normal waves will put material into suspension. If the fall time for the sediment is large and a mean flow is present, the sediment will be carried away before falling back to the bed.

Wave power at breaking may be shown to be proportional to wave height to the 5/2 power. It is therefore assumed that erosion rate would be proportional to this quantity.

$$Erosion\ rate \quad H_b^{5/2} \tag{1}$$

where H_b is wave height at breaking. Obviously prediction of quantitative erosion rates requires knowledge of the coefficient of proportionality.

Since the exponent appearing in Equation (1) is not unity, one cannot simply use the mean wave height to make predictions of long-term erosion rate. Instead, a summation will be employed to capture this time dependency:

$$Erosion\ Rate = \overset{N}{\underset{n=1}{}} k_n H_{b_n}^{5/2} \tag{2}$$

where N denotes the number of observations and k_n is a coefficient of proportionality. Of course this approach does not explicitly include any dependence on reservoir bathymetry, water level (stage), sediment type or size, presence of vegetation, or shoreline geometry. But most of these factors will also be incorporated into the model.

If wind speed and duration, fetch, and water depth are known, wave height and period can be computed using wave forecasting equations (U.S. Army Corps of Engineers 1984). “Deep water” is a relative term, implying that wavelength is no more than twice the water depth. This condition is met for most waves on most hydropower reservoirs, except very close to the shoreline. For this project, wave forecasting equations for deep water conditions will be employed to determine wave heights away from the shoreline, and then shoaling and refraction processes will be included analytically (Dean and Dalrymple 1984) to determine wave heights at breaking.

Water level plays an important role in the reservoir erosion problem by moving the shoreline back and forth as the water moves up and down. A steep, eroding scarp often develops. Erosion at the toe of the scarp leads to slumping and potential rapid erosion. In order to incorporate this process into the model, a simplified geometric representation of the situation has been developed, in terms of two slopes:

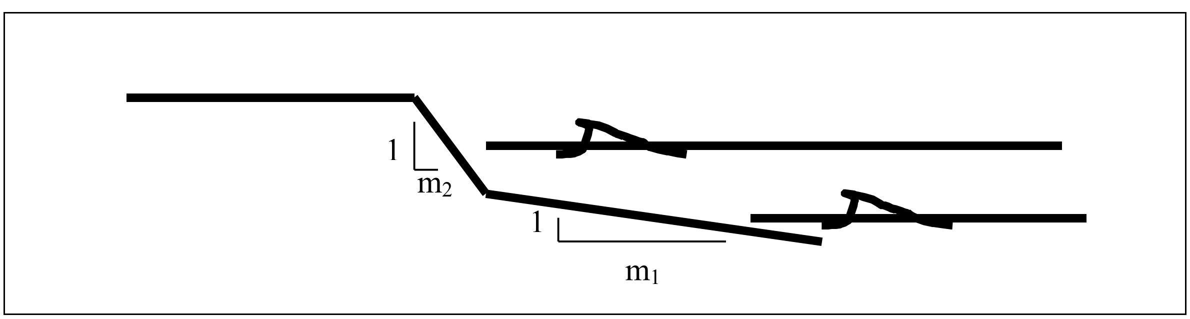

Figure 1. Geometric representation of beach profile.

A description of the erosion rate as a function of the two slopes m_1 and m_2 has been developed so that both water level and wave height are explicitly factored into the calculation. This will allow inclusion of important seasonal variations in both water level and wind characteristics. Previous work has revealed strong seasonal variations in both parameters at the chosen study site.

Two sites on Hartwell Lake, SC/GA, have been surveyed previously with topographic surveying equipment, providing some data on shoreline change. A one-day field trip will be made to visit both sites and collect sediment samples and shoreline position data for model calibration. The sediment samples will be analyzed to determine shear strength and non-cohesive fraction.

Hartwell Lake is a man-made reservoir on the Savannah River, bordering both Georgia and South Carolina. It covers 56,000 acres and has a shoreline of 962 miles (Figure 2). It was built between 1955 and 1963, by the U.S. Army Corps of Engineers, for flood protection, power production, water supply, and recreation purposes. Two additional Corps of Engineers dams (Russell and Thurmond) are located further downstream, and three Duke Power reservoirs (Keowee, Jocassee, and Bad Creek) are located upstream. Hartwell Lake is one of the top 3 most visited Corps lakes in the nation, serving about 10 million visitors annually. It was selected for several reasons: it is widely used, features a large and growing number of residential properties, is convenient for study, and historical data (water levels, discharges, and aerial photographs) are readily available.

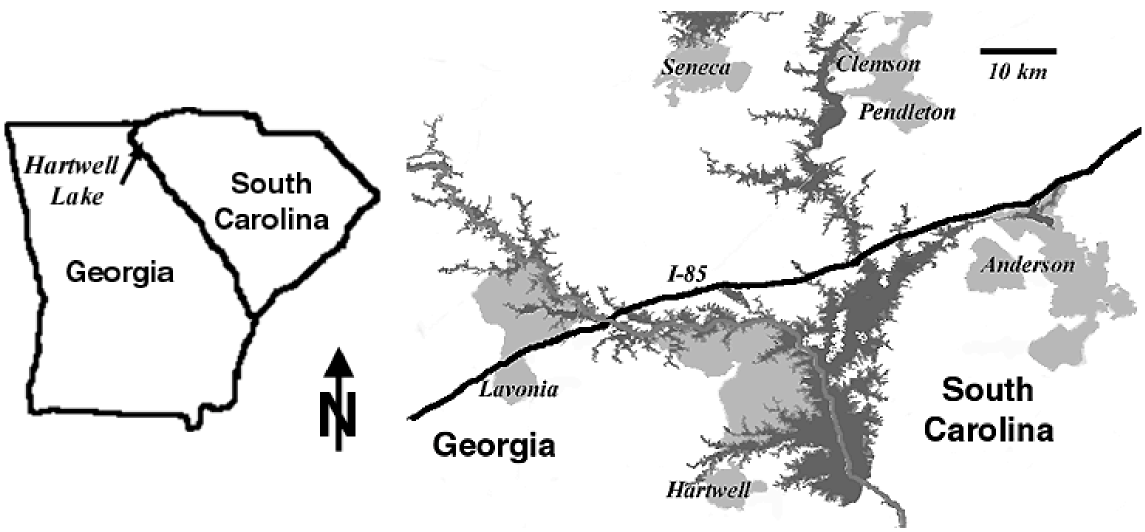

Figure 2. Maps of study area, showing Hartwell Lake on the Savannah River.

The terrain of Hartwell Lake consists primarily of gentle rolling hills and pine forest near the southern terminus of the Appalachian mountain chain. Sediments contain high fractions of silt and clay. Portions of the lake's shores are eroding severely. Vertical bluffs have been carved gradually and are threatening public and private lands (Figure 3).

Figure 3. Erosion at Hartwell Lake, October 1997, resulting in loss of trees. East side of lake.

The methodology described above will be applied to calculate shoreline change at the two chosen calibration locations on Hartwell Lake, and the measurements will be used to calibrate the predictive equation. The approach will then be used to model shoreline change at approximately 25 sites along the shoreline of the main pool of Hartwell Lake. Results will be presented in tabular and graphical form.

The last project objective is related to fate of the eroded sediment, and any other sediment that might be carried to the lake by overland flow or tributaries. A three-dimensional hydrodynamic model of flow within the reservoir will be used. The EFDC (Environmental Fluid Dynamics Code) model (Hamrick, 1996) was chosen for the purposes of this study. This model solves the three-dimensional, vertically hydrostatic equations of motion for a variable density fluid. The model has been successfully applied to Chesapeake Bay, James River, Indian River Lagoon, and the Florida Everglades, as well as several lakes, to investigate transport of sediment, heat, salt, larvae, etc.

Input to the hydrodynamic model includes basin geometry, inflow locations and strengths, and wind forcing. The hydrodynamic model will be used to predict deposition zones for sediment suspended within the water column. Several representative cases will be considered: 1) no wind, low inflow, 2) fall/winter wind, low inflow, 3) fall/winter wind, 10-year inflow, 4) spring/summer wind, low inflow.

The data necessary to run the models are available from the U.S. Army Corps of Engineers, National Weather Service, and published sources. Published topographic maps are suitable for specification of geometry of the lake. Inflow, outflow, and stage data are available from the Corps of Engineers. Long-term wind data are available for Athens Municipal Airport, GA, and Greenville-Spartanburg (GSP) Airport (65 km west and 90 km east of Hartwell Dam, respectively.) Available data include average and peak daily wind speed and corresponding direction, and cover the period 1948-present (Athens) and 1962-present (GSP).

Related Research

Reservoir sedimentation has been the subject of many studies from the standpoint of reservoir operation, efficiency and lifetime (e.g. Arnold et al., 1987; Lo, 1994). Bank erosion will contribute to this problem, but may also be considered as a separate issue (e.g. Penner, 1993). Ferguson and Overend (1998) performed an inventory of erosion problem sites on Clark's Hill/Thurmond Lake, a U.S. Army Corps of Engineers reservoir near Augusta, Georgia, on the Savannah River.

There have been many studies of the erosion resistance of cohesive soils to flowing water (e.g. Mehta et al., 1989). Few studies have focused on erosion of cohesive sediments from reservoir shorelines, however, in a freshwater environment, and clay behavior is quite sensitive to the absence or presence of salts in solution.

Annandale (1996) described an empirical relationship between threshold stream power for erosion of cohesive sediments and an erodibility index. For clay materials the erodibility index is primarily a function of the shear strength of the soil. Kamphuis (1990) and Parson, Morang, and Nairn (1996) describe other empirical techniques for describing sediment erodibility. In these tests, undisturbed samples of consolidated sediment were placed in a drop section of the floor of a high-velocity, unidirectional flow flume. The average rate of erosion was determined by measuring the volumetric loss from the sediment sample within a test period (U.S. Army Corps of Engineers, 1998).

The complexities of the hydrodynamic processes on a reservoir suggest use of numerical modeling approaches to simulate erosion of consolidated sediments. Penner (1993) described an approach to estimate future bank recession rates on Western Canadian lakes and reservoirs. He used a wave hindcast to determine the amount of energy reaching a bluff face, together with an erodibility coefficient to determine the future rate of shoreline recession. The erodibility coefficient is calculated through model calibration for a location with a known history of erosion. Nairn, Pinchin and Philpott (1986), described another approach where downcutting is related to the shear stress generated by orbital velocities under unbroken waves, and to the wave energy dissipation for breaking waves. The predicted downcutting determines the profile retreat rate, which is assumed to determine the bluff retreat rate above water. A more detailed version of this model is described in Nairn and Southgate (1993) and has been applied to sites on the Great Lakes.

Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	1	0	0	0	1
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	2	0	0	0	2

Notable Awards and Achievements

One poster presentation and proceedings publication was done using data from the project "Assessment of Conditions and Public Attitudes Concerning Marine Sanitation of the Lakes Encompassed by the Savannah River Watershed Region: Policy Projects for the Future" for the College of Health, Education and Human Development Faculty Research Forum, March 31, 2001, Clemson University, Clemson, SC.

One poster presentation using data from the project "Assessment of Conditions and Public Attitudes Concerning Marine Sanitation of the Lakes Encompassed by the Savannah River Watershed Region: Policy Projects for the Future" was selected by the graduate deans of Clemson University to be on display April 19, 2001 at the Annual Catfish and Guts Dinner for the State legislatures. This poster was only one of twelve posters chosen for this event.

Publications from Prior Projects

1. Backman, Kenneth F. and Sheila J. Backman, 2001, Assessment of Conditions and Public Attitudes Concerning Marine Sanitation of the Lakes Encompassed by the Savannah River Watershed Region, South Carolina Water Resources Report, South Carolina Water Resources Center, Clemson University, Clemson, South Carolina, 53 pages.
2. Backman, Sheila J. and Kenneth F. Backman, 2001, Perceptions of Water Quality in the Five Lake Savannah Watershed Region in College of Health, Education and Human Development Faculty Research Forum, Clemson University, Clemson, South Carolina, 3 pages.
3. Curran, Mary Carla, Randall Cross and Earl J. Hayter, 2001, South Carolina Water Resources Report, South Carolina Water Resources Center, Clemson University, Clemson, South Carolina, 11 pages.