South Carolina Water Resources Research Institute
Annual Technical Report
FY 2002

Introduction

The director and staff have had an extremely productive year as they continue to build the SC Water Resources Center and the STI Spatial Analysis Laboratory into formidable research units. Listed just below are the three major project areas the director has guided this past year. As projects continue to be funded at an unprecedented pace, the staff will need to work on being more efficient with time and personnel management in order to keep projects moving in a timely and responsible fashion.

Land Use Change STI and SCWRC have been involved in three large projects that have the changing landscape of South Carolina as their focus. The Prime Lands Initiative was a comprehensive investigation of changing land use especially as it relates to prime agricultural and forest lands adjacent to growing urban areas. CLUE is a multidisciplinary project studying the relationship of changing land uses to water quality changes in selected South Carolina Rivers. LUCES is a collaborative venture between several South Carolina and Georgia universities to understand the relationship between changing coastal land uses and resultant changes in coastal ecology.

Biocomplexity STI and SCWRC are also involved in three separate but related studies funded by the National Science Foundation. These studies are using different methodologies to try to gain understanding into the complex relationships and linkages between ecological, physical, social and economic systems. These projects will lead to model building exercises resulting in better information for managers and policy makers regarding human-influenced and natural systems.

Agreement with SpectroTech, Inc. In March 2001, SpectroTech Inc. (SPT), a private company based in Greenville, SC, and the Strom Thurmond Institute agreed to conduct a joint research project involving airborne remote sensing of the environment. The terms and conditions of the agreement allow SPT to provide an aircraft and hyperspectral imaging system for selected data collection and the Institute to provide imagery analysis services using the existing Spatial Analysis Laboratory resident at the Institute. Ownership of the imagery data would be joint in all cases. Additionally, the two parties agreed to endeavor to secure funding for additional research beyond the level that could be supported by SPT or the Institute.

Research Program

Research Publications and Projects Initiated in 2001-2002

Allen, Jeffery S. and Kang S. Lu. 2002. Animal Agriculture and Watershed Impairment in South Carolina. Report submitted to PSA Agrisystems Productivity and Profitibility Competitive Grants Program.

Allen, Jeffery S. and Kang S. Lu. 2002. Modeling and Predicting Future Urban Growth in the Charleston, South Carolina Area. Paper submitted and accepted for a special issue of Conservation Ecology.

Allen, Jeffery S. 2003. The Human Demography of Coastal South Carolina and Georgia. Book chapter in Low Country in Flux. How changing land use patterns in the American Southeast affect coastal ecosystems. G.S. Kleppel, M. Rawson and M.R. DeVoe (eds.)

Lu, Kang Shou. 2002. Using Remote Sensing and GIS Technology to Assess the Relationship of Land Cover to Watershed Impairment for the Saluda River Basin in South Carolina. Proposal submitted to the South Carolina Water Resources Center.

Consequences of Urban Encroachment on Natural Ecosystems. Report submitted to the National Science Foundation Biocomplexity Incubation Activity. 2001

Consequences of Urban Encroachment into Ecosystems on Rural Landscapes. Proposal submitted to the National Science Foundation Biocomplexity Initiative. 2002

The Saluda-Reedy Watershed Consortium: Taking Action for Water Quality Improvement and Watershed Management. Proposal submitted to the V. Kann Rasmussen Foundation. 2002.

Using Remote Sensing and GIS Technology to Assess the Relationship of Land Cover to Watershed Impairment for the Saluda River Basin South Carolina

Basic Information

Title:	Using Remote Sensing and GIS Technology to Assess the Relationship of Land Cover to Watershed Impairment for the Saluda River Basin South Carolina
Project Number:	2002SC1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	3rd
Research Category:	None
Focus Category:	Hydrology, Models, Non Point Pollution
Descriptors:	None
Principal Investigators:	Kang Shou Lu

Publication

Using Remote Sensing and GIS Technology to Assess the Relationship of Land Cover to Watershed Impairment for the Saluda River Basin in South Carolina

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.
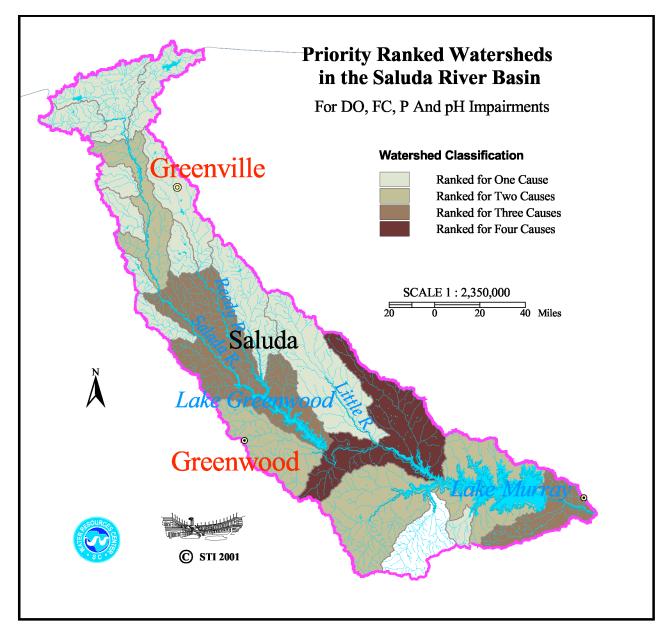
**Priority Ranked Watersheds
in the Saluda River Basin**

For DO, FC, P And pH Impairments

Watershed Classification

Ranked for One Cause
Ranked for Two Causes
Ranked for Three Causes
Ranked for Four Causes

SCALE 1 : 2,350,000
20   0   20   40   Miles

Greenville

Reedy R.

Saluda R.

Saluda

Lake Greenwood

Little R.

Greenwood

Lake Murray

N

© STI 2001

Figure 1. Saluda Watersheds and Priority Ranked Subwatersheds

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.

The proposed research seeks to provide a level of information targeted to the subject at hand. What is the status of current land cover/land use and how much have they changed? Are there any water quality problems, where are they located, and how serious are they? Do land cover and land cover change account for any watershed impairments? What has been the major cause or contributor to the problems? 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 is 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 provide alternative techniques for assessing water quality and its relationship with land cover/land use using remotely sensed data and geographic information systems based on a spatial approach. The goal of the project is to provide better information for public agencies and private organizations to make wise decisions in watershed planning, management prioritization, and plan implementation.

This effort will be confined to the Saluda River Watershed (Fig. 1), which includes Lake Greenwood and 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. These rivers have shaped and been impacted by rapid urbanization and industrialization especially over the last two decades. A recent study (Allen & Lu, 2001) has shown that all but one of these sub watersheds has encountered fecal coliform impairment problems that have been prioritized for management action in the 2000 303(d) list. As South Carolina continues its rapid urbanization, pressure on water resources and watershed environments are anticipated to increase in this watershed area.

Specifically, the objectives of this research project are to:
(1) Extract land cover and change information for the Reedy River and Saluda River Basin using remotely sensed data.
(2) Identify water bodies (stream segments, lake areas) and subwatersheds impaired by fecal coliform and excessive nutrients.
(3) Determine spatial relationships between water quality and land cover using geostatistical methods and BASINS model.

PROJECT METHODOLOGY

This research relies mainly on remote sensing technology and geographic information systems for data sources, change detection, watershed mapping, spatial analysis and modeling. Land cover and change information will be extracted from LANDSAT Thematic Mapper (TM) multispectral imagery and SpectraTech's hyperspectral imagery. Watershed impairments will be measured in terms of fecal coliform and excessive nutrient problems and multiple sources of data will be integrated into GIS for mapping and analysis. The spatial relationship between water quality and land cover will be examined using geostatistical methods and existing data will be used to calibrate EPA's BASINS model. This model will be used to quantitatively determine the possible impact of observed land cover change on water quality in the study area. This effort intends to be less a data

collection process and more of a data gathering, processing, interpreting, analysis task. All the imagery processing and analyses will be conducted using ERDAS imagine and ENVI software package. Spatial analysis and mapping will use ArcView (3.3a). Statistical analyses will be performed using SPSS.

Extracting Land Cover Information
Timely, accurate information of land cover and change is essential to the assessment of the impact of land use change on watersheds. Currently, there has been no such type of data available in the upper state region. The most recent land cover data was collected in 1989 by the South Carolina DNR and not appropriate for this research. Although the agency has started a statewide land use/ land cover change detection project on a county-by-county basis, counties in the upper state region have not been scheduled on the priority list. Therefore, it is necessary to create new land cover and change data sets for this project.

Three remotely sensed data sets will be used to extract and validate land cover and change for the study area. LANDSAT Thematic Mapper (TM) and NAPP aerial photography will be acquired for 1995, 1998, and 2001. TM satellite images (seven spectral bands and 30 x 30m spatial resolution) will be utilized for land cover classification. High resolution of NAPP orthophotos will be used for ground truthing using a random sample of points. Only three principal classes (water, urban, and nonurban) of land cover will be used for this project. While other projects have used highly detailed land cover classifications to correlate with water quality, this project seeks to determine if a simpler, low cost classification might be sufficient for our needs. A post-classification change detection will be performed rather than image (spectral) differencing for generating land cover change. A third set of data is SpectraTech's hyperspectral imagery, which has 37 spectral bands with spatial resolution of 2-3 meters. Since hyperspectral data has great potential to precisely classify materials of interest, it will be used to detect stream or water contaminants. It may also complement NAPP orthophotos in assessing the accuracy of the TM classification.

It is relatively costly to purchase and process these image data. Fortunately, most imagery data sets, especially TM and NAPP orthophotos, will be available for this research by way of data sharing with another project. This related project is tasked to detect urban forest change in the I-85 Corridor in the Upper State South Carolina. This project has a significant overlap with the Saluda Watershed. There will be only 2 scenes of TM images purchased to supplement the land cover classified from this I85 Corridor study. The algorithms of land cover classification and change detection used for the current project will conform to the protocol used in the I85 Corridor project. The simplified, 3-classed land cover is being used nationwide in urban forest change assessments. The 3 classes are much easier to derive than a typical Anderson Level II classification would be. By using this type of classification, we will be able to reduce our cost by using the existing classifications provided by the I85 Corridor Study. This avoids the duplication of effort and save a lot of money and manpower.

Assess Watershed Impairment
Impaired water bodies must be identified before being mapped out for public use and decision-making purpose. This research attempts to identify, map and assess the water bodies with problems of fecal coliform and excessive nutrients that are closely related to urbanization.

There are four data sets that can be used for deriving water quality information. The first set from EPA, embedded in the BASIN model, which has time series data that can be used for model calibration. The water quality indicators are continuous field values and may be more appropriate for analysis that emphasizes within-region differentiation, but the number of sampling sites is often too small for local level analysis. The second set of data are those from the 2000 303(d) list prepared by the South Carolina Department of Health and Environmental Concern (DHEC). They are more recent and have been reduced to four discrete classes, three for priority ranked water bodies and one for the unranked one. They can be treated as normalized data and the ranked water bodies are where the problems are. The third set of water quality 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. These parameters are common indices of nutrient load. The last data set, as ground truth for the hyperspectral imagery, was collected simultaneously with the airborne hyperspectral data. Thirty-five samples were taken from the Reedy and Saluda Rivers. Sampling sites were selected in an interval of approximate 5 miles with consideration given to easy access. Locations of sample sites were recorded using GPS and differentially corrected. Samples were sent to Lander University for lab work that includes fecal coliform (FC), dissolved organic carbon and water chemistry analysis. However, all these data are incomplete and inconsistent in terms of spatial coverage, items collected, and time collected.

It is the intention of the researchers to explore the possibility of using the hyperspectral imagery to identify impaired water bodies or pollutants. Hyperspectral technology was originally developed to aid in mining and petroleum exploration (Lunetta and Elvidge 1998) by detecting stressed vegetation as indicators of subsurface items of interest. Hyperspectral data continues to be used to precisely classify and differentiate vegetation (Price 2001, Gamba and Houshmand 2001, Hepner 1998), but has not been tested extensively for water pollution identification and monitoring in South Carolina or elsewhere. It is acknowledged that many pollutants cannot be reliably identified from imagery. It is more likely that sediments, turbidity, fecal coliform or alga booms, are discernable from the hyperspectral imagery. Success of this effort will have significant implication both in the fields of remote sensing and water quality monitoring.

Correlate Water Quality and Land Cover
This research takes a spatial and watershed approach to determine the relationship between water quality and land Cover. Two different methods will be used to delineate watershed boundaries, and therefore, the units of analysis and modeling. One method is the sample site or pour point delineation based on building watersheds above the sample sites using USGS 30-meter Digital Elevation Models and GIS software. In this case, each sample data point will have an associated contributing watershed. The other method is to use watershed boundaries defined by USGS. The 11-digit hydraulic units are preferred to keep the spatial precision as small as possible. However, some water quality data must be reaggregated to adjust between the watershed types, which may lead error. In either case, land use and land cover data must be aggregated for each watershed in order to conduct geostatistical analysis. US Census data of 1990 and 2000 will also be integrated into GIS database and population and housing data at the block level, the smallest unit, will be reaggregated for each watersheds. Other spatial data representing environmental factors will be used for spatial analysis to reflect the effects of variation of natural variables on the conditions of water quality.

As in a study on animal agriculture and watershed impairment (Allen and Lu 2001), canonical correlation, multiple regression and Pearson correlation will be performed to examine the spatial relationships between water quality indicators and land cover and land use variables. The purpose of these analyses is to determine statistically if there is a close association between watershed impairments and human and natural variables, how strong the relationship is, which variables and factors are significant, and how water quality varies with land cover changes.

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" in 1998 (Allen et al 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 1997 303(d) impairment information indicates whether or not a watershed is impaired on a certain parameter, including dissolved oxygen and fecal coliform. 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 was striking. Many pointed out some weakness in this simplified mapping approach to the issue. 8-digit hydrologic units for watershed impairment is too coarse to truly assess site-specific impacts on

water quality; no statistical analysis has performed to support the conclusion based on the visual interpretations of 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. Four types of impairments (DO, FC, P and pH) were mapped out at the USGS 11-digit hydrologic units using South Carolina 2000 303(d) list. In addition to the updated Agricultural census data, the research has incorporated animal facility data that does not only provide rich information about animal related variables but also better for data aggregation with little error propagation. Four statistical methods, which include canonical analysis, multiple regression, Pearson correlation and crossable summary, were used to perform a comprehensive spatio-statistical analysis. It was found that animal agriculture as a whole does provide a week but statistically significant contribution to watershed impairment but it is not the major factor. Animal Agriculture left over 80% of the variance in watershed rank scores unexplained. This suggests that other factors, such as human population, could be the major contributor of watershed impairment problems. Unfortunately, those factors were not taken into consideration in this research.

Although several studies of land cover classifications, change detections, and even urban prediction have been done in South Carolina (Allen and Lu 2000), none of them have taken place in the Saluda watershed. None of them have addressed the impact of land use change on water quality explicitly. EPA's BASINS software has been around for a while and it uses land use/land cover data as its parameters, but no applications has been found in the Saluda watershed. This research, therefore, seeks to fill the gap of previous studies, to link land cover and watershed impairments, and to meet regional and local information needs for wise planning and management of precious water resources

Renovating Water for Conservation and Reuse: Developing DesignParameters for Constructed Wetlands for Domestic Wastewater Treament and Mitigation

Basic Information

Title:	Renovating Water for Conservation and Reuse: Developing DesignParameters for Constructed Wetlands for Domestic Wastewater Treament and Mitigation
Project Number:	2002SC4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	3rd
Research Category:	None
Focus Category:	Water Use, Waste Water, Water Quality
Descriptors:	None
Principal Investigators:	John H. Rodgers, Alan W. Elzerman, H. Furman Cantrell, Mark A. Schlautman

Publication

1. Rodgers, Jr., John. H., Kristina V. Garber, Jeffery S. Gallagher, Camille L. Stagg, 2002, Renovating Water for Conservation and Reuse: Developing Design Parameters for Constructed Wetlands for Domestic Wastewater Treatment and Mitigation, South Carolina Water Resources Center, Clemson University, Clemson, South Carolina, 28 pages.

Renovating Water for Conservation and Reuse: Developing Design Parameters for Constructed Wetlands for Domestic Wastewater Treatment and Mitigation

Statement of Critical Regional or State Water Problem.

Water resources such as Lake Keowee in northwestern South Carolina are both precious and fragile. Although this resource appears to be plentiful to much of the public, more people are recognizing limitations during the current persistent drought. This resource is used widely for purposes ranging from drinking (domestic supply) and fish and wildlife to primary and secondary contact recreation and industrial supply.   Although the reservoir, Lake Keowee, is the least eutrophic large lake in SC, its current water quality is typical of much of the waters in the Southeastern US in terms of alkalinity, hardness, conductivity and pH.

Lake Keowee is an 18,372-acre impoundment of the Keowee River, with a maximum depth of approximately 155 feet (47 meters) and an average depth of approximately 54 feet (17 meters). The lake's watershed is comprised of 273 square miles (707 km) in NC and SC. From the time of the original study of water quality in this reservoir (Rodgers 1974) to the present, dramatic changes in land use in the watershed have led to heightened public concerns regarding water quality and the future of this resource. Mandated by the Clean Water Act (CWA – Section 303d), recent evaluations of tributaries indicated that nutrients and fecal coliforms are primary constituents of concern in terms of impairment of this water resource for designated uses. These constituents and problems are widespread and a critical need is a reliable and cost-effective approach to mitigate their downstream impacts on water resources in the watershed. Constructed wetlands have been used in a number of situations as part of integrated management strategies to conserve and reuse water and are scientifically defensible, cost-effective and sustainable solutions for these water quality problems.

Statement of Results or Benefits.

The potential benefits of this project are numerous and widespread. The most obvious is provision of a reliable technology for resolving persistent and pervasive water quality problems in watersheds (i.e. fecal coliforms and nutrients). Conservation of limited water resources is another benefit of this project. The results from this study will empower citizens and water resource managers with requisite knowledge to assume responsibility for water quality in watersheds on a local basis. If these systems perform as expected, the potential benefits in terms of tourism and fisheries (especially in the coastal areas of SC) are enormous.

Nature, Scope, and Objectives of the Research.

<u>Nature of the Research</u>. Although constructed wetlands have been used widely for wastewater renovation (Huddleston et al. 2000, Carleton et al. 2000, Kurnaidie and Kunze 2000, Hawkins et al. 1997, Kadlec and Knight 1996, Kent 1994, Moshiri 1993), we still do not have data for design parameters that are dependable and site independent. These data will be crucial as we apply this technology to mitigate adverse impacts on downstream biota and to achieve water reuse for irrigation, groundwater recharge, aquaculture and wildlife habitat. In fact, a recent publication by

the U.S. EPA (U.S. EPA 2000) acknowledged that although hundreds of thousands of dollars had been spent assembling a database from constructed wetlands for domestic wastewater treatment, such an approach is inadequate for development of design parameters. There is a critical need for reliable site independent design parameters that can be tailored for a site–specific design based upon targeted constituents and reasonable transfer and transformation kinetics. The proposed research will provide a comprehensive evaluation and an approach for technology transfer to other sites in SC and the U.S.

Scope of the Research. We propose to develop the design parameters that would permit installation of an appropriately designed and sized constructed wetland treatment system to treat domestic wastewater at a variety of sites. There are considerable but avoidable risks associated with constructing and implementing treatment wetlands that are inaccurately designed or sized (undersized or oversized). The proposed design parameters will be site independent (i.e. independent of latitude, longitude and altitude) and will be based in sound theory and fundamental principles such as the Laws of Thermodynamics. Information regarding both kinetics (rates) and extent of transfers and transformations is needed to successfully produce a site-specific design. In previous research, we have used first order estimates of kinetics coupled with performance results from pilot-scale studies to produce reliable full-scale designs (e.g. Huddleston et al. 2000). Since domestic wastewater should vary significantly only in flow (rate or volume) and concentration (or strength), but not in primary constituents of interest from site to site (Metcalf & Eddy 1991), it is entirely logical that we could develop accurate design parameters without expending time and resources on a pilot study for each site. We have applied this approach with considerable success to industrial wastewaters such as pulp and paper that do not vary widely in primary constituents (Hudddleston et al. 2000). However, we will use pilot-scale systems (Hawkins et al. 1997) for this research in order to efficiently vary input parameters (i.e. domestic wastewater strength or concentration [primary and secondarily treated] and flow rates). Experiments will test hypotheses regarding seasonal (temperature) dependence of rates of transfers and transformations of targeted constituents (Manios et al. 2000, Noah 2001). Both laboratory and nursery (field) experiments will evaluate and confirm the suitability of the treated water for reuse.

Objectives of the Research. The objectives of the proposed research are: 1) to design, construct and monitor the performance of a full-scale constructed wetland and analogous pilot-scale model constructed wetlands for tertiary treatment of domestic wastewater for reuse; 2) to measure kinetics and performance of specifically designed constructed wetlands to remove nitrogen, phosphorus and coliforms from secondary and primary treated wastewater; and 3) to characterize the outflow water from the constructed wetland treatment systems in terms of its suitability for reuse for golf course irrigation or for plantings for shoreline erosion control, wildlife and power line right-of-way beautification and enhancement. An allied objective that will be accomplished as a result of this research will produce site independent design coefficients and parameters that will assist successful transfer of this technology to other sites. Results will be published in peer-reviewed journals and presented at regional meetings and workshops.

Timeline of Activities. Construction will be accomplished in the first two months of this project. Monitoring will begin after one month of acclimation. Results for warm or hot months will be obtained in the first six months of the project and results for colder month will be gathered in the following four months. Monitoring will continue through to the end of the project. Data will be analyzed continuously and manuscripts will be prepared for submission to journals for peer review in the final month of the project. As opportunities arise, results will be presented at regional meetings and workshops.

Methods, Procedures, and Facilities.

Methods and Procedures. The design of the full-scale constructed wetland has already been accomplished and was contributed by Roy F. Weston, Inc. (Atlanta, GA office, Mr. Doug Mooney, P.E.). The design has recently been approved for construction by the S.C. Department of Health and Environmental Control and bidding for construction has begun with construction to be initiated and completed in the next two months. The construction site is located in the gated community of Keowee Key near their domestic wastewater treatment facility for ~1000 people. We have full cooperation and support of the engineering firm (Roy F. Weston, Inc.) and the Keowee Key management and families (especially Mr. Bob Peterson of Keowee Key Utilities who is the certified and licensed operator of the wastewater treatment facility). Basically, the full-scale constructed wetland treatment system will receive secondarily treated wastewater from the existing treatment system. The full-scale constructed wetland will consist of approximately one acre of *Typha latifolia* planted in a low nutrient, sandy hydrosoil. The constructed wetland will be lined with compacted clay to prevent treated water communication with groundwater. Water depths and flows in the constructed wetlands will be controlled by "stop logs" and valves, respectively. The outflow from the full-scale constructed wetland can be introduced into Lake Keowee or diverted for irrigation purposes. Detailed blueprints of the design of this constructed wetland as well as the Conceptual Design Document are available on request.   This full-scale constructed wetland was specifically designed for tertiary treatment of secondarily treated domestic wastewater. Monitoring of targeted constituents will demonstrate the performance of this system. Parameters that will be measured in both inflow and outflow samples include: TN, NH_3, NO_3, TP, Ortho-P, BOD_5, COD, TSS, fecal coliforms and *E. coli.* In addition, laboratory toxicity testing will be conducted on these water samples using *Ceriodaphnia dubia* and *Pimephales promelas* as recommended by the U.S. EPA. Weather parameters will also be continuously monitored using NOAA approved instrumentation (both instruments and assistance provided by Dr. Dale E. Linvill of Clemson University's Department of Agricultural and Biological Engineering). As mentioned above analogous pilot-scale experiments will also be conducted to develop rate coefficients and design parameters. Water reuse suitability experiments will also be conducted on the treated waters.

Facilities. We have full cooperation and collaboration of the Keowee Key wastewater treatment facility and will base the field experiments at that secure location. We have adequate laboratory analytical, aquatic toxicology and microbiological facilities in our modern 38,000 square foot building for the laboratory analyses. For the water reuse suitability experiments, we have access to field sites as well as greenhouse space.

Information Transfer Program

USGS Summer Intern 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	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	3	0	0	0	3

Notable Awards and Achievements

Publications from Prior Projects

1. 2000SC1B ("Assessment of Conditions and Public Attitudes Concerning Marine Sanitation of the Lakes Encompassed by the Savannah River Watershed Region: Policy Projections for the Future") - Water Resources Research Institute Reports - 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. 2000SC1B ("Assessment of Conditions and Public Attitudes Concerning Marine Sanitation of the Lakes Encompassed by the Savannah River Watershed Region: Policy Projections for the Future") - Other Publications - Backman, Sheila J. and Kenneth F. Backman, 2001, Perceptions of Water Quality in the Five Lake Savannah Waershed Region in College of Health, Education and Human Development Faculty Research Forum, Clemson University, Clemson, Scuth Carolina, 3 pages.
3. 2000SC3B ("Reestablishment of an Estuarine Marsh and Waterway after Causeway Removal") - Water Resources Research Institute Reports - 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.
4. 2001SC3781B ("Reservoir Shoreline Erosion and Sediment Deposition with Cohesive Sediments") - Water Resources Research Institute Reports - 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.