Tennessee Water Resources Research Center
Annual Technical Report
FY 2002

Introduction

Water Resources Issues and Problems of Tennessee

Tennessee is fortunate to have what many consider to be an abundant and good quality water supply. Historically, federal government agencies, such as the Tennessee Valley Authority (TVA), Corps of Engineers, Soil Conservation Service, U.S. Geological Survey and others, have been the primary contributors to the management and monitoring of water resources. In recent years, however, the State, through the Tennessee Departments of Environment and Conservation, Wildlife Resources, Agriculture and others, have begun to develop a more active and aggressive role in the management and protection of these resources. The State has moved to establish an integrated and coordinated policy and administrative system for the management of water resources in Tennessee.

While the situation is improving, there remain many of the additional types of water problems. Although the overall supply of water is adequate, the distribution is still not optimal. Local shortages occur during dry periods. The summer of 1980 was a particularly hot and dry one. During this period over 35 water districts out of a total of 671 public systems in Tennessee experienced lesser degrees of difficulty in supply water. The situation continued to worsen in the late 1980's. Beginning in 1985 and continuing on through the summer of 1988, Tennessee experienced another major drought period which severely strained the water supplies of many communities across the state. In recent years, many of the small municipal water suppliers and utility districts that rely on wells, springs, or minor tributaries for their water sources continue to face severe water shortage problems. All across the state many private, domestic, and commercial use wells have become severely strained, forcing users to seek alternative sources of water. Providing an adequate supply of water for industrial, commercial, and domestic uses and the protection of these surface and groundwater resources are of major concern in all regions of the state and vital to the economic development and growth of the state.

Groundwater presents a particular challenge in Tennessee. Over 50% of the population of Tennessee depends on groundwater for drinking water supply. In West Tennessee, nearly all public suppliers, industries, and rural residents use groundwater. However, not enough is known about the quality and quantity of groundwater in the state, and consequently, maximum benefit from and protection of this resource cannot be easily accomplished. More information about the quality of the state's groundwater, particularly about the potential impact of recharge areas, is needed in order to develop an effective management and protection program for this valuable resource.

There is also the problem of potential contamination of groundwater from agricultural and urban non-point sources. The "fate and transport" of agricultural chemicals (herbicides and pesticides) and toxic substances in groundwater is a problem area that must be addressed if the state's groundwater protection strategy is to be effective in protecting this vital resource.

Although the danger of large-scale, main-stem flooding is controlled by mainstream and tributary dams that have been constructed by TVA and the Army Corps of Engineers, localized flooding and even general flooding in unregulated watersheds remain substantial problems across the state. A lack of effective local floodplain management land-use controls is apparent in West Tennessee, where related problems of excessive erosion, sedimentation, drainage, and the loss of wetlands constitutes what many consider to be the greatest single water resource issue in the state from an economic and environmental point of view. Effective regulation of private levee design, construction, maintenance, and safety is needed.

Water quality problems continue to persist from past industrial practices, from the surface mining of coal and other minerals (especially from abandoned mines), from agricultural and urban nonpoint sources and from improperly planned, designed and operated waste disposal sites. As has been the situation in the past, the state program for the construction of municipal wastewater treatment facilities and improved operation and management of the facilities have experienced numerous set-backs due to shortfalls in funding and administrative delays. In major urban areas that have combined storm and sanitary sewers, urban storm water runoff causes increased pollution and, during periods of wet weather, bypasses treatment facilities, which allows raw sewage to enter receiving waters untreated. Tennessee cities, both large and small, are concerned about current (and future) impacts of the new NPDES storm water discharge permit requirements on clean up needs and costs. In certain regions of the state, failing septic fields and the practice of blasting bedrock for new septic fields are serious threats to surface and groundwater resources.

There are existing programs which can address many of these problems. However, some problems do not have easy solutions. Additional research can also play a role in understanding and solving these problems, but the greatest impediments are the lack of agreement between competing interests and a shortage of financial support for existing programs. From the viewpoint of the State government, the legal, institutional, and administrative aspects of water management are major concerns. The state is still working to develop new policy and to refine administrative structure for the effective management of its water resources.

To address the problems and issues of effective water resources management in the state of Tennessee, a truly interdisciplinary and well-coordinated effort is necessary. The Tennes5ee Water Resources Research Center has the capability and organization that can call upon the diverse set of disciplinary expertise necessary to address the key water issues of the state and region.

The Tennessee Water Resources Research Center: Overview of Program Objectives and Goals:

The Tennessee Water Resources Research Center serves as a link between the academic community and water-related organizations and people in federal and state government and in the private sector, for purpose of mobilizing university research expertise in identifying and addressing high-priority water problems and issues and in each of the respective state regions.

The Tennessee Water Resources Research Center, located at the University of Tennessee, is a federally-designated state research institute. It is supported in part by the U.S. Geological Survey of the U.S. Department of Interior under the provisions of the Water Resources Research Act of 1984, as amended by P.L. 101-397 and 10 I - 1 47. The Act states that each institute shall:

1 .plan, conduct or otherwise arrange for competent research that fosters the entry of new research scientists into the water resources fields; the training and education of future water scientists, engineers and technicians; the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and the dissemination of research results of water managers and the public.

2. cooperate closely with other colleges and universities in the state that have demonstrated capabilities for research, information dissemination, and graduate training, in order to develop a statewide program designed to resolve state and regional water and related land problems.

In supporting the federal institute mandate, the TWRRC is committed to emphasizing these major goals:

1. To assist and support all the academic institutions of the state, public and private, in pursuing water resources research programs for addressing problem areas of concern to the state and region.

2. To provide information dissemination and technology transfer services to state and local governmental bodies, academic institutions, professional groups, businesses and industries, environmental organizations and others, including the general public, who have an interest in water resources matters.

3. To promote professional training and education in fields relating to water resources and to encourage the entry of promising students into careers in these fields.

4. To represent Tennessee in the Universities Council on Water Resources, the American Water Resources Association (including Tennessee Section), the Ohio River Basin Consortium for Research and Education, the Clinch-Powell River Basin Consortia, the South Atlantic-Gulf regional grouping of state water resources research institutes, the ORNL-TVA-UT Research Consortium and the National Institutes for Water Resources (NIWR) Directors. To work with these and other associations and with state, local and federal government agencies dealing with watt resources in identifying problems amenable to a research approach and in developing coherent programs to address them. Particularly, to cooperate with the other state institutes and their regional groupings for assisting the U.S. Geological Survey in developing a national water resources strategy.

In fulfilling the Center’s major goals indicated previously, TWRRC emphasizes the application of Section 104 grant and required matching funds for primarily supporting the research and training/education needs of the state. While the information dissemination and technology transfer portion of the Center’s overall program does not receive direct or significant section 104 funding, this is accomplished primarily from the research and training activities of the Center from other funding sources--state, private, or non-profit. The Center recognizes that education and training, research, and information transfer are not independent objectives or are not mutually exclusive. Instead these goals are achieved through the administration of a coordinated, fully- integrated program within the limitations of the resources available to the Center.

Research Program

Acid Catalyzed Hydrolysis of Wastewater Activated Sludge for Removal and Possible Conversion to Products

Basic Information

Title:	Acid Catalyzed Hydrolysis of Wastewater Activated Sludge for Removal and Possible Conversion to Products
Project Number:	2002TN3B
Start Date:	3/1/2001
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	TN2
Research Category:	Water Quality
Focus Category:	Treatment, Waste Water, Models
Descriptors:	Activated sludge, data analysis, economics, energy use and conservation, mathematical models, optimization, pollution control, waste disposal
Principal Investigators:	Paul R. Bienkowski, Robert M. Counce

Publication

1. Perkins L W, K T Klasson, P Bienkowski, R M Counce, 2003, Preliminary Investigation of Nitro-Hydrolysis for Wastewater Sludge Treatment, Separation Science and Technology for Energy Applications, Vol. 38, Nos 12 & 13, pp. 3273 3288.
2. Perkins L W, K T Klasson, R M Counce, P Bienkowski, 2003, Development of Nitrolysis for Excess Sludge Treatment-A Factorial Study, Industrial and Engineering Chemistry Research, 42 3544-3548.
3. Perkins L W, K T Klasson, R M Counce, P R Bienkowski, 2003, Development or Nitrolysis for Excess Sludge Treatment II: A Factorial Study for Industrial Wastes, Industrial and Engineering Chemistry Research (in press).
4. Perkins L W, K T Klasson, R M Counce, P R Bienkowski, Reaction Rate Development and Analysis for the Nitrolysis of Municipal and Industrial Excess Sludge, Chemical Engineering Communications (submitted for publication).
5. PRESENTATIONS -Kentucky-Tennessee Water Environment Association Conference, Marriott Hotel, Knoxville, TN, May 13-17, 2002, Nitrolysis as a Sludge Treatment Alternative -American Nuclear Society Spectrum 2002: 9th Biennial International Spectrum Conference, Reno, NV, August 4-8, 2002, Preliminary Investigation of Nitrolyisis To Treat Biosolids from Wastewater Treatment

-2002 AIChE Annual Meeting, Indianapolis, IN, November 3-8, 2002, Preliminary Investigation of Nitro-Hydrolysis for Wastewater Sludge Treatment -University of Tennessee, Chemical Engineering Dept. Seminar, March 25, 2003, Design and Development of a Process for Acid Hydrolysis of Excess Sludge -2003 AIChE Annual Meeting, San Francisco, CA, November 16-21, 2003, Development of Nitrolysis As An Alternative For Treatment Of Excess Sludge Produced During Industrial Wastewater Treatment Activities

Both municipal and industrial treatment of wastewater using an activated sludge process generates large quantities of biosolids referred to as sludge. Currently the Knoxville Utility Board (KUB) generates 65 tons/day of these solids (dry basis) from their activated sludge wastewater treatment facilities. This material is concentrated from 4.2 wt % up to 35 – 40 wt % via filtration and disposed off-site by trucking it over 70 miles for disposal through land farming. Every year the distance becomes greater due to KUB's inability to find acceptable sites for land farming. At least several industries (DuPont and Tennessee Eastman) have similar problems with sludge disposal. Eastman currently produces 55 dry tons/day of sludge which is incinerated.

On site destruction of the excess biosolids is preferred from both an economic and environmental standpoint. Currently both Dupont and Tennessee Eastman use on site incineration and would prefer a more environmentally benign process which uses less energy. A nitric acid catalyzed hydrolysis process can convert most of the sludge into a biodegradable material suitable for recycle. There is also a possibility that the sludge could be converted into acetic acid for commercial sale. The major products from this hydrolysis are organic acids. It may be possible to optimize production of these acids to the point were it is economically feasible to convert the waste activated sludge stream into a commercial product. If it is not economically feasible to recover the organic acids the stream can be recycled back to the waste treatment unit where the organic acids will biodegrade.

This proposal will consist of a batch scale kinetic study using activated sludge from KUB's Kuwahee treatment facility, employing a factorial experimental design. The variables consist of residence time, reaction temperature, solids concentration, and nitric acid concentration; with percent conversion and acetic acid concentration as the dependent variables. The concentration of the sludge can have a significant impact on the economics of any potential process and must be investigated. The sludge stream from KUB's activated sludge treatment process is 4.2 wt % and is concentrated to 35 – 40 % by filtration prior to land farming. A feed sludge concentration in the range of 4.2 - 40 wt % will be investigated. The data will be analyzed and a mathematical model will be developed for the reaction kinetics over the range of the input variables. The form of the model will depend on the experimental data. If significant quantities of organic acids are obtained a complex model will likely be required; if the organic compounds are not produced in sufficient quantity a much simpler model describing destruction kinetics will be employed. The model will be utilized to evaluate the economics of the process and to develop a preliminary process design. A continuous pilot scale unit will be designed and built. This unit will be used at KUB's Kuwahee treatment facility in the second year of the project.

The First Year Objectives for this research are:

1. A complete data set on the reaction kinetics and development of a mathematical model from this data set for design and optimization
2. Development of a process flowsheet for evaluation of economics
3. Economic potential for recovery of products
4. Complete construction of a 2.0 gph pilot plant capable of continuous operation at the optimum batch reactor conditions.

(7) Methodology and Accomplishments to Date:

During the first year of this project a factorial experimental design was developed for conducting batch kinetic experiments on activated sludge effluent obtained from KUB. The objective of the experiments was two fold; i) to hydrolyze the biosolids to CO_2 and organic material which is biodegradable via recycle to the waste treatment unit and ii) investigate the possibility of producing organic acids that maybe recovered commercially. Four variables were used in the experimental design; i) reaction temperature, ii) residence time, iii) acid concentration and iv) biosolids concentration in the feed. The feed solids range was already been fixed by the sludge availability at KUB (4.2 – 40 wt %). The other three variables are all interrelated. The idea of a factorial experimental design is to set up a four dimensional matrix covering the anticipated range of each of the four control variables, but to only run selected experiments. It would be prohibitive to run all of the possible experiments, instead some initial experiments will be conducted and based on these results (percent reduction of biosoilds and/or quantity of organic acids produced) the direction for future experiments will be determined. This direction can be determined either by numerical regression of the experimental data or by fitting the data to a predetermined kinetic model. Obviously what we want to find is that combination of these four variables that leads to high percentage destruction of biosoilds and possibly high conversion to organic acids. After several experiments were conducted it was determined that it was more useful to combine acid concentration and sludge concentration into one variable, acid/sludge ratio.

(8) <u>Principal Findings and Significance:</u>

The volume and viscosity of both municipal and industrial sludge can be significantly reduced with an acid based hydrolysis at 160 to 180 C with a residence time of 5 to 10 minutes. The effluent stream is suitable for recycle to the wastewater treatment facility. Kinetics have been developed for this process based on batch reactor data. Production of an acetic acid product requires considerably longer residence times and results in a product concentration so dilute as to make recovery uneconomical. Several process flow sheets have been developed to convert the bench scale experiments into a viable process. A continuous pilot plant with a capacity of 2.0 gph of a 4 wt% sludge has been designed and constructed for the purpose of demonstration. The results of the first year of this project are documented in the publications and presentations listed below.

(9) <u>Future Research and Funding:</u>

Eastman Chemical Company and The University of Tennessee have received a $982,500.00 NICE3 grant from DOE (DE–FG44-03R410870) for a commercial demonstration of this technology at the Tennessee Eastman plant site in Kingsport. The grant is for 3 years, 6/23/03 – 6/22/06 with $480,000 from DOE and the remained in matching from Eastman and UTK.

Water Supply Options for Cumberland County, Tennessee: A Policy Assessment

Basic Information

Title:	Water Supply Options for Cumberland County, Tennessee: A Policy Assessment
Project Number:	2002TN4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	TN2
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Water Supply, Management and Planning
Descriptors:	conflict management, institutional relationships, multiple-objective planning, planning, policy analysis, water demand, water resources development
Principal Investigators:	Robert Freeland, David Feldman

Publication

1. Feldman David L, Aaron S Routhe, Emily N Heinrich, Tennessee is a Water Rich State: Myths and Realities, at the 2nd Tennessee Watershed Roundtable, Nashville, TN, March 27, 2003.
2. Feldman David L, Water problems in the Southeast: what we know and what we can do about them, Business Opportunities 2003: East Tennessee Environmental Business Association conference, Alcoa, TN, November 6, 2002.
3. Feldman David L, The State of Affairs: Challenges Facing Southeast and Gulf States in the 21st Century, When the Water Runs Dry; Maintaining A Balance Between Human Water Use and Environmental Needs, Gulf Restoration Project Conference, New Orleans, Louisiana (sponsored by Mott and Turner Foundations and EPA Gulf of Mexico Program), September 9, 2002.
4. Heinrich Emily S, Robert Freeland, David L Feldman, Using ArcIMS to Support Water Supply Policy Development, Southeast Regional Users Group meeting, Chattanooga, TN, November 6, 2002.
5. Heinrich E S, Robert Freeland, David L Feldman, Social, Economic, and Legal Implications in Selecting Water Supply Options, 9th International Symposium on Society and Natural Resource Management, Indiana University, Bloomington, IN: June 2-6, 2002.
6. Routhe A S, Emily Heinrich, Reaching Accord on Meeting Water Supply Needs: Citizen and

Decision- maker Perspectives, Georgia Water Resources Conference, Athens, GA, April 24, 2003.

7. Routhe A S, Robert Emmet Jones, Reid Morrow, Conflict and Collaboration in Regional Water Supply Management, 9th International Symposium on Society and Natural Resource Management, Indiana University, Bloomington, IN: June 2-6, 2002.
8. Two presentations and a poster were presented at the 13th annual Tennessee Water Resources Association meeting at Montgomery Bell State Park, April 9-10, 2003. The poster was: The Southeast Water Policy Initiative, by D. Feldman, R. Freeland, C. Harden, R. Jones, F. Walker, A. Routhe and E. Heinrich. The papers were: Heinrich, E., Using Geographic Information Systems to Support Water Supply Policy Development, and A. Routhe, Resolving Water Disputes: Citizen and Decision-maker Perspectives.

The world is facing a freshwater crisis. People already use over half the world's accessible freshwater, and may use nearly three-quarters by 2025. Over 1.5 billion people lack ready access to drinking water and, if current consumption patterns continue, at least 3.5 billion – nearly half the world's projected population – will live in water-stressed river basins in just 20 years (UNWWAP, 2003). This problem of unsustainable water use is global: economic growth everywhere is constrained by water supply and quality.

Water supply is not just an issue in developing nations. Spain, for example, is pushing for a Hydrologic Plan that will involve the creation of many additional dams and reservoirs. The Yellow River in China, Colorado River in North America, and the Murray River in Australia are among the Earth's major rivers that are regularly depleted of their waters (UNWWAP, 2003). Even in the seemingly water-abundant U.S., increasing municipal and industrial demands for water have led to conflicts over water rights and are constraining growth. Agriculture alone accounts for 70% of water usage - mainly for crop irrigation. As the world's population grows, irrigated land is expected to becoming increasingly significant in feeding people. While the problem is global it manifests itself locally thus, and is thus becoming a local government concern.

Local governments are more prominent than ever in water resource decisions that provide economic opportunities locally**,** as well as those issues perceived as threatening to water quantity and quality such as: sharing supply with neighboring regions, impacts to stream biodiversity, and threats to water quality by way of terrorist attack. It is not uncommon for local officials to address water resource issues, such as procuring residential and commercial water supplies, alleviating water quality concerns, mitigating impacts on wetlands, or diverting water between watersheds (Berry et. al., 1996).

This study focused on Cumberland County, a Tennessee county located atop the Cumberland Plateau that forms the western section of the southern Appalachian Mountains. According to the 2000 Census, Cumberland County is the sixth fastest growing county in the state, up 35% since 1990. The county's limited water resources are increasingly stressed by competing user demands stemming from the escalating population, attendant economic development, and increased urbanization. Adding to the problem, the average elevation of the area is 1200 meters above sea level and the average annual precipitation is 145 mm. The precipitation and its temporal and spatial non-uniform distribution, coupled with elevation and depth to groundwater sources have a magnified effect on the water resources in the region.

Concerns about water shortages are not new to the county. The Cumberland County Regional Water Authority (CWRA) was formed in 1999 by an act of the state legislature and subsequent approval by the Cumberland County Commission (Young, 1999). The purpose of CWRA is to encourage regional water supply planning by examining the potential for cooperation among utility districts to provide for future water supply needs. The Tennessee Department of Environment and Conservation (TDEC) has hoped that CWRA would serve as a model for "regionalization" of water planning (TDEC, 1998). While the five rural utility districts quickly signed on to be part of CWRA, to date the City of Crossville, the county seat and supplier of 80% of the county's water, has chosen not to participate. Crossville's refusal to join CWRA has been attributed to the fact that each member district is allowed a single vote, and the city feels it would be at the mercy of the county districts, which collectively have five votes (Young, 2000a).

Several studies have been commissioned to identify future sources of water for the region – but until our study was undertaken – no study sought to determine decision-maker concerns. Since 1988, utility districts within the county have been actively pursuing a new water supply source. This pursuit became more intense in 1992 when a proposed dam on Clear Creek was rejected by state and federal regulatory agencies. In 1998, the Army Corp of Engineers completed a preliminary engineering report outlining several possible alternatives for meeting the county's future water supply needs. In addition to outlining several possible options, it provided information regarding the economic, environmental, and engineering feasibility of each one (ACE, 1998). However, the study did not make any recommendations. It was designed to be merely a tool for planning. Despite the engineering and technical feasibility of all of the options mentioned in the Corps report, no action has been taken toward

implementation. The City of Crossville has also independently studied potential water sources. It determined that the construction of an impoundment on the Caney Fork River was the best strategy and official began a formal study and the permitting process in the fall of 2000 (Young 2000b).

(7) Methodology and Accomplishments to Date:

In order to assist Cumberland County's decision makers in alleviating their water needs, this project employed a two-fold approach: GIS development; and decision-maker interviews.

GIS Development*:* GIS is an information technology increasing used in public policymaking, particularly for environmental planning and management because it provides access to timely, accurate information that is fundamental to sound decision-making. GIS can successfully help to: identify and guide needed government action on water supply planning and management; enhance the accuracy and efficiency of governmental operations; increase the transparency of government decision-making; and help build regional and national networks. It also helps overcome lack of skills in advocacy by allowing scientist to depict information in a manner that allows decision makers to make up their own minds.

In this portion of the study, our objective was to examine decision-making and GIS applications in Cumberland County, Tennessee in order to help better design a tool for storing, analyzing, manipulating, retrieving, and displaying attributes of spatial data representing multiple databases, formats, and sources for dissemination to resource managers, planners, decision makers, and the public.

To meet our research objective the Cumberland County Water Resources Atlas (CCWRA) was created using Environmental Systems Research Institute's (ESRI) ArcIMS technology. ArcIMS provides the foundation for distributing high-end GIS and mapping services via the Internet. ArcIMS software allows users to integrate local data sources with Internet data sources for display, query, and analysis in an easy to use Web browser. Because it was specifically built to serve GIS on the Internet, ArcIMS is designed to make it easy to create map services, develop Web pages for communicating with the map service, and administer sites. Using this technology allows users of the CCWRA to browse and interact with maps and data using their standard Web browser without requiring the purchase of expensive GIS software.

Decision-maker Interviews: The design goals of the atlas were to disseminate information pertinent to Cumberland County's water supply. To determine the types of information needed, informal interviews were held with six different decision makers in Cumberland County prior to designing the atlas. The interviewee's represented four types of decision makers from the area: state and federal agency representatives, local elected officials, utility district board members or managers, and representatives from environmental and conservation organizations.

Each participant was informed about the production of the atlas and its goal as a tool for use by anyone interested in the water supply issue. The participants were asked: "In order to make this GIS tool useful to yourself (or your organization) as well as the citizens of Cumberland County, what types of information would you (or your organization) like to see depicted and how do you feel this information will be helpful?" Five of the six decision makers responded with various suggestions on what they thought would be useful (**Table 1**). One of the six decision makers stated that they "did not see a need for computer assistance with their water supply issues".

Table 1. Decision Maker response to preliminary question regarding what types of information they would like to see in the atlas.

Participant #	Affiliation	Suggestion
1	Environmental	What/ Who will be impacted by each water supply option
2	Utility District	Where water lines are
3	Utility District	Tool will not be useful to citizens without Internet capabilities
4	Local Government	Supply each option is capable of providing
5	Local Government	Which options are capable of meeting long term demands
6	State and Federal	Information on Utility district operations

Interviews were used to examine the perspective of decision makers on the county's water supply problems. Decision makers hold contradictory notions on which, if any, option should be chosen for meeting future water supply needs (Rich, 1997). We contended that before any option is implemented, accord must be reached by making sure to take into account the needs and demands of the county citizens and decision makers. To determine public acceptability face-to-face interviews were conducted in the county's various communities and with stakeholders from four groups: (1) utility district board members and managers, (2) city and county officials, (3) state and federal agency officials, and (4) representatives of environmental, conservation, and recreation organizations from in, and around, the region. The purpose of the interviews was to determine public support of efforts to regionalize the utility districts and preference of supply options.

Interviews were scheduled and preformed at the interviewee's home and office. Interview questions were designed to be non-threatening and unbiased. To date 57 interviews have been completed and analyzed. When completed we will have 60-70 interviews. Based on a content analysis of local media interview participants were selected and classified into four groups. In order to ensure interviewee's agreed with that classification they were also asked to classify themselves at the beginning of every interview. Only once did our classification conflict with the group with which participant associated.

(8) Principal Findings and Significance:

Many are viewing the atlas. By monitoring the Website established for our research program (the Southeast Water Policy Initiative), we have been able to determine the types of users accessing the atlas and what country they are accessing it from. While privacy considerations prevent us from determining exactly who is using the atlas and to what end, general statistics are encouraging. In April 2003, the CCWRA Website received over 170,000 requests domestically. The greatest number of "hits" came from educational servers (nearly 70,000). Nevertheless, the atlas also received numerous requests from commercial, network, and government servers between 35,000 – 50,000 hits). Similarly, people from other countries are viewing the atlas. In just one month, we received requests from more than 50 countries.

It is impossible to determine whether every decision maker involved in the Cumberland County issue finds the atlas useful. However, in verbal comments with various decision makers we have received positive feedback ranging from "wow this is neat" to statements of the benefits such a tool provides. One representative of a state and federal agency stated that the atlas was extremely useful to his organization and likewise could greatly benefit the government officials of Cumberland County. Within the region, the CCWRA appears to be a tool for disseminating important data regarding water supply by geographically depicting complex relationships. The audience for the atlas includes water users, planners, and decision makers. Within the atlas, the public will have access to spatial information such as the distance from their homes to a proposed water storage location, discharge pipe, or abandoned mine. Planners can relate current and proposed hydrologic features and structures to important variables such as land use, urban areas, and population growth. Decision makers can compare proposed water sources to permits for water quality and determine what types of pollutants are discharged upstream.

In regards to decision-maker attitudes, a number of significant findings have emerged in three areas. These are: 1) perceptions of future water supply problems; 2) the sufficiency of a single option for meeting water supply needs; and 3) policy-maker preference for various options for actually meeting water supply needs. Major findings under these three categories are as follows:

1. Of a total of 48 decision-makers interviewed in spring 2003, 66% believe water supply problems are very likely within 10 years, while 82% believe they are very likely in 50 years.
2. 23% of decision-makers believe water supply problems are very unlikely to occur within 10 years, while 9% believe they are highly unlikely to occur in the next 50 years.

3. As regards the sufficiency of a single water supply option, 86% of decision-makers interviews believe no single option can meet the country's water supply needs, while 14% believe a single option can satisfy the country's needs.
4. 45% of decision-makers interviewed favor building a new dam; while 31% favor raising the height of an existing dam to provide adequate supply. 12% believe groundwater can be utilized, 10% favor greater conservation, and 2% favor water harvesting.
5. The project has also provided the research base for the direct training of one graduate assistant in Biosystems engineering, as well as the indirect training of a second student in sociology who assisted with the project.

(9) Future Research and Funding:

The future of the atlas is expected to be comprehensive. As new data is collected, additional elements will be incorporated, such as results of a survey of the public and further interviews with decision makers. The atlas may assist in water policy formulation in Cumberland County by referencing social and environmental data to spatial or geographic coordinates on one platform for use by resource managers, planners, and decision makers over the Internet. CCWRA is can be easily accessible to a variety of non-technical users, as well as be modifiable in response to decision maker needs. The atlas will facilitate a better understanding of the connection between social and natural resource constraints on water supply among decision makers in Cumberland County – by providing images that illustrate the various issues. The atlas could serve as a template, adaptable by other areas facing similar problems: where users would input there own data enabling the atlas to spatially depict important issues pertaining to their unique problems

Initial interviews with decision makers reveal a wide variation of views about possible options for meeting future needs – dependent, of course, on future funding as well. Based on this, we are continuing to testing four hypotheses in the formal interviews. The first is that utility districts and local officials will be most likely to support structural options. Second, environmental, conservation, and whitewater recreation groups will be less likely to support any structural option. These groups, however, will support any option that promotes conservation, limits growth, or encourages regional cooperation. Third, state and federal agencies will support any option that has consensus. Finally, contention between the county and city for control over water supply options will block accord. While some citizens embrace the alternative paradigm, most decision makers continue adhering to the traditional dominant paradigm for managing water resources.

Water Quality monitoring in two 303(d)-listed East Tennessee streams

Basic Information

Title:	Water Quality monitoring in two 303(d)-listed East Tennessee streams
Project Number:	2002TN5B
Start Date:	3/1/2002
End Date:	6/30/2003
Funding Source:	104B
Congressional District:	TN2
Research Category:	Water Quality
Focus Category:	Geomorphological Processes, Sediments, Methods
Descriptors:	water quality monitoring, land-water interactions, urban hydrology, suspended sediments, streams, runoff, geomorphology
Principal Investigators:	Carol Harden

Publication

1. Harden C, R Milam, 2002, Partnering for student stream monitoring yields more than data, in Proceedings from the Thirteenth Tennessee Water Resources Symposium, April 9-11, 2003, Tennessee Section of the American Water Resources Association pp. 3C-10 3C-14, (also presented orally).
2. Heaton A, A Ridenour, R Vananda,2003, A year-long study of water quality in Third Creek. Presentation and poster at Undergraduate Research Fair, University of Tennessee, April 3-4, 2003.
3. Jolly, B A, 2002, Testing the Chemical Perturbation Index in a mixed land-use Knoxville stream, in Proceedings from the Thirteenth Tennessee Water Resources Symposium, April 9-11, 2003, Tennessee Section of the American Water Resources Association, pp. 2B-2 2B-7, (also presented orally).
4. Lawson, J, 2003, Know the creeks to understand the river, Story with photo in the Knoxville News-Sentinel Monday, May 5, 2003, page B-8.
5. Other products include (i) the poster from undergraduate fair, (ii) student reports and presentations from Geography 436 research groups, (iii) the M.S. thesis by B. A. Jolly (expected Dec. 2003 or early 2004), and (iv) suspended sediment data (mg/L) from Stock Creek from fall 2002.

In 2000, the Tennessee Department of Environment and Conservation reported that more than 6,500 miles of streams and rivers surveyed did not meet water quality standards. An associated and especially critical problem is that of the difficulty and cost of obtaining sufficient information about the quality of the state's streams and rivers to identify and remediate water quality. The same TDEC report noted that only 40 % (36,000 of 60,000 total river and stream miles in the state) have not been recently assessed. Monitoring is labor-intensive, and hence expensive, so water quality data are very scarce for Tennessee streams. Third Creek, the primary stream chosen for study in this project, is classified as impaired due to pathogens, nutrients, siltation, and habitat alterations.

The objectives of this research are:

(a) To develop a one-year record of water quality for Third Creek and also to monitor water quality in an impaired Blount County tributary of the Little River.
(b) To analyze the data collected during this year and also to compile and analyze data previously acquired by other entities.
(c) To examine and compare sampling methods and sampling strategies, especially to test the Chemical Perturbation Index (CPI).
(e) To involve undergraduate and graduate students at the University of Tennessee in stream monitoring

This research was also undertaken to extend understanding about sampling methods and strategies. One component of the project compared methods of sampling for suspended sediment. Two other areas of research emphasis, relates to sampling strategies and methods were:

(1) To test the Chemical Perturbation Index (CPI) to determine whether it is a useful indicator for these watersheds, and whether groups of students (essentially the general public) can achieve replicable results using this index.

(2) To have a group of 35 to 40 citizens (UT students) involved in the water quality monitoring offers an opportunity to assess the strengths and weaknesses of citizen monitoring and to propose ways of improving the quality of data obtained by such groups.

(7) Methods and Accomplishments:

The major accomplishment of this project was completion of a year of water quality monitoring on Third Creek, in Knoxville. Monitoring occurred in two phases. In the first, between February and April 2002, 37 UT students enrolled in Geography 436 (Water Resources) monitored water quality at 10 sites on Third Creek and the East Fork of Third Creek. Students sampled weekly, and did their own lab analyses using LaMotte kits for nitrate-N and phosphate, ammonia, calcium hardness, chromium, copper, and dissolved oxygen. They measured pH using meters in the lab, determined temperature at the stream with thermometers, and used "Coliscan" kits to grow and count colonies of *E. Coli*. Turbidity and conductivity were measured on some samples in the lab using meters. Students measured the width and depth of the wetted channel and estimated flow (float method) in the field. They also completed a visual assessment of the study reach using the NRCS protocol, and a windshield survey of the contributing watershed.

In the second phase, after the Water Resources course ended, the number of sites was reduced to three (Sullivan and Western, Webb Lane, and the Third Creek Greenway at Painter Ave.). Summer sampling (biweekly) and lab work were done by one undergraduate student, Nicole Grant, a microbiology major who had taken the Water Resources course in the spring. During the fall, two sites (Sullivan/Western and Greenway/Painter) continued to be sampled biweekly by two teams of two undergraduate students Allison Ridenour, Renee Vananda, Will Wise, and Leslie Currah. Ashley Heaton joined the team in January 2003 after Wise and Currah graduated. All of these students had taken Geog. 436. Students were paid hourly

wages for sampling and lab work until the spring semester of 2003, when Heaton, Ridenour and Vananda elected to do the work for course credit (Geography 494 Research Experience) rather than be paid.

Graduate student B. Alan Jolly collected water samples from Third Creek (also First and Goose Creeks) and analyzed them for conductivity, alkalinity, and hardness to develop a database with which to test the utility of the Chemical Perturbation Index in urban streams. He also compiled information on previous water quality data for Third Creek. The graduate student (Young) who had intended to monitor suspended sediment in Stock Creek installed a rising stage sampler at Martin Mill Pike and began to develop a database (processed 22 suspended sediment samples), but then changed thesis topics and did not continue with the Stock Creek project.

Monitoring of Third Creek by Geography students was done as a collaboration between the UT class, the Water Resources Research Center, and the City of Knoxville. Roger Milam, from the city's Stormwater Engineering Department spoke to the class and attended the class meetings during which students presented their results.

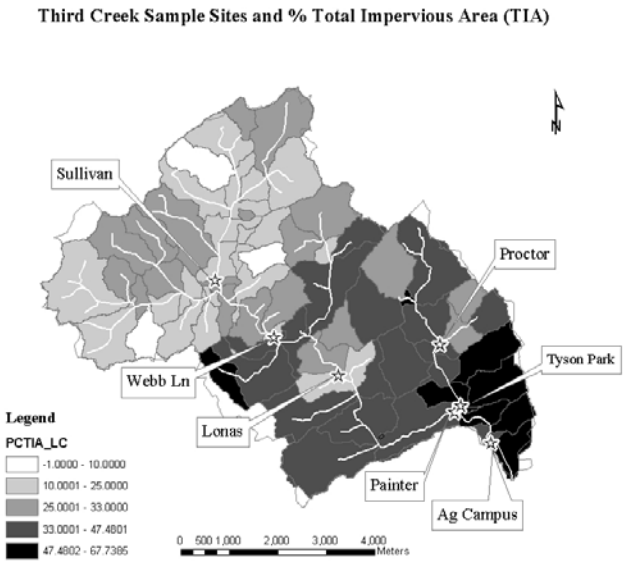
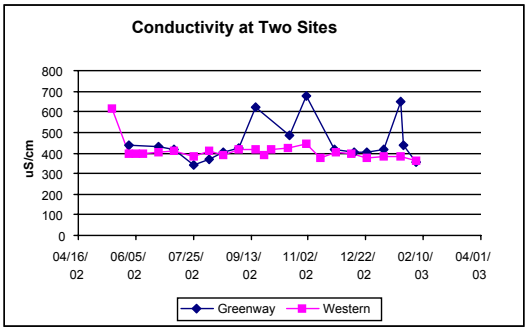


Figure 1

(Figure from B.A. Jolly)

(8) Principal Findings and Significance:

a) Third Creek water chemistry:



- Conductivity and hardness tend to increase downstream (between Western Ave and Painter Ave.).

- Nitrate-N (ppm) was almost always present, except at the upstream (Sullivan and Western) site.
- Phosphate (ppm) was almost always absent above the petroleum tank farm, but almost always present
  below the tank farms and on the East Fork. One grab sample from Third Creek below Middlebrook Pike, and two from the East Fork near Western Ave. had elevated phosphate levels of 4 ppm.

Harden met with TDEC and City personnel in the spring of 2002 to present preliminary results. A very important contribution of the Geography 436 students was their weekly presence at streamside at 10 locations. They noted unusual conditions and odors as well as changes over time in riparian and channel environments. One group, sampling Third Creek immediately downstream from Middlebrook Pike, reported a petroleum odor throughout the term. Just upstream, at Lonas Rd., students exploring a small tributary found what appeared to be a spring with an oily sheen and a dead turtle. These field observations helped the City to target a petroleum leakage problem, and led TDEC to test for (and find) hydrocarbons and work with the responsible parties toward better monitoring and mitigation. On other occasions, students telephoned the City's water quality hotline to report water quality problems they encountered in the field.

b) Bacteria:

E. Coli counts varied from 0 to 3000 per 100 mL. We ran 17 Coliscan tests for the upstream site (Sullivan and Western Ave.), of which seven had no *E. Coli*, and 10 had concentrations ranging from 100 to 1000 per 100 mL. At the Painter Ave. site (at the Third Creek Greenway bridge), 7 of 14 tests showed no *E. Coli*. The highest *E. Coli* counts came from the East Fork of Third Creek, at Western and Tennessee Ave and at Western Ave. and the railroad (up to 3000 per 100 mL). Although the data do not comprise a full time-series, they show the recurring but variable problem of bacteriological contamination, even in the upstream sector of the creek.

c) CPI (Chemical Perturbation Index):

Preliminary results showed that conductivity varied predictably with the ratio of alkalinity to hardness in Third Creek, so Jolly was encouraged to continue to develop his database to test the CPI on Knoxville streams. He extended his database to include sites on Goose and First Creeks, as well as Third Creek, and he is on schedule to complete his thesis in late 2003 or early 2004.

d) Sediment sampling methods:

In a limited comparison of single-stage, grab, and depth-integrating (DI) sampling methods, single-stage samplers performed poorly in flows that moved woody debris. In one comparative test of grab versus DI, the suspended sediment concentration measured with DI was twice that of the grab sample.

e) Student involvement:

Data collected during spring 2002 by Water Resources students are quite valuable for indicating presence or absence of water quality constituents. Some of the actual values obtained are questionnable. We have most confidence in temperature readings and values obtained for Ca hardness and alkalinity. After the initial training, much of the sampling and lab analyses by student teams was done with only minimal supervision—the emphasis on monitoring numerous sites combined with the difficulty of fitting in this extra out-of-class assignment with other classes and work schedules meant that students did their sampling and lab work at various hours during the week. With very limited staff resources, field and lab safety necessarily had highest priority and data quality control received less attention, especially in spring

2002. Data from summer 2002 through Feb. 2003 are more reliable because they were obtained by a small number of students who were better trained, more responsible, and more closely supervised.

Student involvement had outstanding educational benefits. In written evaluations at the end of the term, students unanimously indicated that they would be more likely to participate in a volunteer citizen monitoring effort or a watershed alliance. They commented that they now noticed and thought about streams they crossed daily. Attendance in the Water Resources class was excellent, and the Third Creek sampling project appeared to add meaning and engagement to the student experience. One of the undergraduate students, Ashley Heaton competed for and was awarded a Summer Research Fellowship in Watershed Studies at the College of William and Mary. She participated in the 8-week program in the summer of 2003. Another undergraduate, Susanna Sutherland, is now working toward a Master's degree in Environmental Sciences at UT (gathering primary data from Ellejoy Creek). Alan Jolly, the graduate student involved with this project is completing a water quality modeling internship this semester with TVA and has accepted a water quality modeling research appointment with the UT College of Agricultural Sciences and Natural Resources.

(9) Future Research and Funding:

(i) Contract with TDEC (Tennessee Department of Environment and Conservation) for water quality water quality sampling of 16 streams that drain to Fort Loudoun Lake ($9554 plus $9890 match), Fall 2003.
(ii) Proposal "A watershed classification system for headwater contributing areas of the Southern Appalachian region" requesting $636,214 was submitted by Harden, Robinson, Etnier, and Shaw to EPA for study of Little River Watershed (not successful on first attempt).
(iii) Future research plans include involving undergraduate students in an assessment of the channel status of Beaver Creek (north Knoxville) in spring 2004, and ongoing research investigating sediment movement.

Information Transfer Program

Tennessee Water Resources Research Center Information Transfer Program

Basic Information

Title:	Tennessee Water Resources Research Center Information Transfer Program
Project Number:	2002TN6B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	TN2
Research Category:	Not Applicable
Focus Category:	Education, Non Point Pollution, Water Quality
Descriptors:	training, nonpoint source pollution, technology transfer
Principal Investigators:	Timothy Gangaware

Publication

1. Buchanan, J., P. Schmierbach, B. Tschantz, and T. Gangaware, 2002, Teaching the Fundamentals of Erosion Prevention and Sediment Control to Tennessee Construction Contractors, "in" Proceedings of the 12thAnnual Tennessee Water Resources Association Symposium, Montgomery Bell State Park, April 3-5, pp.2B-11-12.
2. Tschantz, B.A., T.R. Gangaware, and R.G. Morton, 2002, Guide to the Selection and Design of Stormwater Best Management Practices: A Guide to Phase II MS4 Communities for Protecting Post-construction Stormwater Quality and Managing Stormwater Flow, Tennessee Water Resources Research Center, University of Tennessee, Knoxville, TN.

TRANSFER PROGRAM

The major emphasis of the information transfer program during the FY 2002 grant period focused on technical publication support, conference planning/development, and improvement in the information transfer network. The primary purpose of the program was to support the objectives of the technical research performed under the FY 2002 Water Resources Research Institute Program.

The primary objectives, as in previous years, of the Information Transfer Activities are:

- To provide technical and structural support to water researchers performing research under the WRRIP.
- To deliver timely water-resources related information to water researchers, agency administrators, government officials, students and the general public.
- To coordinate with various federal, state, and local agencies and other academic institutions on program objectives and research opportunities.
- To increase the general public's awareness and appreciation of the water resources problems in the state.
- To promote and develop conferences, seminars and workshops for local and state officials and the general public which address a wide range of issues relating to the protection and management of the state's water resources.

During the FY 2002 grant period, a major focus of the information transfer activities was on the participation of the Center staff in the planning and implementation of several statewide conferences and training workshops.

As co-sponsor, the Center was involved in the planning and implementation of the Twelfth Tennessee Water Resources Symposium, which was held on April 3-5, 2002 at Montgomery State Park in Burns, Tennessee. The purposes of the symposium are: (1) to provide a forum for practitioners, regulators, educators and researchers in water resources to exchange ideas and provide technology transfer activities, and (2) to encourage cooperation among the diverse range of water professionals in the state. As with previous symposia, the twelfth symposium was very successful with over 240 attendees and approximately 54 papers being presented in the two-day period. The event received a good deal of publicity across the state.

The Center also participated in several meetings and workshops across the state that were held to address water related problems and issues such as stormwater management, water quality monitoring, non-point source pollution, water supply planning, TMDL

development, watershed management and restoration, multiobjective river basin management and lake management issues and environmental education in Tennessee.

The following is a brief listing of formal meetings, seminars and workshops that the Center actively hosted, supported and participated in during FY 2002:

• Tennessee Watershed Roundtable, March 27, 2002, Sheraton Hotel, Nashville, TN.

• Tennessee Water Resources Research Center Statewide Advisory Committee annual meeting, interaction among researchers and researcher users, March 1e, 2001, Knoxville, TN.

• Knox County Site Planning Roundtable Kick off meeting. March 15, 2002, Knoxville, TN. The beginning of a year long process working with key stakeholder to make recommendations for changes to Knox County's codes and ordinances to meet new stormwater regulations. Monthly meetings of the Roundtable participants occurred after this initial meeting.

• Sustainable Development Practices, Cumberland River Compact Conference, March 28-29, 2002, Nashville, TN.

• Tennessee Wetlands Technical Advisory Task Force meeting, April 16-17, 2002, Nashville, Tennessee. Meeting of government agency staff and technical experts to advise to the State on issues related to the Tennessee Wetlands Management Plan.

• WaterFest, May 3, 2002, Knoxville, TN. An annual community-wide event sponsored by the Water Quality Forum that highlights the importance of our water resources and the activities of the WQF partners to protect and manage those resources.

• NPDES Phase II Storm Water Training Workshop sponsored by the U.S. Environmental Protection Agency Region 4, Tennessee Department of Environment and Conservation, Division of Water Pollution Cotrol and the Tennessee Water Resources Research Center. Held June 4, 2002 in Murfreesboro, TN. And June 5, 2002 in Knoxville, TN. Over 100 persons attended the workshops.

• Adopt-A-Watershed Southeast Leadership Institute, June 23-29, 2002, Cradel of Forestry Pisgah National Forest near Brevard, NC. TNWRRC sponsored and particapanted in a leadership team from Knoxville. Over 12 leadership teams from 7 southeastern states were accepted to this first AAW Leadership Institute in the southeastern United States.

• Kids-In the-Creek, April 17-18, 2002, Farragut Middle School, May 6, 2002 Gap Creek Elementary School, and September 25, 2002 Holston Middle School, Knoxville, TN. A watershed experience sponsored by Tennessee Valley Authority, TNWRRC and the CAC AmeriCorps Water Quality Team. An all day event for approximately 75 3rd & 5th grade

students introducing them to watershed science including biological and chemical monitoring and land use impacts on water quality.

• Fundamentals of Erosion Prevention and Sediment Control Level I Training workshops, sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. A one day course for developers, contractors, road builders and others involved with construction activities across the State. The course was offered on the following dates in 2002: March 19, Memphis, TN.; March 20, Nashville, TN.; March 22, Chattanooga, TN.; March 25, Knoxville, TN.; May 7, Knoxville, TN.; May 20, Memphis, TN.; May 21, Jackson, TN.; May 22, Cookeville, TN.; May 24, Johnson City, TN.; June 12, Nashville, TN.; October 21, Jackson, TN.; October 22, Memphis, TN.; October 24, Nashville, TN.; October 28, Knoxville, TN.; October 30, Chattanooga, TN.; November 13, Nashville, TN.; January 28, 2003, Nashville, TN.; February 10, 2003, Knoxville, TN.; and February 21, 2003 Pigeon Forge, TN. In FY 2002 over 900 persons were trained in this program.

• Design Principles for Erosion Prevention and Sediment Controls for Construction Sites Level II workshops sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. A two-day training workshop for engineers and other design professionals responsible for the development of Storm Water Pollution Prevention Plans for construction activities. The course was offered on the following dates: January 16-17, 2003, Nashville, TN.; and February 5-6, 2003 Knoxville, TN. Fifty-six engineers and design professionals completed this advanced training.

• Nonpoint Source Program Education Working Group, August 20, 2002, Nashville, TN.

• Urban Runoff Working Group, September 4, 2002, Nashville, TN.

• Knox County Soil Conservation District BMP Tour, October 1, 2002, Knoxville, TN. TNWRRC staff made presentations on streambank restoration demonstration projects in Knox County.

• Tools and Programs for the Development and Implementation of a Local Storm Water Management Program: A workshop for Phase II Communities in Tennessee, sponsored by the Tennessee Water Resources Research Center, the Tennessee Department of Environment and Conservation. County Technical Advisory Service and the Municipal Technical Advisory Service. October 2, 2002, Jackson, TN.; October 3, 2002, Nashville, TN.; and October 8, 2002, Knoxville, TN.

• Twelfth Annual SAMAB Conference, November 6-8, 2002, Gatlinburg, TN. Sponsored by the Southern Appalachian Man and the Biosphere. TNWRRC staff made several presentations on watershed assessment projects.

• Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2002 and January 2003. Meeting of government agencies and other organizations to share

information and discuss water quality issues in the Tennessee River and it's tributaries in Knox County.

• Little River , French Broad River, Bull Run Creek, Beaver Creek Stock Creekand Emory River Watershed Associations, monthly meetings. Agency staff and community leaders working towards protection of the Little River, lower French Broad, the Emory/Obed and smaller tributaries watersheds.

• Joint UT-TVA-ORNL Water resources Consortium Seminar Series on timely water resources topics, issues and projects of common interest to the three organizations.

Other principal information transfer activities which were carried out during the FY 2002 grant period focused on the dissemination of technical reports and other water resources related reports published by the Center as well as other types of information concerning water resources issues and problems. A majority of the requests for reports and information have come from federal and state government agencies, university faculty and students, and private citizens within the state. The Center also responded to numerous requests from across the nation and around the world.

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	6	0	0	6
Masters	1	2	0	0	3
Ph.D.	0	1	0	0	1
Post-Doc.	0	1	0	0	1
Total	1	10	0	0	11

Notable Awards and Achievements

Graduate Research Assistant Aaron Routhe was honored by the American Water Resources Association at the 2002 AWRA Annual Water Resources Conference held November 2002 in Philadelphia, PA. for Outstanding Presentation. Mr. Routhes presentation, Planners and the Public: The Role of Attitudes in Water Policy, was one of six student presentations selected by those attending the four-day meeting to receive the award. Mr. Routhe worked on the research project 2002TN4B, Water Supply Options for Cumberland County, Tennessee: A policy Assessment, under the direction of Dr. David Feldman of the Southeast Water Policy Initiative at the University of Tennessee, Knoxville.

Publications from Prior Projects

1. 2001TN4041B ("Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils") - Conference Proceedings - Gentry, R.W., J. Carmichael, D. Larsen, L. McKay, 2002, Development of the Shelby Farms Study Site for the Purpose of Studying Recharge Mechanisms to the Memphis Aquifer Near Windows Sites, "in" Proceedings of the 12thAnnual Tennessee Water Resources Association Symposium,Montgomery Bell State Park, April 3-5, pp.2A-1-6.
2. 2001TN4041B ("Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils") - Conference Proceedings - Waldron, B., 2002, Preliminary Investigation of the Use of Naturally Occurring Chloride within the Unsturated Zone to Determine Aquifer Recharge to the Memphis Aquifer, "in" Proceedings of the 12thAnnual Tennessee Water Resources Association Symposium, Montgomery Bell State Park, April 3-5, pp.2A-1-6.
3. 2001TN4041B ("Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils") - Conference Proceedings - Ivey, S., D. Larsen, J. Anderson, and R. Gentry, 2002, Use of Lumped Parameter Models for Wellhead Protection Delineation, "in" Proceedings of the 13th Annual Tennessee Water Resources Association Symposium,Montgomery Bell State Park, April 9-11, pp.2C-8-14.
4. 2001TN4041B ("Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils") - Conference Proceedings - Layton, A.C., D. Willams, G. Sayler, and L.D. McKay, 2002, Validation of a Real-time PCR Method for the Quantification of E.Coli in Surface Water, "in"

Proceedings of the 13th Annual Tennessee Water Resources Association Symposium, Montgomery Bell State Park, April 9-11, pp.3A-1-5.

5. 2001TN4101B ("Constructed Wetland Cleanup of Pirtle’s Container Nursery Runoff") - Conference Proceedings - Stearman, G.K., D. George and L. Hutchings, 2003, Constructed Wetland Cleanup of Pirtles Container Nursery Runoff: Removal of Nitrogen, Phosphorus and Prodiamine from a Subsurface Flow Constructed Wetland at 1, 2 and 3 Hydraulic Rentention Times, "in" Proceedings of the 13th Annual Tennessee Water Resources Association Symposium, Montgomery Bell State Park, April 9-11, pp.P 28-31.