Tennessee Water Resources Research Center
Annual Technical Report
FY 2001

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 Tennesee 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 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

Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils

Basic Information

Title:	Investigation of Factors Controlling Transport of Microbial Pathogens in Saprolite Soils
Project Number:	2001TN4041B
Start Date:	3/1/2001
End Date:	7/31/2002
Funding Source:	104B
Congressional District:	Tennessee, 2nd
Research Category:	Not Applicable
Focus Category:	Groundwater, Water Quality, Non Point Pollution
Descriptors:	groundwater quality, contaminant transport, wastewater, public health, septic tanks, bacteria, viruses, infiltration
Principal Investigators:	Larry D. McKay, Alice Layton

Publication

1. McKay, L.D., A. Layton, M. Rietti-Shati, S. Direse, 2002, Transport of Microbial Pathogens and Pathogen Surrogates in Saprolite subsoils in east Tennessee, 12th Tennessee Water Resources Symposium, Nashville, TN, April 3-5, 2002
2. McKay, L.D., S.E. Driese, and K. Smith, In-review, Hydrogeology and pedology of saprolite formed from sedimentary rock parent material, eastern Tennessee, U.S.A.: Geoderma.
3. McCarthy, J.F., L.D. McKay, and D.D. Bruner, 2002, Influence of ionic strength and Cation charge on transport of colloidal particles in fractured shale saprolite: Environ. Sci. Technol., v. 36, p. 3735-3743.
4. McKay, L.D., A.D. Harton, and G.V. Wilson, 2002, Influence of flow rate on transport of phage in a highly weathered and fractured shale: J. Environ. Quality, 31, 1095-1105.

Problems and Research Objectives:

In recent years, most waterborne disease outbreaks in the US were associated with groundwater (Mathewson, 1998) and studies show that up to half of all US drinking-wells tested have evidence of fecal contamination (Macler and Merkle, 2000). A recent example of the risk to human health posed by pathogens in groundwater is a disease outbreak in Walkerton, Ontario in May 2000, that resulted in the hospitalization of dozens of people, 7 of whom died. The outbreak was attributed to fecal contamination of a water supply well in a fractured rock aquifer with *Escherichia coli* (Gillham, personal comm., Toronto Globe and Mail, 2000). Common sources of fecal contamination include septic systems, leaking sewer lines, cesspools and livestock feedlots (Macler and Merkel, 2000). Rural water supplies are particularly susceptible to contamination by pathogens because of the prevalence of septic fields and livestock, often in close proximity to the wells, springs or streams which provide drinking water to single homes or small communities. The risk of illness due to contamination by pathogens is increased because monitoring of these systems tends to be erratic.

In a recent natural gradient field tracer experiment in fractured saprolite (highly weathered rock) in Eastern Tennessee, non-pathogenic bacteriophage and bacteria-sized particles (microspheres) traveled at rates of 5 to 200 m/day over monitored distances of up to 35 m (McKay et al., 2000). This study and related laboratory studies of colloid transport (Harton, 1996; Haun, 1998; Cumbie and McKay, 1999) suggest the likelihood that pathogens may also travel rapidly in saprolite. Since saprolite mantles much of the bedrock of the southern Appalachians and the Valley and Ridge physiographic regions, it is possible that pathogens can travel down through the saprolite, into aquifers containing wells or springs used for water supply. There is a great need to develop improved methods for assessing risks related to transport of pathogens in saprolite soils and to develop a better understanding of the factors controlling their transport.

A variety of microbial pathogens can contaminate wells and springs, causing outbreaks of disease in humans. The enteric protozoa *Cryptosporidium* and *Giardia* are the most significant causes of reported waterborne disease in the US today (Rose and Yates, 1998). Both of them can originate in either animal or human fecal wastes. Previously, these protozoa were considered as microbial contaminants of surface water only. However, as 40 % of all the drinking water outbreaks associated with the enteric protozoa documented in the US in 1993 and 1994 occurred in well water sources, this original view has changed. Bacterial pathogens also commonly contaminate groundwater (Mathewson, 1998). They can be divided into 2 groups, those that cause intestinal infections, such as *Shigella*, *Salmonella*, diarrheagenic *Escherichia coli* and *Vibrio cholerae* and those that cause extra-intestinal infections such as *Legionella* and *Leptospira*. Enteric viruses include the enteroviruses (poliovirus, Coxsackie A and B viruses, echovirus), rotaviruses, Norwalk and Norwalk-like viruses (Abbaszadegan and Dowd, 1998). Enteric viruses are more resistant to environmental factors than are enteric bacteria, and they exhibit longer survival times in natural waters. Enteroviruses are also resistant to commonly used disinfectants (Pitt et al. 1994).

The first hypothesis for this study is that bacteria-sized pathogens will have greater mobility in saprolite than larger (Protozoan), or smaller (Virus) pathogens. This is what was observed in experiments using latex microspheres in saprolite (Haun, 1998; Cumbie and McKay, 1999), where the larger particles experienced greater losses due to settling and the smaller particles experienced greater losses due to attachment to fracture walls. The second hypothesis is that chemical composition of the effluent will have a major influence on pathogen attachment and retention in saprolite, with greater retention occurring in more concentrated solutions. This can help immobilize pathogens near the septic field, but may become less effective during seasonally wet periods when the effluent is rapidly diluted by infiltration.

The objectives of the study outlined in this proposal are to test these two hypotheses under controlled laboratory conditions, using undisturbed, representative samples of typical East Tennessee saprolite, and geochemical conditions typically found in or near a septic system. The experiments were carried out under saturated flow conditions, at flow rates similar to those observed in the field. Saturated conditions frequently develop in the upper saprolite during heavy rainstorms (Solomon et al., 1992; Wilson et al., 1993), and pathogen transport is expected to be greater during these periods.

The transport experiments utilized microorganisms that are representative of each of the three main types of pathogens: viruses, bacteria and protozoa. Of the various types of *Cryptosporidium*, *Cryptosporidium parvum* has been identified as the primary cause for illness in humans and domestic animals (Swiger, 1999). *Giardia* species isolated from humans are *Giardia lamblia*, *Giardia intestinalis*, and *Giardia duodenalis* (Swiger, 1999). The groundwater bacterial pathogens are *Shigella*, *Salmonella*, Diarrheagenic *Escherichia coli, Vibrio cholerae, Legionella* and *Leptospira*. Enteric viruses include the enteroviruses (poliovirus, Coxsackie A and B viruses, echovirus), rotaviruses, Norwalk and Norwalk-like viruses.

The influence of groundwater geochemistry was be evaluated by repeating the transport experiments using influent solutions that are representative of conditions both near a septic field (high ionic strength, high dissolved organic carbon, etc.), and further downgradient, where the contaminants are much more dilute. The tracer experiment will be performed separately for each type of pathogen, and then will be repeated using a mixture of all three pathogen types.

7. Methodology:

A column of interbedded shale/limestone saprolite was excavated from about 50-80 cm depth at a research site near Clinton, TN (McKay et al., in review). The sample was located in the soil-saprolite transition zone, which is a zone of relatively high hydraulic conductivity (about 2 x 10^{-5} m/s). This is also identified as the "stormflow zone" and is characterized by development of perched water table conditions and rapid downslope flow during periods of heavy rain .

The 25 cm diameter by 30 cm long saprolite column was set up in a permeameter in the laboratory and a series of tracer experiments were carried out using MS-2, PRD-1, *E. coli, P. fluorescens*, and a killed protozoan tracer, under different geochemical conditions. The protozoans never made it through the column, presumably due to losses from straining or settling. Breakthrough of all the bacterial and viral tracers were observed, although because of difficulties in getting quantitative measurements of some of the tracers it isn't clear whether there was actually an "optimum size" for transport as had previously been observed for experiments using microspheres. Ionic strength of the tracer solution had a strong effect with greater recovery of the microbial tracers occurring in the more dilute solutions.

8. Principle Findings and Significance:

The experimental results of the current experiments are generally consistent with our previous studies, which were based mainly on experiments using latex microspheres (Cumbie and McKay, 1999; McCarthy, McKay and Bruner, 2002) or bacteriophage (McKay, Harton and Wilson, 2002). Together, the studies demonstrate that pathogens or pathogen surrogates can be rapidly transported in typical sedimentary rock saprolite. The principal environmental controls on transport are fracture or macropore aperture, flow rate, particle size, ionic strength, valence state of the dominant cations, pH, and temperature. Each of the laboratory scale experiments addressed a different factor, usually by varying that factor while keeping the others constant. The results of the laboratory-scale tracer experiments are summarized in Table 1. They indicate that there is an optimum size for transport, of about 0.5 to 1 micron, which is about midway between the size of typical bacteria and typical viruses. This indicates that both bacteria and viruses are likely to be mobile in groundwater in saprolite. The studies also indicate that under conditions of high flow rate and low ionic strength, losses of particles due to the above mentioned factors are minimal. These conditions (high flow and low ionic strength) typically occur during periods of high precipitation, which suggests that pathogen transport will tend to be intermittent. In summary, both bacterial and viral pathogens are likely to be mobile in saprolite, and there is potential for them to be transported quickly and with little concentration loss during seasonally wet periods or during heavy rainstorms.

Table 1. Summary of laboratory-scale particle tracer experiments.

Experimental factor varied	Summary of results	References
Particle diameter (microspheres)	Optimum particle size of 0.5 to 1 micron. Electrostatic attachment dominates, with settling as a secondary factor.	Cumbie and McKay (1999)
Flow velocity (bacteriophage)	Losses due to attachment are strongly effected by flow rate, with almost no loss at high flow rates	McKay, Harton and Wilson (2002)
Groundwater chemistry (microspheres)	Particle losses are minimized at low ionic strength and in	McCarthy, McKay and Bruner (2002)

	solutions dominated by monovalent cations	
Type of microbial tracer (MS-2, PRD-1, *E. coli, P. fluorescens*, and protozoa) and groundwater chemistry.	Protozoa are completely lost to straining or settling. Losses of bacteria and viruses are strongly influenced by ionic strength.	McKay, Layton and Rietti-Shati (manuscript in-preparation)

9. <u>Future Research and Funding:</u>

The most significant result of the WRRIP project was that it was the first step for the principal investigators, Drs. McKay and Layton, in the field of pathogen research. Our initial theoretical research on colloid transport is now being applied to practical issues related to pathogens in waters in Tennessee. Since this project began, we have developed a major research initiative, which includes Drs. John McCarthy and Randy Gentry at UT, as well as other researchers at TDEC and USGS. Several projects have already been funded as follows:

- L. McKay and A. Layton (with a subcontract to G. Johnson at USGS), TDEC, $186,611, "Assessing the Extent of Viral Contamination and the Effectiveness of Wellhead Protection Setbacks for Wells and Springs in Fractured and/or Karst Aquifers"

- L. McKay and A. Layton, TDEC, $30,000, "Development and Testing of a Real-Time PCR Assays for the Quantification of E. coli and Host-Specific Fecal Anaerobes in Surface Waters"

We are also working on an effort to examine methods of assessing the impact of pathogens on TMDLs using Stock Creek in south Knoxville as our "research watershed". For this project we are working very closely with TDEC and City/County government and are looking at a variety of funding sources, including TDEC, TVA and local utilities.

Constructed Wetland Cleanup of Pirtle’s Container Nursery Runoff

Basic Information

Title:	Constructed Wetland Cleanup of Pirtle’s Container Nursery Runoff
Project Number:	2001TN4101B
Start Date:	3/1/2001
End Date:	8/1/2002
Funding Source:	104B
Congressional District:	Tennessee, 6th
Research Category:	Not Applicable
Focus Category:	Wetlands, Treatment, Water Quality
Descriptors:	wetlands, wastewater treatment, water quality monitoring, runoff
Principal Investigators:	G. Kim Stearman, Dennis George

Publication

1. Stearman, K.G., G. B. George, Constructed Wetlands at Pirtle?s Container Nursery, USA., 11th Tennessee Water Resources Symposium, Nashville, April4-6, 2001.
2. Stearman, K.G., G. G. George, Clean Water Using Constructed Wetlands in Container Nurseries: Guidelines for Construction, Maintenance and Costs, USA., Tennessee Department of Agriculture, Nonpoint Sources Program, #904-B-00-900, 11p.
3. Stearman, G.K., Dennis B. George, Kris Carlson, and Stacey Lansford. 2003. Pesticide Removal from Container Nursery Runoff in Constructed Wetalnd Cells. Journal of Environmental Quality. (accepted for publication).
4. George, D.B., G.Kim Stearman, Kristofer Carlson, and Stacey Lansford. 2003. Simazine and Metolachlor Removal by Subsurface Flow Constructed Wetlands. Water Environmental Foundation (in press)
5. Robinson, Charles Westley, 2002, Mathematical Description of Subsurface Flow (SF) Constructed Wetlands Using the Advection-Dispersion Mass Balance Equation. MS Dissertation, Civil and Environmental Engineering, Tennessee Technological University, Cookeville, Tennessee, 81 pps.
6. Lansford, S.N. 2000. Pesticide and Nutrient Removal from Container Nursery Runoff by Constructed Wetlands. MS Dissertation Biology, Tennessee Technological University, Cookeville, Tennessee, 128 pps.
7. Carlson, Kristofer, 1999, Subsurface Flow Constructed Wetlands as an Effective Practice for the Remediation of Potential Herbicide and Nutrient Contamination in Container Nursery Runoff, MS Dissertation, Civil and Environmental Engineering, Tennessee Technological University, Cookeville,

Tennessee, 164 pps.

8. Lansford, S.N., G.K. Stearman, D.B. George, K.L. Carlson, and C.D. Belew. 1998. Bulrush Response to Simazine and Metolachlor in Constructed Wetlands from a Container Nursery. In Agronomy Abstracts of the 1998 Annual Agronomy Meetings, October 18-22, Baltimore, MD, p.36
9. Lansford, S.N., G.K. Stearman, D.B. George, and K.L. Carlson. 1998. Soft stem Bulrush Response to Simazine and Metolachlor in Constructed Wetlands from a Container Nursery. Tennessee Academy of Science, Cookeville, TN, November 20. Poster.
10. Stearman, G.K., S.N. Lansford, K.L. Carlson, and D.B. George. 1999. Pesticide and Nutrient Removal in Constructed Wetlands. Presented to the Ninth Tennessee Water Resources Symposium, American Water Resources Association, Nashville, TN, April 14
11. Stearman, G.K., D.B. George, E.W. Davis, and S.N. Lansford. 2000. Constructed Wetlands Removal of Herbicides and Nutrients from Container Nursery Runoff. Southern Nurserymen?s Association Annual Conference, Atlanta, GA, August 3-5.
12. Stearman, G.K., D.B. George, E.W. Davis, and S.N.Lansford. 2000. Constructed Wetlands Removal of Herbicides and Nutrients from Container Nursery Runoff. SNA Research Conference Atlanta, GA, Vol 45:520-523.
13. Stearman, G.K., D.B. George, E.W. Davis, and S.N. Lansford. 2000. Constructed Wetlands Removal of Herbicides and Nutrients from Container Nursery Runoff. Tennessee Green Industry Field Day, Presentation, August 15, McMinnville, TN.
14. Hutchings, L D.., G.K. Stearman, D.B. George, and C.W. Robinson. 2002. Nitrogen and Phosphorus Removal from Runoff in a Subsurface Flow Constructed Wetland. In Agronomy Abstracts of the 2002 Annual American Society of Agronomy Meetings, and presented Nov. 10, Indianapolis, IN.
15. Stearman, G.K., D.B. George, and L. B. Hutchings. 2003. Constructed Wetland Cleanup of Pirle?s Container Nursery Runoff: Removal of Nitrogen, Phosphorus and Prodiamine from a Subsurface Flow Constructed Wetland at 1,2, and 3 day Hydraulic Retention Times. To be presented as a poster to the Thirteenth Tennessee Water Resources Symposium, American Water Resources Association April 9 Montgomery Bell State Park, Burns, TN.

6. Problem and Research Objectives:

Nurseries apply large amounts of agricultural chemicals to sloping terrains that are highly susceptible to soil erosion. Pesticides and fertilizers may run off into surface water causing detrimental effects to nontarget organisms. Identification and implementation of best management practices, including constructed wetlands, that reduce agricultural chemicals in waterways are essential to reduce agricultural chemical pollution of water resources. N and P removal in constructed wetlands have been reported in a few studies, while pesticide removal has seldom been studied in constructed wetlands.

A 192 m^2 gravel subsurface flow constructed wetland was designed and installed at Pirtle's Nursery in Smithville, TN February, 2000. The wetland was 45 cm deep and contained approximately $20 m^3$ of water. Softstem bulrush (*Scirpus validus*), cattails (*Typha latifolia* L.), and juncus (*Juncus* spp.) were planted in the wetland. A standpipe controlled water level in the wetland and a bypass pipe averted heavy flow. Total nitrogen (N), phosphorus (P), and the pesticde prodiamine were measured from the influent and effluent water during daily irrigation events.

The objective of this study was to determine the removal of nitrogen (N), phosphorus (P), and the herbicide prodiamine from irrigation runoff water at Pirtle's Nursery into a vegetated subsurface flow gravel constructed wetland at 1,2, and 3 d hydraulic retention times (HRTs).

7. Methodology:

Constructed Wetlands

The constructed wetlands are located at Pirtle's Nursery in Smithville, TN. Irrigation runoff water from a 1.0 ha container nursery pod flows into the wetland. The wetland is 45 cm deep and 25 x 7.68 m in surface area. The pore volume is estimated to be 20 m^3 based on 30% porosity. The media consisted of 22.5 cm depth of limestone gravel (diameter size 2.5-5.0 cm) overlain by finer gravel (diameter size 0.63-1.88 cm). The entrance to the wetlands held coarse gravel for the entire depth for a distance of 3 m so that flow into the wetlands was not restricted by the fine gravel. The wetland was planted primarily with soft stem bulrush, with cattails and juncus growing on the back edge of the wetland .

Sampling

Sampling dates were from May 16 until August 2, 2002. Effluent water samples were collected in a 1 L amber bottle each day prior to irrigation at 1230 h. Influent water samples were collected in a 1 L amber bottle each day at 1300 h, 30 min after irrigation began. Water samples were transported to the Water Center lab for analysis of N, P, and prodiamine.

Flow Determination

A water valve into the wetlands controlled hydraulic retention times (HRTs) of 1,2, and 3 d. The valve controlling water into the wetlands was set at 75, 60, or 50 % of full flow for 1, 2, and 3 d HRTs, respectively.The nursery runoff was channeled to a concrete box where it split. An overflow stand pipe transported the bulk of the flow beneath the wetland to the holding pond while a submerged orifice located approximately 2.5 cm (1in) from the bottom of the box discharged runoff to the wetland. The water depth or head in the flow splitter box was measured with a Stevens Recorder. Maximum head was 15.2 cm (6 in). Hydrographs obtained during runoff events were used to determine the head in the box as a function of time during the event. The submerged orifice equation was used to estimate the flow to the wetland

$$Q = C_d A_o \sqrt{2g(h_i - h_o)}$$

Where,

Q = the discharge flow through the orifice (cfs),
C_d = coefficient of discharge (dimensionalless),
A_o = Orifice cross-sectional area (ft^2),
G = acceleration of gravity (fps),
H_i = water head (ft) at any specific time, and
H_0 = water depth to lower invert of orifice (ft).

The coefficient of discharge, C_d, was computed by measuring the discharge flow at various control valve settings. The control valve limited the flow to the wetland.

Valve (%)	Flow (cfs)	Flow (gal/d)	Orfice Area (sqft)	h (ft)	Cd
100	0.0740	47824	0.04908739	0.375	0.306763
75	0.0444	28694	0.03681554	0.375	0.245411
60	0.0226	14606	0.02945243	0.375	0.156145
50	0.0191	12344	0.02454369	0.375	0.158356

Water inflow at these valve settings had been measured previously to determine appropriate settings. Irrigation began at 1230 h every day. A Stevens chart recorder recorded the water level in the flow distribution box during daily runoff of irrigation.. Water influent (L) was computed using the hydrograph from the Stevens chart recorder and the hydraulic head orifice equation.

N, P, and Prodiamine Analysis

Total N was conducted using the persulfate digestion method and analyzed on a TRAACS 800 Auto Analyzer using the cadmium reduction method. Total P was digested by a mild acid hydrolysis and analyzed using the ascorbic acid colorimetric method (Murphy-Riley technique). Prodiamine was extracted with isooctane and analyzed by gas chromatography with an electron capture detector.

8. <u>Principle Findings and Significance:</u>

N, P and Prodiamine Removal in the Constructed Wetland

Mean N removal was 70 to 72% of total influent N. with a standard deviation of 8%. There was no difference in N removal from 1 to 3 day HRTs. Mean P removal varied from -2 to 10% of total influent P with a standard deviation of almost 40%. The erratic nature of phosphorus adsorption was largely attributed to pH shifts in water especially rain water which was acid. The irrigation water runoff was above 7.5 and the outflow water was usually around pH 8. The acidification of water caused phosphorus to dissolve from the alkaline wetland. Also sorption sites become saturated and as pH shifts downward phosphate is released into solution Mean prodiamine removal ranged from 49-65% of total influent prodiamine. Prodiamine removal was consistent with previous studies at Baxter, TN using constructed wetland cells. Results from the Baxter study showed that pesticides simazine and metolachlor were removed at 60-65% at 2 and 3 day retention times.

Mass of N entering and mass of N removed from the wetland were positively correlated. Maximum N concentration entering the wetland were 30 mg/L.

Removal Processes

N was removed primarily by denitrification with some plant removal. Nitrification is the rate limiting step in the denitrification process. Three days apparently is not enough time for all N conversion into nitrate so that denitrification can proceed in the wetland system. P was removed primarily by adsorption/precipitation reactions. P effluent values varied widely due to pH shifts in the wetland, especially during and after rain events. Prodiamine was removed both by microbial degradation and sorption.

Significance

Subsurface flow constructed wetlands are a promising technology for removal of N and pesticides from container nursery runoff. P removal was more problematic due to finite wetland gravel sorption sites and variation in runoff pH water due to acid rain. More research is needed to examine and implement technologies efficient in removing P that could be utilized with constructed wetlands.

The wetland required little maintenance other than occasional sediment removal after heavy rain, occasional sediment flushing of the inflow pipe to maintain flow and weed removal.
A poster was presented at the Annual Agronomy Meetings in Indianapolis November 10, 2002 and published an abstract for the same conference. Hutchings, L.D., G.K. Stearman, D.B. George, C.W. Robinson. Nitrogen and Phosphorus Removal from Runoff in a Subsurface Flow Constructed Wetland. Annual American Society of Agronomy Meetings, Indianapolis, IN. November 10, 2002.

9. <u>Future Research and Funding :</u>

A contract from the Tennessee Department of Agriculture 319 Non-Point Source Pollution Program through EPA entitled "Peat Application to Constructed Wetlands for Pesticide Cleanup at a Nursery" was awarded and began July 1, 2002. On November 30, 2002 the contract from USDA on "Pesticide Fate and Removal in Constructed Wetlands" was completed..

Information Transfer Program

The major emphasis of the information transfer program during the FY 2001 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 2001 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 2001 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 workshop.

As co-sponsor, the Tennessee Water Resources Research Center (TNWRRC)was involved in the planning and implementation of the Eleventh Tennessee Water Resources Symposium, which was held on April 4-6, 2001 in Nashville, Tennessee. The purposes of the symposium are: (1) to promote communication on water resources research and management, and (2) to encourage cooperation among the diverse range of water professionals in the state. As with previous symposia, the tenth symposium was very successful with over 225 attendees and approximately 72 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, multiobjective river basin management and lake management issues 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 2001:

Tennessee Clean Water Network Conference, October 7-9, 2001, Nashville, TN.

Tennessee Water Resources Research Center Statewide Advisory Committee annual meeting, interaction among researchers and researcher users, March 16, 2001, Knoxville, TN.

Building a Better Community, Cumberland River Compact Conference, March 21-22, 2001, Montgomery Bell State Park, Burns, Tennessee.

Sustainable Watersheds Balancing Multiple Needs: 10th Annual Southeastern Lakes Conference, North American Lake Management Society, March 20-23, 2001, Knoxville, TN.

Tennessee Wetlands Technical Advisory Task Force meeting, April 25-26, 2001, 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 4, 2001, Knoxville, TN. An annual community-wide event sponsored by the Water Quality Forum (WQF)that highlights the importance of our water resources and the activities of the WQF partners to protect and manage those resources.

Adopt-A-Watershed Teacher Training Workshop, June 18-21, 2001, Knoxville, TN. A workshop to train high school and middle school teachers the AAW science based curriculum program that utilizes the local watershed as a living laboratory.

The Southeast Watershed Roundtable, August 14-15, 2001, Atlanta, GA. The Roundtable was sponsored by the Southeast Watershed Forum and TNWRRC. It is an annual regional Roundtable convened to assess watershed restoration progress in the Southeast. It is a key element of the President Clintons Clean Water Action Plan.

Kids-In-the-Creek, May 10, 2001, Copper Ridge Elementary School, Knoxville, TN. A watershed experience sponsored by Tennessee Valley Authority, TNWRRC and the CAC AmeriCorps Water Quality Team. An all day event for 75 5th grade students introducing them to watershed science including biological and chemical monitoring and land use impacts on water quality.

The Tennessee River: Beauty, Bounty and Balance Conference, Tennessee Valley Authority. June 14-15, 2001, Knoxville, TN.

Fundamentals of Erosion Prevention and Sediment Control training workshops sponsored by the Tennessee Department of Environment and Conservation and TNWRRC, June 26-29, 2001 in Memphis, Nashville, Chattanooga and Knoxville.

Nonpoint Education for Municipal Officials (NEMO) training. The University of Connecticut, Tennessee Valley Authority (TVA) and TNWRRC, August 2-3, 2001, Knoxville, TN. TNWRRC staff along with TVA worked with local government officials to bring the NEMO model to Tennessee communities.

Nonpoint Source Program Education Working Group, August 30, 2001, Nashville, TN.

Urban Runoff Working Group, September 13, 2001, Nashville, TN.

Knox County Soil Conservation District BMP Tour, October 16, 2001, Knoxville, TN. TWWRRC staff made presentations on streambank restoration projects in Knox County.

Tennessee Nonpoint Source Partnership Conference, October 10-11, 2001, Nashville, TN. TNWRRC cosponsored the conference and staff made several presentations.

Twelveth Annual SAMAB Conference, November 7-9, 2001, Gatlinburg, TN. Sponsored by the Southern Appalachian Man and the Biosphere. TNWRRC staff made several presentations on watershed assessment projects.

Fundamentals of Erosion Prevention and Sediment Control training workshops sponsored by the Tennessee Department of Environment and Conservation and TNWRRC, October 16-18, 22-24, 2001 in Memphis, Jackson, Nashville, Chattanooga and Knoxville.

Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2001 and January 2002. Meeting of government agencies and other organizations to share information and discuss water quality issues in the Tennessee River and its tributaries in Knox county.

Little River , French Broad River, Bull Run Creek and Emory Watershed Associations, monthly meetings. Agency staff and community leaders working towards protection of the Little River, lower French Broad and the Emory/Obed and smaller 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 2001 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.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	7	0	0	0	7
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	12	0	0	0	12

Notable Awards and Achievements

None

Publications from Prior Projects